TOP-DOWN ATTENTIONAL CONTROL IN AFFECTIVE CONTEXTS

BY

JENIKA ROCHELLE BECK MCDAVITT

THESIS

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Advisers:

Professor Gregory A. Miller, Director of Research
Professor Wendy Heller

Abstract

Executive function, a collection of cognitive processes that guide, monitor, and inhibit behavior, is critical for human cognition. However, little is known about how executive function operates within the transient affective states of everyday life, even though research suggests that such affective states may influence cognition. The present study examined top-down attentional control, one component of executive function, during three distinct affective contexts. The color-word Stroop task was used to measure top-down attentional control, and an autobiographical memory task manipulated the affective context in which the task was performed. Each participant performed the Stroop task in positive, neutral, and negative affective contexts. Stroop performance was enhanced in the presence of a positive affective context when it occurred after a negative affective context. Implications for future research are discussed.

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Introduction

Executive function is critical for human cognition. Though executive function is a multidimensional construct with many proposed models and definitions (Banich, 2009), it has been broadly described as a collection of control processes that guide, monitor, and inhibit behavior (Friedman, Miyake, Young, DeFries, Corley, & Hewitt, 2008). Some important components include maintaining an attentional set of tasks and information most relevant to current goals, resisting task-irrelevant information, and inhibiting automatic or stereotyped behaviors, along with other processes that help direct behavior toward goals (Banich, 2009). Executive function has been studied extensively as a critical cognitive domain that influences many others. However, most laboratory studies designed to examine executive function purposely create impoverished environments for participants and therefore do not entirely approximate the conditions under which most human cognition occurs.

Throughout the day, people experience a variety of transient affective states. There is evidence that activity in the prefrontal cortex, an area associated with executive function, is altered in affective contexts (for review, see Davidson, Pizzagalli, Nitschke, & Putnam, 2002; Murphy, Nimmo-Smith, & Lawrence, 2003; Herrington, Mohanty, Koven, Fisher, Stewart, Banich, Miller & Heller, 2005). However, relatively little is known about how executive function operates within the context of these transient affective contexts. Proposed models of executive function have yet to fully illuminate the relationship between specific affective contexts and specific components of executive function. Yet an ecologically valid model cannot overlook such a pervasive aspect of human experience, particularly not one that is already known to influence cognition.

Executive Function and Negative Affect

Much of the literature on executive function and negative affect is drawn from clinical populations. Depression has been associated with impairments in many executive functions, including planning, disengaging from negative material, shifting between tasks, and ignoring task-irrelevant information (for review, see Levin, Heller, Mohanty, Herrington, & Miller, 2007; and Gotlib & Joorman, 2009). However, it is sometimes unclear whether diminished task performance observed in individuals with depression is due to differential executive function deficits, or to other general symptoms and cognitive problems frequently seen in depression, such as overall concentration difficulties, fatigue, and competition for cognitive resources from other effortful tasks such as rumination (Gotlib & Joorman, 2009). It is also uncertain whether negative affect *per se* influences these cognitive problems. Some cognitive problems persist in people who have a history of depression but who are not currently experiencing a major depressive episode (Davidson et al., 2002). Thus, a clinical population may not be the most reliable or generalizable model for studying executive function in the context of negative affect.

In nonclinical populations, the relationship between executive function and negative emotion has most commonly been studied by examining the effects of task-irrelevant negative stimuli on performance. The emotional Stroop task, for example, requires participants to identify the color of words, some of which have emotional content and some of which are neutral (e.g. McKenna, 1986; Koven, Heller, Banich, & Miller, 2003). Executive function is required to maintain an attentional set to identify the ink color in the face of more salient word information. Reaction time is reliably slowed when participants must identify the ink color of negative words, and brain regions associated with maintaining attention and suppressing irrelevant information are activated (e.g., Compton, Banich, Mohanty, Milham, Herrington, Miller, Scalf, Webb, & Heller, 2003). However, it has been suggested that the emotional Stroop task does not directly assess the interplay between emotional processing and cognitive processing but rather shows that the parallel processing of emotional stimuli can draw attention away from the main, unrelated task of color-naming (Etkin, Egner, Peraza, Kandel, & Hirsch, 2006). Etkin and colleagues (2006) designed a paradigm in which participants identified the emotional expression on a face, ignoring an emotional word distractor superimposed over the face. Though this eliminated attentional competition between emotional and non-emotional stimuli, their paradigm still only allows the examination of how a participant processes emotional stimuli, and not necessarily how they process stimuli within an emotional context.

These studies inform us that the presence of distracting negative information or a conflict between pieces of negative information can affect our ability to perform a task. They do not establish how executive function performs in a broader context of negative affect. In other words, these tasks do not show how diffuse, transient, negative affective states (such as those that occur in everyday life) might affect executive function; they only indicate how executive function operates in response to salient negative stimuli that are embedded in the task itself. Although fMRI and clinical literature hint that executive function may be suppressed or hindered in negative contexts, this has not fully been investigated in nonclinical populations.

Few studies have created negative affective contexts to examine how specific executive functions might change in the presence of everyday shifts of emotion in nonclinical populations. Some research has examined broader cognitive abilities, which may include executive functions. For example, one study found that negative affect was associated with an increased likelihood that participants would attend to local features of visual stimuli rather than global features, indicating that affective state may broadly influence attentional strategies (Gasper & Clore, 2002). Although it appears that participants changed what they attended to in an unconstrained task, it remains unclear which, if any, executive functions were involved with this change. Overall, studies that do examine specific executive functions tend to find more null results than the clinical literature (for review, see Chepenik, Cornew, & Farah, 2007). It has been suggested that the prevalence of null results indicates that negative affective contexts are not responsible for the changes seen in depression, but that the deficits associated with depression may be attributable to other factors (Chepenik et al., 2007).

Only one study appears to have systematically evaluated several forms of executive function in the context of a negative affect manipulation. Chepenik and colleagues (2007) manipulated negative affect by instructing participants to imagine the death of a loved one while listening to sad music. After the affective manipulation, participants completed several cognitive tasks, including four tasks that measured aspects of executive function (Chepenik et al., 2007). Two "booster" affect manipulations were interspersed every 2-3 tasks. No performance differences were found on any of these four executive function tasks between negative and neutral affect conditions.

The authors took these results to suggest that the cognitive deficits seen in depression are not attributable to negative affect, but rather to other variables associated with depression. However, there are some important caveats to consider when interpreting data collected in the context of affective manipulations. These caveats are not exclusive to this study, but rather reflect methodological issues inherent in employing affect manipulations in the study of cognition. First, other work has shown that when manipulations of negative affect occur just twice in the same session, the second manipulation is less effective (Richell & Anderson, 2004). In order to maintain the affective context throughout extensive cognitive testing, "booster" sessions may be administered, but subsequent manipulations may be less effective than the first. One might contend that participants' ratings can demonstrate that negative affect was sustained across all tasks. However, in a meta-analysis of mood induction procedures, Westermann and colleagues (1996) observed that a major obstacle to assessing whether emotions had been successfully induced in study participants is that participants are typically eager to comply with study procedures. Because participants can easily guess what the "point" of an affective manipulation is, and are eager to be "good" participants, their self-reported ratings may not accurately reflect their inner experience (Westermann, Spies, Stahl, & Hesse, 1996). This may cast doubt on the validity of affect ratings, particularly across a long study.

Second, although Chepenik and colleagues (2007) did not specify how long each task lasted, they observed that when 2-3 tasks elapsed between each affect manipulation, negative affect had dissipated. Other research has demonstrated that even in the absence of a distracting task, the effects of affect inductions dissipate dramatically in the first six minutes after administration, and then progress slowly back to baseline (Chartier & Ranieri, 1989). When including multiple cognitive tests in the same study, particularly in the absence of any emotional content during the tasks themselves, it is possible that participants may not experience significant negative affect while performing most of the tasks. Indeed, non-emotional cognitive tasks have been used as “fillers” between mood induction procedures in other studies for the express purpose of dissipating emotions (e.g. Gilboa-Schechtman, Revelle, & Gotlib, 2000). Given the literature on the dissipation rates of affect induction procedures, there is reasonable doubt as to whether strong negative affect can be sustained throughout multiple cognitive tasks within the same experimental session.

Taken together, the transient nature of induced affect, the problems repeating the same valence of affect manipulation within the same experimental session, the uncertainty of the validity of self-reported ratings, and the amount of time needed to actually perform a cognitive task, all represent methodological hurdles to creating a sustained affective context in which cognitive tasks might be administered. This casts some doubt on how well the results of Chepenik and colleagues’ (2007) study address how specific executive functions operate in a negative affective context. Further research is needed to see whether these null results can be replicated or whether they are the product of methodological problems specific to that study or problems inherent in studying affective contexts.

Executive Function and Positive Affect

Positive affect appears to promote cognitive flexibility, problem-solving abilities, and information categorization and organization. Many studies induced relatively mild positive affect using simple experimental manipulations such as having participants watch funny film clips or giving them an unanticipated gift (see Isen, 2009; Ashby, Isen, & Turken, 1999, for review). Subsequent testing showed that these positive affective states enhanced performance on many tasks requiring executive function. Broadly speaking, positive affect appears to enhance creativity and flexibility, promotes the formation of associations between task components that might otherwise go unnoticed, and improves the ability to switch between different perspectives (Isen 2009; Ashby et al., 1999). However, some of this literature does not precisely address positive affect relative to specific components of executive function, but rather to broader performance abilities requiring executive function.

Positive affective contexts have perhaps been most extensively studied relative to attentional control, but there is some conflict in the literature as to what the exact effects may be. Positive affect appears to broaden the scope of attentional filters, which increases the capacity to form associations between distantly related items (Frederickson & Branigan, 2005; Johnson, Waugh, & Frederickson, 2010; Rowe, Hirsch, & Anderson, 2007). However, it has been suggested that this relaxation of selective attention can also interfere with the ability to ignore task-irrelevant information (Rowe et al., 2007). Rowe and colleagues (2007) found that a positive affective state, induced by exposure to clips of music, interfered with participants' performance on a flanker task in which they had to attend to a central target letter and ignore nearby distractors. Thus, this broadening of attentional filters appeared to enhance some executive functions, such as discovering relationships and patterns between items, while interfering with other executive functions, such as inhibiting task-irrelevant information. However, another study failed to replicate the findings that induced positive affect worsened performance on a flanker task or a color word Stroop task which requires similar inhibition of salient but irrelevant information (Martin & Kerns, 2011). Other work has demonstrated that people in positive affective states can flexibly switch between attending narrowly and broadly depending on the demands of the task (see Isen, 2009, for review), so conflict remains as to whether or not the broadening of attention seen in positive affective contexts actually interferes with the ability to inhibit irrelevant information.

Harmon-Jones and Gable (2009) suggested that positive affect can narrow or broaden attentional control depending on how high in approach motivation an individual might be. They found that in situations of low approach motivation (e.g., after viewing pleasant pictures of cats), attention is broadened, whereas in situations of high approach motivation (e.g., after viewing pictures of desserts), attention is narrowed (Gable & Harmon-Jones, 2008). This finding does refine theories of how positive affect might influence attentional control, but does not explain the conflicting findings in other literature. Namely, it does not account for the discrepancies in results found for performance on the flanker task, both of which were presumably found in low approach motivation positive contexts (one induction was done using positive music, the other with a positive film clip).

Like negative affect, the relationship between positive affect and cognitive performance has also been studied with positive emotional stimuli embedded within a task. Broadly speaking, exposure to task-irrelevant positive stimuli tends to be associated with increased activity in the dorsolateral prefrontal cortex (DLPFC) (see Herrington et al., 2005, for review). When Herrington and colleagues (2005) examined brain activity during an emotional Stroop task, they found that exposure to pleasant words increased activity bilaterally in the DLPFC, and particularly in the left DLPFC. This suggests that positive contexts have potential to boost or at least alter executive function performance.

The Experimental Problem

A growing literature suggests that positive and negative affect influence performance on a variety of tasks requiring executive function. However, only loose connections have been established between specific emotions and specific components of executive function, with much work remaining to be done. Much of the research done on negative emotion and executive function was conducted using tasks with emotional content embedded within the task, rather than creating an affective context in which the task was performed. The literature on negative affect contains few examples of specific cognitive processes being examined within a negative affective context and focuses more on clinical populations. One study that did examine specific components of executive function in a negative affective context found null results, but questions remain as to whether enough of a sustained affective context existed to address the research questions at hand. Within the research that discussed the effects of positive affective contexts, specific components of executive function were often not defined or directly examined. When it was, as in the case of attentional control, conflicting results have been found.

Overall, research has not fully addressed how the presence of normal, transient affective states affect behavior that falls under the control of executive function in nonclinical populations. There is evidence to suggest that positive affective contexts have potential to boost performance on tasks requiring executive function and that negative affective contexts may impair performance, but no systematic evaluation of a specific affective context and a specific component of executive function has directly compared the two. The goal of the present study is to begin to address this gap in the literature.

The present study used the color-word Stroop task to study the effects of an affective context manipulation on executive function. The color-word Stroop task has been used extensively to study one component of executive function, sometimes described as prepotent response inhibition (Martin & Kerns, 2011) or top-down attentional control (Herd, Banich, & O'Reilly, 2006). The color-word Stroop task requires the inhibition of an automatic but task-irrelevant response (reading a word presented on a computer screen) in order to perform a task (identifying the color the word is written in). Words may be congruent with the color they are written in (e.g. "blue" written in blue letters), incongruent (e.g. "blue" written in green letters), or neutral (e.g. "hour" written in blue letters). The interference from the incongruent words typically increases the color-naming reaction time. The color-word Stroop task is widely used in studies of executive function, and the relevant regional brain activity has been mapped extensively (e.g. Herd et al, 2006; MacLeod, 1991; Banich, Milham, Jacobson, Webb, Wszalek, Cohen, & Kramer, 2001; Banich, Milham, Atchley, Cohen, Webb, Wszalek, Kramer, Liang, Barad, Gullett, Shah, & Brown, 2000a; Banich, Milham, Atchley, Cohen, Webb, Wszalek, Kramer, Liang, Wright, Shenker, & Magin, 2000b; Mohanty, Engels, Herrington, Heller, Ho, Banich, Webb, Warren, & Miller, 2007; Compton et al., 2003), thus making it an ideal task in which to study a specific component of executive function within an affective context.

A major goal in the design of the present affective context manipulation was to make it as ecologically valid and relevant as possible. Thinking about and mentally elaborating upon emotional events that have happened in one's life is a natural affect manipulation that most people engage in frequently. The affective context was thus created using a guided imagery task (Miller, Levin, Kozak, Cook, McLean, & Lang, 1987; Salovey, 1992), wherein participants received audio instructions (adapted from Salovey, 1992) guiding them to vividly imagine and relive an autobiographical emotional memory. Each participant experienced three conditions, positive, neutral, and negative, and completed a run of the color-word Stroop task immediately after each affective context manipulation. Because the effects of induced affective contexts can dissipate quickly (Chartier & Ranieri, 1989), the color-word Stroop task was interspersed with "cue words" to remind them of their memory, thus helping to maintain the affective context more robustly throughout the task. Cue words appeared briefly between Stroop stimuli on some, but not all trials.

This study design is similar to that of one conducted by Gilboa-Schechtman and colleagues (2000), in that each participant received three affective context manipulations and provided self-relevant cue words for use during a cognitive task that immediately followed each affective manipulation. However, the task Gilboa-Schechtman and colleagues used was an emotional Stroop task with emotional word stimuli embedded in the task. The present study used a color-word Stroop task to examine executive function in the absence of directly conflicting emotional stimuli. Participants were not instructed beforehand to attend to or respond to the emotional cues, but the cues acted as subtle reminders of the manipulation throughout the task.

The hypotheses were first, that a classic Stroop effect would be observed, with reaction times for incongruent trials slower than neutral trials, and faster for congruent trials relative to neutral trials. Second, that there would be a linear trend across mean reaction times for the positive and negative affective context conditions. Specifically, it was expected that participants would show faster reaction times during the positive affective context than during the negative affective context. To evaluate regional brain activity during executive function and in affective contexts, fMRI data were also collected during the study. However, the fMRI data do not address present goals and will not be discussed further here.

Method

Participants

Participants (*N* = 36, 53% female, 72% Caucasian) were paid volunteers recruited from undergraduate psychology classes through email lists collected at group questionnaire screening sessions. Participant age ranged from 18 to 28 years (*M* = 18.97, *SD* = 1.84.) All were native speakers of English. Because this study took place in a magnetic resonance imaging (MRI) environment, all participants were right-handed and screened for abnormal color vision, claustrophobia, history of a loss of consciousness that lasted longer than 10 minutes, recent drug or alcohol use, excessive caffeine intake, lack of sleep, and any contraindications for MRI scanning. Participants were informed of the study procedures and provided written consent in a separate laboratory tour session.

Materials and Procedure

Affective Context Manipulation (ACM). At the beginning of the experimental session, subjects provided baseline state affect ratings using the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988) to assess for possible group differences in baseline state affect. Participants then filled out a short survey in which they briefly described three autobiographical memories – one “happy,” one “neutral,” and one “sad” memory, counterbalanced for order of recall. This procedure helped ensure that they could articulate one clear memory for each condition. After the descriptions, participants provided five “cue words” for each memory. Each cue word was required to be a single word, eight letters or less in length, with no colors or word abbreviations allowed. The length of the words was restricted so that the visual angle of the word on the screen would not exceed that of the longest Stroop word stimuli.

During the experiment, participants listened to audio instructions (text adapted from Salovey, 1992) asking them to focus on their memory (e.g. *"imagine the situation as vividly as you can," "see the people or objects, hear the sounds, experience the event happening to you," "let yourself react as if you were actually there."*) There were 9 lines of instructions, presented with 25 seconds elapsing between each line to give participants time to think about the memory. Participants rated how they felt before and after each ACM using the Valence and Arousal scales of the Self-Assessment Manikin (SAM), a non-verbal pictorial scale that has been widely used to measure affect (Bradley & Lang, 1994). Participants thought about all three memories during the experiment, counterbalanced for order of ACM presentation, and completed a color-word Stroop task after each memory instruction condition.

Color-Word Stroop Task. Color-word Stroop data were collected in three separate 6.4-minute runs, with each run immediately following an ACM. The task itself was modeled closely after one used extensively in previous fMRI and EEG work (e.g. Silton, Heller, Towers, Engels, Spielberg, Edgar, Sass, Stewart, Sutton, Banich, & Miller, 2010). The task contained three types of words: congruent (e.g. the word "blue" presented in blue letters), incongruent (e.g. the word "blue" presented in green letters), and neutral (e.g. the word "hour" presented in green letters). Words were presented in 32-second blocks of 16 trials each, alternating between blocks of congruent, incongruent, and neutral words. To prevent the adoption of word-reading strategies, half of the trials in the congruent and incongruent blocks were neutral words. Each run of the Stroop task consisted of 12 blocks (192 trials total) presented in one of six counterbalanced block orders designed such that congruent, incongruent, and neutral blocks preceded each other equally often.

Stimulus presentation and response recording were controlled by Psychtoolbox 2 in MATLAB. Participants viewed the stimuli via backprojection onto a screen outside the scanner and a mirror attached to the head coil. Words were presented in capital letters using Arial 100-point font, providing a vertical span of 1.17 degrees and a horizontal span of 3.30 to 8.91 degrees. Participants held a Lumitouch response box in each hand and responded to the colors (red, yellow, green, or blue) via a button press using the index and middle fingers on both hands. Participants received 32 practice trials to map the colors onto the buttons before the task began.

Each trial (2000 ms +/- 225 ms onset to onset) began with the presentation of one word for 1500 ms, followed by either a fixation cross or a cue word presented for an average of 500 ms (+/- 225 ms). Cue words appeared pseudorandomly on two-thirds of trials, counterbalanced to ensure that they would not convey any information about the upcoming Stroop word condition or the length of time between trial onsets. There were ten cue words for each affect condition. Five of the cue words were the words generated by the participants during the short survey before the experiment. The other five were standardized, affect-congruent words. The standardized positive and negative words were selected from the set used by Gilboa-Schechtman and colleagues (2000). Positive words (excitement, friendly, cheer, joyful, tender, carefree) and negative words (upset, lonely, depressed, helpless, misery) were matched for mean frequency and arousal, per the word information listed in the Affective Norms for English Words set (Bradley & Lang, 1999). Because the neutral words used by Gilboa-Schechtman and colleagues

(2000) were not listed among the ANEW words, a new set of neutral words (phase, clock, sphere, avenue, context) were drawn directly from the list of ANEW words, and matched for frequency and arousal with the positive and negative words.

Results

Efficacy of Affective Context Manipulation

To assess the efficacy of each affective context manipulation, SAM valence ratings taken before and after each ACM were compared. Valence ratings are on a scale of 1-9, with 1 being happiest, 9 being saddest, and 5 representing 'neutral.' Change scores were calculated by subtracting the post-ACM valence rating from the pre-ACM valence rating. Mean change scores were 2.25 (*SD* = 1.94), 0.06 (*SD* = 1.22), and -2.19 (*SD* = 1.49) for the positive, neutral, and negative conditions, respectively. All changes were reported in the expected direction for the respective valence categories (see Figure 1). Paired t-tests showed that the changes in valence ratings were significant for both positive ($p<.001$) and negative ($p<.001$) conditions, with no significant change for the neutral ACM ($p=.786$). A repeated-measures ANOVA using ACM condition as a between-subjects factor and time (pre-ACM, post-ACM) as a within-subjects factor indicated that there was a main effect of emotion ($p<.001$) and an emotion by time interaction ($p<.001$). This indicates that the ACMs impacted self-reported affect in the expected direction for all three ACM conditions.

SAM arousal ratings were also taken before and after each ACM. Arousal ratings are on a scale of 1-9, with 1 being most aroused and 9 being least aroused. Change scores were calculated by subtracting the post-ACM arousal rating from the pre-ACM arousal rating. Mean change scores were -0.42 (*SD* = 2.61), 0.61 (*SD* = 1.63), and 0.47 (*SD* = 2.18) for the positive, neutral, and negative conditions, respectively. Paired t-tests showed that there were no significant changes in arousal ratings between the pre-ACM and post-ACM ratings for the positive or negative ACM conditions. There was a significant change in the neutral condition (p=.031), with subjects reporting slightly less arousal at the end of the neutral ACM than at the beginning.

There was a significant interaction between ACM condition, time, and order in which the ACMs were administered (positive before negative and negative before positive, regardless of when neutral occurred) (p=.043). Self-reported affect in the positive and negative conditions did not return to baseline after the run of the color-word Stroop task, which affected the subsequent, pre-ACM valence rating. Following a positive ACM, participants started out with slightly higher valence ratings. Following a negative ACM, participants started out with slightly lower valence ratings. The impact of these order effects on Stroop task performance will be discussed later.

A one-way ANOVA showed that baseline PANAS ratings did not differ between the group that received the positive ACM before the negative ACM and the group that received the negative ACM before the positive ACM. There were no baseline differences in either state positive affect (p=.690) or state negative affect (p=.396). In order to ensure that participants did not miss the first line of instructions (which occurred immediately after the first SAM rating), participants were told over the MRI intercom immediately before the first ACM what affective condition they would begin with. Knowing what their first ACM would be appears to have slightly but significantly influenced their first SAM rating. A one-way ANOVA showed a between-group difference in the expected directions for each affective condition on the first, pre-ACM SAM valence rating (p=.024). Simply telling participants what the upcoming affective condition was going to be appeared to be a slight affective manipulation in and of itself. The actual ACM procedure went on to further boost the affective state ratings in the expected directions, with a significant change in ratings between time points ($p=.044$) that differed by affect condition ($p<.001$).

Color-word Stroop Task

Mean color-naming accuracy was 93% across all participants. A repeated-measures ANOVA showed that the number of errors did not differ by affective context condition ($p = .744$). The same analysis indicated that there was a slight difference in the number of errors between word conditions ($p=.001$), with subjects making an average of 4 more errors (out of 192 trials) during the incongruent condition than in the congruent condition, in line with predictions about Stroop performance across word type conditions. There was no interaction between word type and affective context condition in the number of errors ($p = .620$). Response latencies for incorrect trials were not included in the calculation of mean reaction times.

To check for practice effects, overall mean reaction time was calculated for the first, second, and third runs of the color-word Stroop task. A repeated-measures ANOVA indicated that there were no significant differences in overall reaction time between the three Stroop runs ($p=.238$) and also no significant linear trend over time ($p=.238$). Thus, no practice effects were found that could confound the results of performing the same task three times within session.

An omnibus repeated-measures ANOVA was performed using ACM condition and word type as within-subject variables and the order the ACMs were presented in (positive before negative and negative before positive, regardless of when the neutral ACM occurred) as a between-subject variable. A main effect of Stroop word type was observed, with the expected effect of reaction times to incongruent words being slowest, to congruent words the fastest, and to neutral words in the middle. This Stroop effect was robust throughout all conditions and analyses, as expected. No main effect of ACM type ($p=.141$) or interaction of ACM type by word type ($p=.109$) was observed in this omnibus test. However, there was a significant 3-way interaction between ACM condition, word type, and emotion ($p=.007$), indicating that mean reaction times differed depending on the order in which participants experienced the ACMs.

The participants who received the positive ACM before the negative ACM and the negative ACM before the positive ACM ($N = 18$ each) were examined separately. For participants who received the positive ACM first, a repeated-measures ANOVA was conducted with ACM condition and word type as within-subject factors. There was no main effect of ACM condition ($p=.312$). There was an ACM condition by word type interaction ($p=.018$), but this appeared to be driven mostly by a simple emotional arousal effect, with the positive and negative conditions slowing reaction time. This interpretation is supported by a quadratic ACM type by linear word type interaction ($p=.022$), but no linear trend for emotion ($p=.867$). A second repeated-measures ANOVA was conducted using only positive and negative ACMs. The mean reaction times did not differ between ACM conditions ($p=.867$), and there was no longer a significant interaction ($p=.200$). It appears that, for participants who received the positive ACM before the negative ACM, there was an overall effect of an emotional affective context generally slowing performance slightly relative to a neutral affective context. However, there was no difference in performance between the positive and negative ACM conditions as predicted (see Figure 2).

The same analyses were conducted for participants who had received the negative ACM first. A repeated-measures ANOVA looking at all three ACM conditions showed no main effect of emotion ($p=.124$), and no ACM condition by word type interaction ($p=.073$). However, there was a linear trend indicating that participants' performance differed between the positive and negative ACM conditions ($p=.044$), and a linear by linear trend indicating that the positive and negative conditions differed by word type ($p=.012$). When comparing only the positive and negative ACM conditions, there was a main effect of ACM condition ($p=.044$), as well as an ACM condition by word type interaction ($p=.005$). This indicated that, overall, mean reaction time was faster in the positive ACM condition than in the negative ACM condition, and this pattern was especially pronounced for the incongruent trials (see Figure 2). Positive and neutral ACM conditions differed in reaction time to incongruent trials (2-tailed t-test, $p=.042$), but the negative and neutral ACM conditions did not differ in reaction time to incongruent trials (2-tailed t-test, $p=.487$). This suggests that there was performance facilitation in the positive affective condition rather than performance slowing in the negative condition. Thus, for participants who received the negative ACM before the positive ACM, hypotheses about participants performing differently in positive and negative affective contexts were supported, with the positive affective context improving performance on the Stroop task.

Discussion

Previous literature has suggested that affective contexts might influence executive function performance, but few studies have examined the relationships between specific components of executive function and specific affective contexts. The present study used an ecologically relevant affective context manipulation and a color-word Stroop task to examine top-down attentional control in positive, neutral, and negative affective contexts. Prior studies have shown that positive affective states can improve performance on executive function tasks (Isen, 2009; Ashby et al., 1999), but results were conflicting with regard to the relationship between positive affect and attentional control (e.g. Rowe et al., 2007; Martin & Kerns, 2011). A main finding of the present study is that a positive affective context can indeed improve performance relative to a negative affective context on a task requiring top-down attentional control, but only when the positive context occurs after experiencing a negative context. It appears that it is not a positive affective context *per se* that matters, but rather the timing and existing affective environment in which the positive affective context occurs. Simply engaging with a positive experience did not enhance performance, but when a person had recently experienced a negative affective context, the positive affective context did boost performance. This finding may help clarify conflicts in existing literature, and has implications for future cognitive and clinical research.

When the results were collapsed across all participants, it appeared that affective contexts did not impact performance on the color-word Stroop task. This finding appeared at first glance to be in line with many other studies that also found null results for the effects of induced affect on executive function (e.g., Chepenik et al., 2007).

However, the within-subjects design allowed further examination of the effects of the order of ACM presentation. When subjects experienced the positive affective context first, positive affect did not appear to boost their performance. Both positive and negative affective contexts seemed to slow performance slightly relative to neutral, in line with literature that has suggested that emotional states in general interfere with task performance (e.g., Philips, Smith, & Gilhooly, 2002). However, when participants experienced a negative affective context first, they subsequently showed a boost in performance in a positive affective context. So it appears that positive affect can enhance performance when someone has recently had a negative experience. This effect would seem evolutionarily adaptive, as a temporary boost in cognition associated with a mild positive event might help an individual better handle the consequences of a recent negative event. Specifically, enhanced attentional control associated with a positive affective context that occurs after a negative event might help an individual ignore irrelevant, distracting information and re-orient to desired goals at hand.

It is possible that these results reflect a ceiling effect. In other words, if someone is in a relatively neutral affective state, then pushing them into a positive state may not improve their performance because the overall change was only 2.25 SAM rating points. However, if they are in a slightly negative state and then are put into a positive state, the overall magnitude of change is greater. A large change toward positive affect may be what produced the facilitation of Stroop performance. It is also possible that the positive ACM helped participants "recover" from the negative experience, and this context of 'recovery' facilitated performance. Further research could clarify how a positive experience would enhance executive function following a negative experience.

Although positive affect may indeed broaden attentional filters as prior literature has suggested (Rowe et al., 2007; Isen 2009), the present findings do not indicate that positive affective contexts interfere with participants' ability to ignore irrelevant information on the color-word Stroop task. This finding is in line with work reviewed by Isen (2009) that suggests that positive affect contributes to cognitive flexibility, and that people are able to adapt their attentional control to the demands of the task at hand.

The order effects of ACM presentation may help explain some of the conflicts in the literature on cognitive performance during an induced affective state. People experience various transient affective states throughout the day. Even if their affect is rated at or near a neutral 'baseline' when they start a task, it appears to matter what they have experienced prior to the task. Null results in prior literature on positive affect may be the result of a lack of control over the baseline condition in which participants entered the positive affective condition. Future research in this area might include an affective context manipulation (even a neutral one) prior to the start of the manipulation of interest to gain more control over the baseline state that participants are in when they begin the task of interest. Even cognitive research unrelated to the domain of emotion might consider controlling baseline affect, or at least assessing it, to prevent or account for unnecessary noise in the data caused by the affective states of the participants.

These findings may have implications for the clinical literature. For example, a recent study found that individuals with Major Depressive Disorder and Minor Depression reported greater drops in negative affect after experiencing positive events than a healthy control group (Bylsma, Taylor-Clift, & Rottenberg, 2011). Further research should examine possible cognitive effects of enhanced affective reactivity in clinical groups. This greater reactivity to positive events within clinically-significant negative affective contexts such as mood disorders may create a condition in which individuals with depression, but not healthy controls, would experience enhanced executive function performance. Much of the clinical literature focuses on the relationship between negative affect and cognition. The relationship between cognition and positive affective contexts in clinical populations merits further exploration in light of the present findings.

Limitations and future research

The SAM ratings show that, although the affective context manipulations were effective, their effects dissipated throughout the Stroop task. The task was shortened to approximately six minutes in an attempt to take advantage of what may be the strongest effects possible (Chartier & Ranieri, 1989) while still containing sufficient trials to perform meaningful analyses. In order to maintain an affective context of constant strength, future research might further shorten the duration of the task of interest. The transient nature of induced affective states is partially what makes them ecologically valid. However, this transience also makes them difficult to study systematically. These methods merit improvement.

Although the effects of affect did dissipate over time, they did not return to baseline, thus "bleeding over" into the subsequent ACM ratings. Future studies might consider taking the lead of Gilboa-Schechtman and colleagues (2000) and adding "filler tasks" between ACMs to further allow effects to return to baseline, or employ ACMs of different emotional valence in separate sessions. In the present study, the within-subject design allowed us to examine the effects of ACM order, adding to existing knowledge of affect changes and their effects on executive function performance. However, future research should carefully consider the questions at hand when deciding whether and how to control the baseline affective states of participants before beginning each new manipulation.

Finally, this study represents only one component of executive function. The present findings indicate that affective contexts can influence performance on tasks requiring top-down attentional control under certain conditions. There are many other components of executive function, and with few exceptions most have not yet been thoroughly examined in the presence of affective contexts. More work needs to be done to understand the relationship between everyday affective states and executive function.

Figures

Figure 1. SAM Valence Ratings taken before and after each ACM. Participants' self-reported affect changed in the expected direction for both the positive and negative ACM conditions, with no change in the neutral ACM condition.

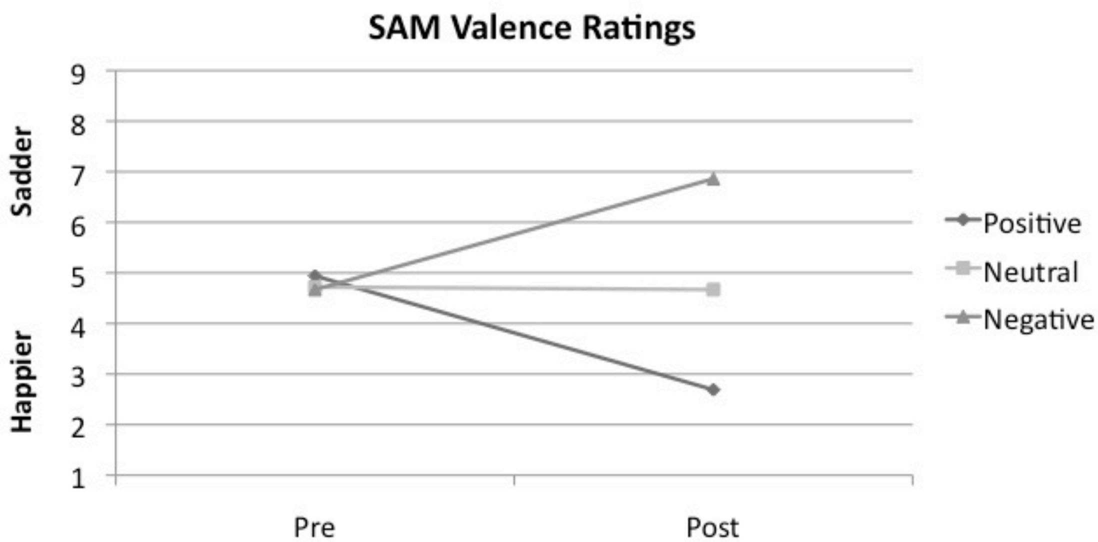
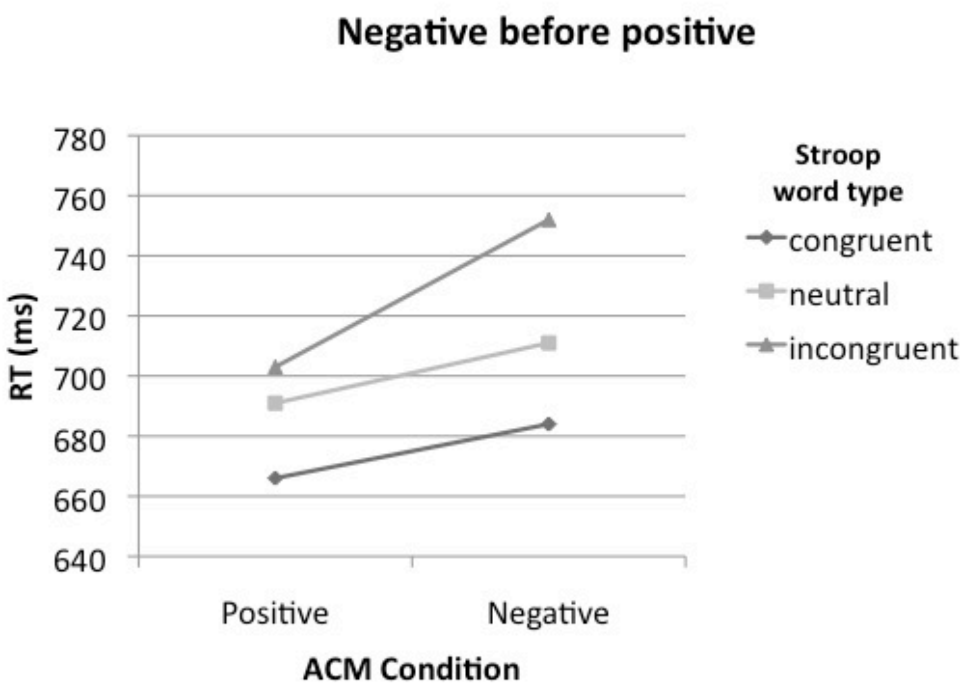
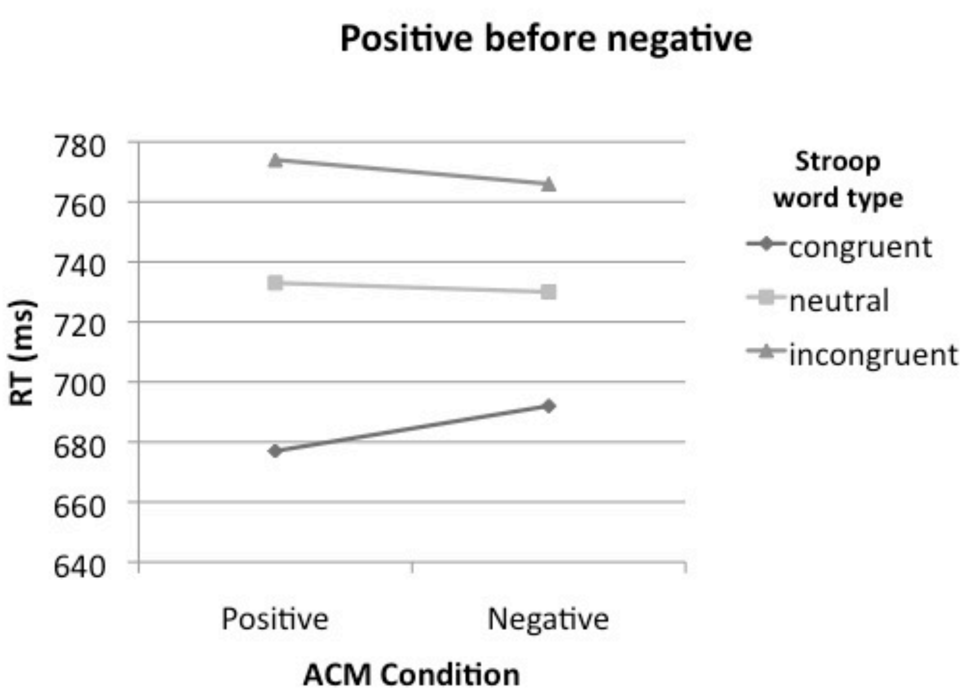


Figure 2. Color-word Stroop reaction times by order of ACM presentation. Participants who received the negative ACM before the positive ACM showed decreased reaction times to incongruent Stroop words. Participants who received the positive ACM before the negative ACM did not show this performance facilitation.





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