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ERP components associated with an indirect emotional stop signal task in healthy and depressed participants

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ABSTRACT

Recent research has provided evidence to suggest that emotional stimuli may interfere with response inhibition, due to automatic capture of attention. Whilst previous studies have provided data regarding changes to event-related potentials (ERPs) in emotional Go/NoGo tasks, few studies to-date have utilized an emotional stop signal task (SST). Thirty-five participants were included in the study; 21 healthy controls and 14 depressed. An indirect emotional SST was employed, which consisted of the presentation of neutral, negative or positive visual images. The primary two-choice reaction time task required responding to frame colour (blue or green), whilst in 33% of trials an auditory stop signal was presented, with stop signal delay adjusted according to an adaptive tracking procedure. ERPs associated with both the primary visual task and the auditory SST were analysed using temporal principle components analysis (tPCA). In the primary task, reaction times were found to be slower for negative compared to neutral images. Stop signal reaction time (SSRT) was not found to be affected by image category or depression status. However, the NoGo-N2 component was found to be reduced for positive images, whilst the NoGo-P3 component was reduced for both positive and negative images in comparison to neutral images in the stop signal task. This effect was found to be enhanced for the depressed participants, indicating that inhibitory processing in the presence of positive stimuli may be inhibited to a greater extent in depressed individuals than in healthy controls. These findings provide further evidence for the ability of emotional valence and major depressive disorder to influence inhibitory processing.

1. Introduction

Emotional stimuli possess intrinsic motivational salience, and for this reason have the ability to bias attention (Hajcak et al., 2010; Schimmack, 2005). Whilst a large body of work attests to electrophysiological differences in the processing of emotional target stimuli (Olofsson et al., 2008), more recent evidence has also emerged regarding their ability to modulate inhibitory processing (Albert et al., 2012; Buodo et al., 2017; Yuan et al., 2012). The two most common behavioural tasks employed to study inhibitory processing are the Go/NoGo and the stop signal task (SST). The process of successful inhibition of motor responses in the SST is conceptualized as depending on a "horse race" between the response to the primary task and the response to the stop-signal (Logan and Cowan, 1984), with whichever process that finishes first determining the outcome. Due to the SST requiring the inhibition of a response which is already underway it places a particularly high load on response inhibition (Rubia et al., 2001).

Electrophysiological studies of response inhibition have revealed that frontal-midline NoGo-N2 (200–400 ms) and NoGo-P3 (300–600 ms) event-related potentials (ERPs) most commonly occur in concert with NoGo or stop stimuli (Huster et al., 2013). Current understanding suggests that the NoGo-N2 is associated with competition between response execution and inhibition (Donkers and Van Boxtel, 2004; Yeung et al., 2004), whilst the NoGo-P3 relates more specifically to motor inhibition (Huster et al., 2013; Smith et al., 2008). Both of these components are generated within the anterior cingulate cortex (ACC; Albert et al., 2012; Bekker et al., 2005; Braver et al., 2001), which may modulate motor responses via connections with premotor, supplementary motor and primary motor areas (Paus, 2001).

According to the dual competition model (Pessoa et al., 2012) high arousal emotional stimuli may impair inhibitory task performance due to the fact they compete with executive control for attentional resources, whilst emotional stimuli of mild intensity may improve inhibitory performance when relevant to the task, due to their positive

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effects on perceptual processing and attention. Behavioural SST studies have reported impaired task performance as measured by increased stop signal reaction time (SSRT; Logan and Cowan, 1984) for emotional pictures (e.g. Verbruggen and De Houwer, 2007) or faces (Rebetez et al., 2015) in comparison to neutral stimuli. A recent fMRI study by Patterson et al. (2016) also provided evidence to suggest that the decrease in SST task performance for negative emotional imagery was associated with reduced activation in executive control and attentional brain structures. However, performance enhancement with emotional stimuli has also been reported, for example the finding of decreased SSRT for angry compared to neutral stop trials in a study by Pawliczek et al. (2013). However, few studies to-date have investigated the effects of emotional stimuli on electrophysiological indices of response inhibition in the stop signal task. In the first study of its kind, Senderecka (2016) presented negative emotional images and neutral images as stop signals in conjunction with a binary arrows SST task. Both N1, N2 and LPP event-related potentials (ERPs) were enhanced with negative in comparison to neutral imagery. Also, in line with the dual competition model, the task-relevant negative images were found to be associated with a faster stop-signal reaction time (SSRT). The authors interpreted these findings as suggesting that the negative imagery was associated with enhanced perceptual processing (Senderecka, 2016).

Previous electrophysiological studies to investigate the effect of emotional stimuli on inhibitory processing have relied largely on the Go/NoGo task, which places a lower load on inhibitory control processes when compared to the SST (Rubia et al., 2001). These studies have focussed on modulation of the inhibitory NoGo-N2 and NoGo-P3 components with emotional stimuli (Albert et al., 2010, 2012; Buodo et al., 2017; Yuan et al., 2012; Zhang and Lu, 2012), although there is some inconsistency in the literature regarding whether the modulation is best explained by variance in dimensions of emotional valence (pleasant-unpleasant) or arousal (calm-excited) (Lang et al., 1993). Albert et al. (2010) utilized a Go-NoGo task with differing emotional contexts and found the NoGo-P3 amplitude to be larger in a positive context in comparison to neutral and negative contexts. In a follow-up study which utilized an indirect emotional Go/NoGo task, Albert et al. (2012) found that activation within an ACC region of interest (ROI) associated with both emotion and response inhibition was greater for arousing positive images in comparison to neutral and arousing negative images within the time range of the P3. Similarly, in a study by Zhang and Lu (2012) which utilized emotional facial expressions, NoGo-P3 amplitude was found to be greater for emotional (both positive and negative faces) in comparison to neutral faces.

However, other studies have found stronger results for the NoGo-N2. For example, in a study by Yuan et al. (2012), greater NoGo-N2 amplitude was found for arousing negative images in comparison to pleasant and neutral images. In a more recent study by Buodo et al. (2017) which presented pleasant and neutral images together with threat and mutilation images, NoGo-P3 was found to be larger for emotional compared to neutral images, yet only the NoGo-N2 was found to be larger for threat imagery in comparison to mutilation imagery. In contrast, in a study by Chiu et al. (2008), which utilized emotional words, neither the NoGo-N2 or NoGo-P3 were found to be modulated by emotion.

Whilst electrophysiological activity associated with the non-emotional version of the Go/NoGo task and the SST has been found to be largely comparable in previous studies (Huster et al., 2013; Van Boxtel et al., 2001), there are practical and conceptual advantages associated with the use of the SST in studying the effects of emotion on electrophysiology. The first of these is that the SST places a greater load on inhibitory control than the Go/NoGo task (Rubia et al., 2001). The second is that through the use of an adaptive algorithm, task difficulty may be adjusted through the course of the experiment to ensure approximately equal numbers of trials with successful (SS) and unsuccessful (SF) inhibitory responses. In contrast, in the Go/NoGo task experimental analyses typically include a higher proportion of successful inhibitions due to the lack of adaptive control over task difficulty. Thirdly, the SST design provides the opportunity for emotional stimuli to be used in conjunction with a stop signal which is unrelated to the emotional content of the stimuli. In this way, the processing of visual emotional stimuli can be measured directly, whilst the indirect effect of these stimuli on the processing of a neutral inhibitory signal can be measured separately (Albert et al., 2012; Berkman et al., 2009; Goldstein et al., 2007).

In addition to differences in inhibitory processing that may be revealed using an emotional SST in healthy participants, there is also reason to believe that differences in task performance and ERP components will be exhibited for individuals with depression. Deficits to inhibitory control have often been reported in association with major depressive disorder (MDD), both during the acute stage as well as in remission (Bora et al., 2013; Wagner et al., 2012). Specific deficits in the ability to inhibit attention towards negative emotional stimuli have also been widely reported, with tasks such as the emotional Stroop or dot-probe (Peckham et al., 2010). Importantly, it has been argued that deficits in the ability to inhibit attention to negative stimuli may explain the emotion regulation difficulties observed in MDD (Aker et al., 2016; Joormann and D'Avanzato, 2010).

Whilst a number of studies have identified ERP components which are altered in depression, such as the late positive potential (LPP; Proudfit et al., 2015) or the P1 or N170 in face processing (Zhang et al., 2016), there have been few studies to-date which have investigated the electrophysiological correlates of emotional response inhibition in these patients. In one such study Dai et al. (2011) presented happy, neutral and sad faces as part of an affective priming task with depressed and healthy participants. They reported that both P1 and P3 amplitudes were larger for sad faces in the positive priming condition, whilst P3 amplitude was reduced for sad faces in the negative priming condition. These findings were interpreted as indicating that depressed participants have deficient distracter inhibition and excessive facilitation for positive and negative stimuli (Dai et al., 2011). There is also reason to believe that the late positive potential (LPP) component may also be reduced for emotional stimuli in depressed individuals as a result of attentional disengagement from these stimuli. For example the LPP has been found to be reduced in response to threatening faces (Foti et al., 2010) and aversive pictures (Kayser et al., 2000), as well as a more recent study by MacNamara et al. (2016) demonstrating an association between greater MDD symptom severity and less emotional modulation of the LPP.

Only one previous study to-date (Senderecka, 2016) had been conducted to investigate electrophysiological correlates of response inhibition using an emotional SST. However, in contrast to this previous study the current electrophysiological investigation utilizes an indirect version of an emotional SST whereby emotional imagery is not the target for either the primary choice reaction time task or the stop signal inhibitory task. On the basis of the dual competition model (Pessoa et al., 2012) it was predicted that inhibitory performance, as measured by the SSRT, would be impaired with emotional stimuli, due to the fact that they divert perceptual and attentional resources away from the inhibitory task. This prediction is also in line with empirical data from Albert et al. (2012) whereby commission errors in an indirect emotional Go/NoGo task were increased for positive compared to neutral imagery.

In line with previous electrophysiological studies, it was also expected that the NoGo-N2 and NoGo-P3 amplitudes in response to the stop signal would be decreased in the presence of emotional stimuli, due to impairment of inhibitory processing. In the current study inhibitory performance in depressed individuals was also compared with that of healthy controls, with the prediction that both behavioural (SSRT) and electrophysiological indices (NoGo-N2, NoGo-P3) of response inhibition would be impaired to a greater extent in the presence of negative emotional stimuli. A temporal principal components (tPCA) approach (Dien, 2010) was used in order to determine NoGo-N2 and NoGo-P3 components in visual and auditory ERPs, as well as to explore