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Threatening visual stimuli influence response inhibition and error monitoring: An event-related potential study

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ABSTRACT

The present study investigated the effect of emotion on response inhibition and error monitoring using event-related potentials. Participants performed an emotional stop-signal task that required response inhibition to briefly presented threatening and neutral visual stimuli. Negative, arousing pictures improved behavioral performance by decreasing the stop-signal reaction time and increasing the inhibitory rate, but had no enhancing effect on inhibitory processing at the electrophysiological level (N2–P3 complex). The perceptual processing of threatening stop-signals resulted in a larger and earlier N1 component. The Pe component, associated with conscious evaluation or affective processing of an error, was stronger in negative than in neutral trials. The stronger Pe correlated with superior task performance in the emotional condition. Prioritized perceptual processing of the stop-signal was associated with better conscious error monitoring. These results support the hypothesis that threatening, arousing stimuli improve behavioral inhibitory performance and error monitoring due to the enhancement of perceptual processing.

1. Introduction

Response inhibition and error monitoring play a crucial role in adaptive human behavior. Response inhibition is described as the ability to suppress actions that are no longer behaviorally relevant or contextually appropriate (Mostofsky & Simmonds, 2008; Pessoa, Padmala, Kenzer, & Bauer, 2012). Error monitoring is the metacognitive process by which we are able to automatically detect and consciously evaluate an error, allowing our actions to be shaped by their outcomes (Falkenstein, Hoormann, Christ, & Hohnsbein, 2000; Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001; Yeung & Summerfield, 2012). Both functions can be investigated experimentally with laboratory tasks, such as go/no-go and stop-signal tasks (SST) (Aron, 2007). The latter paradigm is a particularly useful tool, because it provides an assessment of the latency of inhibitory processes—the stop-signal reaction time (SSRT) (Logan & Cowan, 1984).

Relatively little is known about the role of affective significance in inhibitory function (Pessoa, 2009). Both enhancement (Chiu, Holmes, & Pizzagalli, 2008; Pawliczek et al., 2013; Pessoa et al., 2012) and impairment (De Houwer & Tibboel, 2010; Herbert & Sütterlin, 2011; Kalanthroff, Cohen, & Henik, 2013; Pessoa et al., 2012; Verbruggen & De Houwer, 2007) of response inhibition by emotions have been observed. These multi-faceted results are in line with the dual competition framework, proposed by Pessoa (2009). According to Pessoa's model, emotions can either improve or impair behavioral performance, depending on how they interact with perceptual and control functions. The effect of emotion on cognition depends on the intensity of the affective information. Stimuli of mild intensity enhance behavioral performance when relevant to the task, as they improve perceptual processing and attract further attention. These phenomena are reflected in increased no-go accuracy (Chiu et al., 2008) and shorter stop-signal reaction times (Pawliczek et al., 2013; Pessoa et al., 2012). In contrast, highly arousing stimuli generally impair task performance, because they compete with executive control for attention resources. This is reflected in decreased no-go accuracy (Yang et al., 2014) and longer SSRTs (Pessoa et al., 2012; Verbruggen & De Houwer, 2007).

The use of event-related potentials (ERPs) is the ideal approach for measuring the influence of emotional content on cognitive functions, even those that are carried out covertly. The electrophysiological markers of perceptual processing, response inhibition, and error monitoring may be obtained in the SST paradigm by selectively averaging stop-signal-locked segments of

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electroencephalography (EEG) data on successfully and unsuccessfully inhibited trials and motor reaction-locked segments on erroneous and correct response trials.

Components of ERP in response to the stop signal include the N1, which is linked to perceptual processing, and the N2–P3 complex, which is associated with response inhibition. The early visual N1, which contains at least three subcomponents, peaks about 140 ms after the onset of a picture and is visible at different locations (Hillyard & Anllo-Vento, 1998). Directing attention to a stimulus typically results in an enhanced amplitude of the N1. The N2 component, which peaks around 200–250 ms over fronto-central regions, is considered to be an index of an early mechanism of inhibitory control that reflects a "red flag" signal generated to trigger the inhibitory process (Falkenstein, Hoormann, & Hohnsbein, 1999; Falkenstein, Hoormann, & Hohnsbein 2002; Jodo and Kayama, 1992; Kok, 1986). The P3 component, which peaks around 300–350 ms over centro-parietal sites, has been specifically identified as an index of a late stage of monitoring the outcome of the inhibitory process (e.g., Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003).

With regard to ERPs that have been linked to motor responses, two components associated with error monitoring have been studied in the SST—the ERN (Error Related Negativity) and Pe (Positivity error). The ERN is a sharp negative deflection with a fronto-central scalp distribution, which peaks approximately 50 ms after erroneous response onset (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991; Falkenstein et al., 2000; Gehring, Goss, Coles, Meyer, & Donchin, 1993). It is typically followed by the Pe, a slow positive wave with a diffuse, predominantly posterior and central scalp distribution, and a maximum amplitude between 200 and 400 ms (Overbeek, Nieuwenhuis, & Ridderinkhof, 2005). The ERN has been associated with the detection of response conflict (Carter et al., 1998) or the detection of a mismatch between an intended and a produced response (Gehring et al., 1993), while the Pe has been attributed to an adaptive mechanism that is activated to adjust post-error decisions (Falkenstein et al., 2000), a more conscious stage of error detection (Nieuwenhuis et al., 2001), or to some other process associated with error-context updating, similar to P3 activity in relation to correct responses (Leuthold & Sommer, 1999).

A large number of experiments have demonstrated that ERPs are modulated by a variety of visual emotional stimuli, including complex arousing emotional scenes (Sabatinelli, Lang, Keil, & Bradley, 2007; Schupp, Flaisch, Stockburger, & Junghöfer, 2006). This modulation by emotional pictures can affect relatively early and/or late neural processes following stimulus onset and arise as distinct components, among others, the N1 and the LPP (Late Positive Potential; Pourtois, Schettino, & Vuilleumier, 2013). This second component is a sustained positivity, maximal at centro-parietal sites, that can begin around 300 ms after the onset of an affectively significant picture (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Schupp et al., 2000 Schupp, Junghöfer, Weik, & Hamm, 2004). The LPP has been shown to be related to subjective ratings of emotional intensity (Cuthbert et al., 2000) and to reflect the continued allocation of attention to emotional stimuli (Hajcak & Olvet, 2008). It also has been suggested that the LPP is associated with facilitated processing and encoding of motivationally relevant, emotional stimuli (Foti, Hajcak, & Dien, 2009).

Numerous studies have investigated the neural mechanisms underlying response inhibition; however, ERPs have been used relatively rarely to study the emotional modulation effect on response inhibition (Albert, López-Martín, Tapia, Montoya, & Carretié, 2012; Albert, López-Martín, & Carretié, 2010; Chiu et al., 2008; Wang et al., 2011; Zhang & Lu, 2012). The results of such experiments have been mixed and generally limited to the N2–P3 components. For instance, Chiu et al. (2008) used neutral and emotional (positive and negative, matched on arousal ratings) words as go/no-go stimuli. They observed a larger N2 to neutral go stimuli, reflecting the allocation of enhanced cognitive resources to neutral words during responses, and a more pronounced P3 to affective go stimuli, associated with the cognitive engagement by motivationally salient words, but no effect on no-go components. Albert et al. (2010) presented go and no-go experimental stimuli, consisting of two capital letters, in the background context of three positive, three negative (one disgusting, two threatening) and three neutral pictures. They registered larger amplitudes during positive than during negative contexts in no-go P3, but not in no-go N2 associated with early monitoring of response conflicts. Regression analyses between ERPs and emotional assessments showed that valence but not arousal explained the observed experimental effect. Zhang and Lu (2012) used neutral (calm), positive (happy) and negative (angry, fearful) faces as go/no-go stimuli. They observed decreased amplitudes and latencies of the go N2 component in both positive and negative conditions of a facial go/no-go task, reflecting top-down attention toward emotions. They also noticed larger amplitudes and shorter latencies of the P3 following positive and negative faces in both go and no-go trials, which indicated the modulation of inhibitory-related activity by facial expressions. Positive, negative and neutral stimuli did not differ in arousal level.

Yang et al. (2014) recently presented happy, unhappy (sad, afraid) and neutral faces as go and no-go experimental stimuli. Positive and negative expressions were matched on arousal values. The authors observed that emotional content impaired response inhibition in a go/no-go task, as evidenced by decreased response accuracy and N2 amplitudes in no-go trials. Additionally, they found that emotional expressions elicited larger N170 amplitudes than neutral expressions, and this effect was more pronounced in no-go than in go trials. They interpreted these emotional effects on no-go components as suggesting that affective significance impairs response inhibition due to the prioritization of emotional content processing. Yu, Yuan and Luo (2009) studied the effect of auditory-induced emotion on inhibitory control in the go/no-go task. In order to create an affective context, they presented for 5 s positive, negative and neutral sounds just before the presentation of go and no-go simple tones. The arousal values of the three sound categories were not significantly different. The reaction times were longer for go stimuli under the negative condition than under the positive and neutral emotion conditions. The ERP results showed larger amplitudes in the N1 component and the no-go N2, which indexes response conflict monitoring, in the neutral condition than in the emotional condition. As far as I know, only two latter ERP studies have focused on the emotional modulation of both kinds of components—inhibition-related, such as the N2 and P3, and perceptual, such as the N1. Moreover, earlier findings on the neural mechanisms underlying emotional response inhibition were based mainly on the go/no-go paradigm, which is a selective attention task with a relatively low load on inhibitory control (Rubia, Smith, Brammer, & Taylor, 2003). Thus, whether the perceptual processing of emotional stimuli biases response inhibition or not remains unclear.

There is a growing body of research on error monitoring that points to potential affective and motivational influences on the error-related ERP components. Several ERP studies have demonstrated a larger ERN in participants who are emotionally distressed (such as patients with obsessive-compulsive disorder), worried, or experiencing high negative affect (Gehring, Himle, & Nisenson, 2000; Hajcak, McDonald, & Simons, 2003; Johannes et al., 2001; Luu, Collins, & Tucker, 2000). It has been proposed that error-related ERP components may be sensitive to dynamically established goal states and reflect the negative emotional response to errors (Falkenstein et al., 2000; Luu et al., 2000; van Boxtel, van der Molen, & Jennings, 2002). Hajcak, Moser, Yeung and Simons (2005)