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Impact of negative affectively charged stimuli and response style on cognitive-control-related neural activation: An ERP study

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The canonical AX-CPT task measures two forms of cognitive control: sustained goal-oriented control ("proactive" control) and transient changes in cognitive control following unexpected events ("reactive" control). We modified this task by adding negative and neutral International Affective Picture System (IAPS) pictures to assess the effects of negative emotion on these two forms of cognitive control. Proactive and reactive control styles were assessed based on measures of behavior and electrophysiology, including the N2 event-related potential component and source space activation (Low Resolution Tomography [LORETA]). We found slower reaction-times and greater DLPFC activation for negative relative to neutral stimuli. Additionally, we found that a proactive style of responding was related to less prefrontal activation (interpreted to reflect increased efficiency of processing) during actively maintained previously cued information and that a reactive style of responding was related to less prefrontal activation (interpreted to reflect increased efficiency of processing) during just-in-time environmentally triggered information. This pattern of results was evident in relatively neutral contexts, but in the face of negative emotion, these associations were not found, suggesting potential response style-by-emotion interaction effects on prefrontal neural activation.

1. Introduction

Being able to control one's behavior, in response to both planned and unexpected events, is critical for socio-emotional functioning, especially when faced with emotionally challenging environments. Cognitive control is a heterogeneous set of psychological processes that can be parsed into unique constructs, including proactive and reactive control. According to the Dual Mechanism of Control (DMC) model, the term "proactive control" refers to psychological processes leading to deployment of planned action patterns derived through actively-maintained contextual information (Braver, Gray, & Burgess, 2007). The term "reactive control" refers to psychological processes evoked by stimuli that change action patterns (Braver et al., 2007). These two processes can be deployed in distinct fashions reflecting different styles of responding. Thus, a more proactive control style of responding leads to better performance in situations that allow for previously planned and strategically executed action strategies, while a more reactive control style of responding leads to better performance in situations that require last minute adjustments to action strategies based on environmental cues. The present study extends the extant literature on these control processes: (1) by comparing the impact of neutral and negative contexts on neural activation underlying events that require proactive and reactive control; and (2) by examining the relations between a person's relative degree of proactive or reactive control style and underlying neural activation, both in neutral and negative-valence contexts.

Proactive and reactive control mechanisms are generally investigated in the context of one particular task, the AX-CPT, a type of continuous-performance task (CPT; Rosvold, Mirsky, Sarason, Bransome, & Beck, 1956). This task consists of a cue, to which participants have to provide a speeded response, then a delay period, and then a probe, to which participants have to provide a second speeded response. The combined cue and probe information informs the participant on the type of trial being presented and thus the required responses. Proactive control processes are recruited during the cue time period and sustained over the delay time period to actively maintain planned action strategies. Transient reactive control processes, on the other hand, are recruited during the probe time period, either to elicit the primed motor response or to adjust action strategies based on new contextual information. Additionally, the current study uses the Behavior Shift Index (BSI; Braver et al., 2009), a measure generated from task reaction times and error rates, to ascertain a participant's control style (i.e., more reactive or proactive in nature). This provides a person-specific

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measure from the task that can be linked to other individual-difference variables, such as personality factors or level of anxiety, which have been linked to styles of cognitive control. Lastly, separate blocks of trials were created, containing either neutral or negative affectively charged pictures. A picture from one of these categories was presented during the delay period, so that neural activation underlying events that illicit proactive and reactive control could be measured in the context of either neutral or negative affective stimuli.

A number of brain regions have been linked with the recruitment of proactive and reactive control processes, including areas of prefrontal cortex. Specifically, recruitment of proactive and reactive control have been associated with activation in the dorsolateral prefrontal cortex (DLPFC), ventrolateral prefrontal cortex (VLPFC), dorsal anterior cingulate cortex (ACC), and ventromedial prefrontal cortex (VMPFC; Braver et al., 2007, 2009; Krug & Carter, 2012; Nee & Brown, 2012; Paxton, Barch, Racine, & Braver, 2007). However, at present it is unclear if these prefrontal activation patterns for proactive and reactive control change in the context of negative emotion.

Tasks that require other cognitive control processes have yielded prefrontal cortical activation differences depending on the emotional context of the task. For example, Monk et al. (2003) found greater ACC activation to fearful faces than neutral faces during an attention task; Ochsner et al. (2004) found ACC, VLPFC, and DLPFC activation during emotional up-regulation and down-regulation; and lastly, Lamm and Lewis (2010) found elevated VMPFC activation for a negative condition compared to a neutral condition in a motivated go/no-go task. Thus, it may be that prefrontal activation underlying the recruitment of proactive and reactive control processes could also reveal emotion-specific differences.

Prior work also generates specific hypotheses concerning the impact of emotion on neural correlates of cognitive control. Specifically, based on event-related potential (ERP) profiles, van Wouwe, Band, and Ridderinkhof (2009) suggest that reactive control processes, but not proactive control processes, are differentially recruited in unemotional and emotional contexts. This study found decreased (less negative) N2 activation for reactive control in the context of positive affectively charged stimuli compared to neutral stimuli. However, because this study did not include negative emotion, it remains unclear how proactive and reactive control mechanisms are recruited in the context of negative emotion. The present study examined ERP activation underlying proactive and reactive control in the context of both relatively neutral pictures and negative pictures. We examined behavioral performance and N2 activation—an ERP component associated with cognitive control (Folstein & Van Petten, 2008)—for time periods that required proactive and reactive control. We also performed a Low Resolution Tomography (LORETA) analysis to estimate cortical activation. We then exported activation values for four regions of interest (ROIs): the DLPFC, dorsal ACC, VLPFC, and VMPFC. Building on the van Wouwe et al. (2009) results and based on findings from other cognitive control tasks (e.g., Lamm & Lewis, 2010), we predicted greater activation for the negative condition than the neutral condition.

Finally, we attempted to extend previous neuroimaging studies linking neural processing efficiency with reduced neural activation during cognitive control tasks (Casey et al., 1997; Durston et al., 2006). Here we examined associations between individual differences in response style and brain function, predicting that participants who utilize a more proactive control style of responding would recruit fewer neural resources during the cue and delay periods than individuals utilizing alternative styles. Furthermore, we predicted that participants who exhibit a more reactive control style of responding would reveal less activation during the probe period than individuals utilizing alternative styles. We predicted this pattern of activation for the neutral condition, based on prior results specifically in this context. However, since negative emotions have complex effects on neural activation patterns (Lamm & Lewis, 2010; Lamm, White, Martin McDermott, & Fox, 2012), it is unclear if the previously outlined associations between control style and brain activation would be moderated by the negative condition. More specifically, control style/brain activation associations may show the same pattern of effects in the negative condition compared to the neutral condition but simply at elevated activation levels or the increased more effortful activation for the negative condition may ''flood'' control style/brain activation associations and thus show few significant effects. Moreover, given prior work documenting associations in cognitive control, effects of negative emotion on brain function, and individual differences in anxiety, we also explored the ways in which individual differences in anxiety related to response style and neural activation.

2. Method

2.1. Participants

Thirty-two undergraduate students (age $M = 20.19$, SD = 4.40, range = 18–39 yrs, 14 males) participated in the current study. Participants were recruited through Psychology and Human Development Department undergraduate classes at the University of Maryland. An additional seven participants were excluded due to insufficient artifact free trials. These seven excluded participants did not differ from included participants in demographic factors, such as age, gender, and country of origin. All participants had normal or corrected to normal vision. The current study received IRB approval from the University of Maryland.

2.2. Procedure

Participants were seated in a chair 67 cm from the computer screen and completed the State and Trait anxiety questionnaires of the State-Trait Anxiety Index (STAI). Next, the electrode sensor net (Electrical Geodesic, Inc., Eugene) was applied and the emotional AX-CPT task was administered. Between each block of the task, participants were given the opportunity to stretch and ask questions. After the task was completed, the STAI State Anxiety Questionnaire was administered a second time. Upon completion of the study, participants were given credit to be applied to a psychology class.

2.3. Measures

Spielberger State Trait Anxiety Inventory (STAI; Spielberger, 1983) The STAI is a reliable and valid measure capturing both state and trait anxiety. In the state measure, participants are asked to respond to 20 items describing how they are feeling 'right now, at this moment'. The trait measure asks participants to respond to 20 items describing how they 'generally feel'.

2.3.1. Emotional AX-CPT

Images were presented on a 17-in. monitor using Eprime Software (Psychology Software Tools, Inc., Pittsburgh, PA; Schneider, Eschman, & Zuccolotto, 2002). Stimuli were shown on a black screen and consisted of negative and neutral photos from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008) and single letters presented in either blue (cue) or white (probe). Negative and neutral pictures were 11 cm wide by 8 cm tall and presented in black and white (visual angle was 9.39°). Letters were presented in 60-point size uppercase bold Courier New