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Response competition and response inhibition during different choice-discrimination tasks: Evidence from ERP measured inside MRI scanner

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ABSTRACT

We investigated the neural correlates underlying response inhibition and conflict detection processes using ERPs and source localization analyses simultaneously acquired during fMRI scanning. ERPs were elicited by a simple reaction time task (SRT), a Go/NoGo task, and a Stroop-like task (CST). The cognitive conflict was thus manipulated in order to probe the degree to which information processing is shared across cognitive systems. We proposed to dissociate inhibition and interference conflict effects on brain activity by using identical Stroop-like congruent/incongruent stimuli in all three task contexts and while varying the response required. NoGo-incongruent trials showed a larger N2 and enhanced activations of rostral anterior cingulate cortex (ACC) and pre-supplementary motor area, whereas Go-congruent trials showed a larger P3 and increased parietal activations. Congruent and incongruent conditions of the CST task also elicited similar N2, P3 and late negativity (LN) ERPs, though CST-incongruent trials revealed a larger LN and enhanced prefrontal and ACC activations. Considering the stimulus probability and experimental manipulation of our study, current findings suggest that NoGo N2 and frontal NoGo P3 appear to be more associated to response inhibition rather than a specific conflict monitoring, whereas occipito-parietal P3 of Go and CST conditions may be more linked to a planned response competition between the prepared and required response. LN, however, appears to be related to higher level conflict monitoring associated with response choice-discrimination but not when the presence of cognitive conflict is associated with response inhibition.

1. Introduction

Inhibition and cognitive conflict are broad concepts that have frequently been used in the context of psychophysiological and neuroimaging studies. There is certainly an increased interest in studying paradigms associated with response conflict and the inhibition process, which has led to the investigation of these paradigms using both Event-Related Potential (ERP) and functional magnetic resonance imaging (fMRI) techniques, acquired each over separate or simultaneous recording sessions. Although multimodal integration of electrophysiological and hemodynamic information is highly desirable in neuroscience, and different approaches are currently available (Huster et al., 2012; Rosenkranz and Lemieux, 2010), many of these studies have focused on the assessment of the feasibility and reproducibility of recording reliable ERP components during fMRI scanning, using available artefact removing procedures (Comi et al., 2005; Strobel et al., 2008). Thus, several studies have employed simultaneous recordings, to reliably investigate whether long-latency ERP components and source localization of ERP generators can be obtained reliably, while preserving a good quality EEG signal; as this would increase the sensitivity of the technique. Recently, some of these studies have investigated long-latency ERP components during the performance of different response inhibition and response conflict tasks (Assecondi et al., 2010; Lavric et al., 2010; Vanderperren et al., 2010).

An important requirement of goal-directed responding is the need to select the appropriate response in situations when there is conflict between different actions or responses. In this respect, paradigms more frequently used to observe response inhibition are the Go/NoGo task, in which subjects have to respond to a target stimulus (Go) and to inhibit their response to a non-target stimulus (NoGo). Another example is the Stop-signal task, in which subjects are instructed to inhibit that response upon the presentation of a stop signal, which can occur any time at, or after, the onset of the primary task stimulus. On the other hand, response conflict has been extensively examined using the word–colour Stroop test, because it produces interference from two competing

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streams of information, from which individuals must inhibit the processing of one to select and respond to the other. To date, the most explicit hypothesis regarding response conflict comes from ERP studies during choice-response time tasks like Go/NoGo or Stroop tasks. These studies have reported that both the amplitude and topography of different ERP components are modulated as a result of being generated in Go or NoGo and congruent or incongruent Stroop conditions. The majority of ERP studies have interpreted the NoGo-related N2/P3-complex as an indicator of the inhibition of a response (e.g., Falkenstein et al., 1999; Kaiser et al., 2006) or to the detection of conflict (e.g., Donkers and Van Boxtel, 2004; Nieuwenhuis et al., 2003). More specifically, it has been proposed that N2 would reflect conflict monitoring, rather than inhibition (Nieuwenhuis et al., 2003), but also that N2 reflects neither inhibition nor conflict (Smith et al., 2007). On the other hand, it has been proposed that P3 following NoGo trials would reflect inhibition of the intended action (Verleger et al., 2006), or cognitive inhibition (Smith et al., 2008).

Source analysis of the N2/P3-related NoGo in adults has partially identified the neural generator underlying the N2/P3-complex. For instance, this technique has helped identify cortical generators in both the cingulate cortex (Bruchmann et al., 2010; Huster et al., 2010; Nieuwenhuis et al., 2003; Van Veen and Carter, 2002) and right orbitofrontal cortex (Bokura et al., 2001). Regarding the Stroop task, N2 and also late negativities (LNs) such as the N450 component seem to be modulated by the degree of conflict, being greater in amplitude when conflict is high relative to when conflict is low (Kopp et al., 1996; Nieuwenhuis et al., 2003; West and Alain, 2000). Source analyses during the N450 time window have demonstrated a particular involvement of the cingulate cortex during conflict conditions in the Stroop task (Badzakova-Trajkov et al., 2009; West et al., 2004). These findings are in line with the general consensus that different areas of the prefrontal cortex, particularly the anterior cingulate cortex (ACC), the dorsolateral prefrontal cortex (DLPFC), and the pre-supplementary motor area (pre-SMA) play a prominent role in the executive control of cognition (Carter and Van Veen, 2007; Huster et al., 2011; Posner and Dehaene, 1994).

A critical issue in refining and testing the cognitive conflict hypothesis concerns the nature of the task conditions. For instance, recent studies using EPRs have tried to understand whether the Go/NoGo and Stop tasks are based on the same cognitive processes (Huster et al., 2011; Krämer et al., 2013), whereas other studies have investigated whether Stop and Stroop tasks share a common cognitive control mechanism and if this could be dissociable (Kalanthroff et al., 2013; Kalanthroff et al., in press). Another particular challenge is to distinguish whether the ERP modulations frequently observed during Go/NoGo tasks are elicited by conflict or inhibition or both. In other words, there is debate over whether ERP waveforms associated to Go/NoGo task and other response conflict tasks reflect the detection of conflict, conflict monitoring, or conflict related to inhibition response (Dimoska et al., 2006; Falkenstein et al., 1999; Folstein and Van Petten, 2008; Kopp et al., 1996; Nieuwenhuis et al., 2003, 2004; Smith et al., 2007, 2008). For this reason, further research investigating the interaction between tasks which may share common cognitive processes are desirable, in order to elucidate the electrophysiological basis of cognitive conflict and the inhibitory control of responses (Benikos et al., 2013; Huster et al., 2013).

Despite the substantial literature on this matter so far, much remains to be determined about the role of N2 or P3, and there is still controversy surrounding whether these components would reflect inhibition, conflict, or both (Donkers and Van Boxtel, 2004; Falkenstein et al., 1999; Nieuwenhuis et al., 2003; Smith et al., 2007, 2008; Proverbio et al., 2009; Verleger et al., 2006).

Since results from other inhibitory and cognitive conflict tasks show both similarities and differences with respect to results from the Go/NoGo or Stroop task, the purpose of the present study was to manipulate these tasks to investigate which ERP component, N2, P3, or LN, best reflects not only response inhibition and response choice, but also response conflict. For that, we combined closely matched task conditions by using identical stimuli in the three tasks and manipulating choice/conflict demands across task conditions and varying the response required. Thus, participants had to perform a simple reaction time response task (SRT), a response inhibition task (Go/NoGo) and a response choice-discrimination task based on a Stroop-like task (CST). Apparently, manipulating congruent trials with different levels of choice-discrimination responses and incongruent trials across different cognitive conflict situations (inhibition and choice responses) could be a straightforward method used to identify ERP components that are associated with response inhibition and response competition.

In our hybrid Go/NoGo and Stroop-like task, and based on evidence available concerning the use of these tasks mentioned above, we assumed that responses involving both conflict and inhibition (i.e., N2 NoGo-incongruent) would elicit higher N2 and frontal P3 amplitudes compared to those involving only response conflict. However, if frontal P3 is modulated across all conflict conditions, this component may be a non-specific marker related to conflict detection, whereas posterior P3 would be linked to the monitoring of the ongoing response. We further assumed that LN is not related to motor inhibition and therefore occurs in specific conflict response (CST-incongruent) but not in the nonspecific conflict/inhibition response (NoGo-incongruent).

In addition, we also measured Cortical Current Density (CCD) modelling of the resulting ERP data, in order to accurately identify the spatiotemporal distribution of brain sources undergoing activation during the Go/NoGo and the CST tasks. We also compared our source analysis findings to classical ERP and neuroimaging literature using these paradigms. Concurrently, acquisition of ERP during fMRI scanning allowed us to actually examine the quality of our resultant EEG signal by using a more refined artefact removing method, and to thus verify the feasibility of recording high-quality EEG signal and fMRI simultaneously.

2. Methods

2.1. Subjects

Nine right-handed, healthy subjects with no history of psychiatric or neurological disorders were recruited (3 women, mean age: 23.9 ± 2.5 years), all unfamiliar with the EEG and fMRI environment gave their informed consent to participate in the study, which was approved by the local ethics committee.

2.2. Tasks and procedure

Visual stimuli consisted of coloured words (green, yellow, blue, and red) appearing on a black background and were administered through MRI-compatible goggles (Visuastim XGA, Resonance Technology, Los Angeles, CA) in random sequence using Presentation 13.0 (Neurobehavioral Systems, Albany, CA, USA). A series of 100 stimuli for each task were delivered at a random inter-stimulus interval of 3–5 s. Three visual tasks were associated with these stimuli and the three tasks were randomly performed by the participants of our study (see Fig. 1), who were instructed to respond (via MRI-compatible response PAD) as quickly as possible while trying to avoid errors. Each task had a duration of 6 min. The first task was a simple reaction time task (SRT), in which participants had to press a button key with their left index finger as quickly as possible upon the appearance of every stimulus. The second task was a modified Go–NoGo task that contained the congruent and incongruent stimuli of a Stroop-like task, in which participants were asked to press the left key when the colour words were presented in the colour denoted by the corresponding word (Go-congruent, e.g., the word “red” shown in red). In the corresponding NoGo trial, the response was to be withheld when a colour name stimulus was presented in a colour other than that represented by the colour name (NoGo-incongruent, e.g. the word “red” in blue). The third and