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Inferior frontal cortex activity is modulated by reward sensitivity and performance variability

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ABSTRACT

High reward sensitivity has been linked with motivational and cognitive disorders related with prefrontal and striatal brain function during inhibitory control. However, few studies have analyzed the interaction among reward sensitivity, task performance and neural activity. Participants ($N = 57$) underwent fMRI while performing a Go/No-go task with Frequent-go (77.5%), Infrequent-go (11.25%) and No-go (11.25%) stimuli. Task-associated activity was found in inhibition-related brain regions, with different activity patterns for right and left inferior frontal gyri (IFG): right IFG responded more strongly to No-go stimuli, while left IFG responded similarly to all infrequent stimuli. Reward sensitivity correlated with omission errors in Go trials and reaction time (RT) variability, and with increased activity in right and left IFG for No-go and Infrequent-go stimuli compared with Frequent-go. Bilateral IFG activity was associated with RT variability, with reward sensitivity mediating this association. These results suggest that reward sensitivity modulates behavior and brain function during executive control.

1. Introduction

Research of individual differences has become increasingly important in the cognitive neuroscience of executive control. Investigating and exploring individual differences has been a standard research tradition within psychology (Underwood, 1975), but has only recently become more strongly emphasized in cognitive neuroscience. The study of individual differences in cognitive neuroscience is complex because it requires considering performance differences during task completion given their influence on the interpretation of brain-related variables (e.g., evoked potentials, hemodynamic changes). For example, in studies of executive function such as inhibitory control, individual differences in task performance and inhibitory ability have been associated with brain activity in the frontal cortex (Bellgrove, Hester, & Garavan, 2004; Cai, Ryali, Chen, Li, & Menon, 2014; Congdon et al., 2010; Hirose et al., 2012). Poor inhibitory ability has been proposed to subserve engagement in risky and impulsive behaviors (Bari & Robbins, 2013), which are also affected by individual differences in personality traits associated with approach motivation, namely reward sensitivity (Knyazev, 2004). On the other hand, there is some evidence to suggest that enhanced response inhibition might characterize individuals with strong avoidance tendencies, like those with high trait anxiety or punishment sensitivity (Avila & Parcet, 2001; Sehlmeyer et al., 2010). Therefore, knowledge of cognitive and brain functions will make full use of an approach that considers individual differences and behavioral performance (Braver, Cole, & Yarkoni, 2010). In the present study, we used this approach to study the neural correlates of inhibitory control, exploring how individual differences in reward sensitivity and behavioral performance interact and modulate brain activity.

Inhibitory control is posited as one of the functions that involve the prefrontal cortex and, although the inferior frontal cortex (IFC) has been suggested to be a critical area for this function – particularly the right inferior frontal gyrus (IFG) – its role is still controversial (see Aron, Robbins, & Poldrack, 2014b; Swick & Chatham, 2014; for a discussion). The IFG is a relevant brain region for cognitive control processes, particularly those involving inhibition and switching. Neuroimaging and lesion studies have demonstrated a prominent role for the IFG and the adjacent anterior insula in response inhibition tasks (Aron, Fletcher, Bullmore, Sahakian, & Robbins, 2003; Aron & Poldrack, 2006; Boehler, Appelbaum, Krebs,

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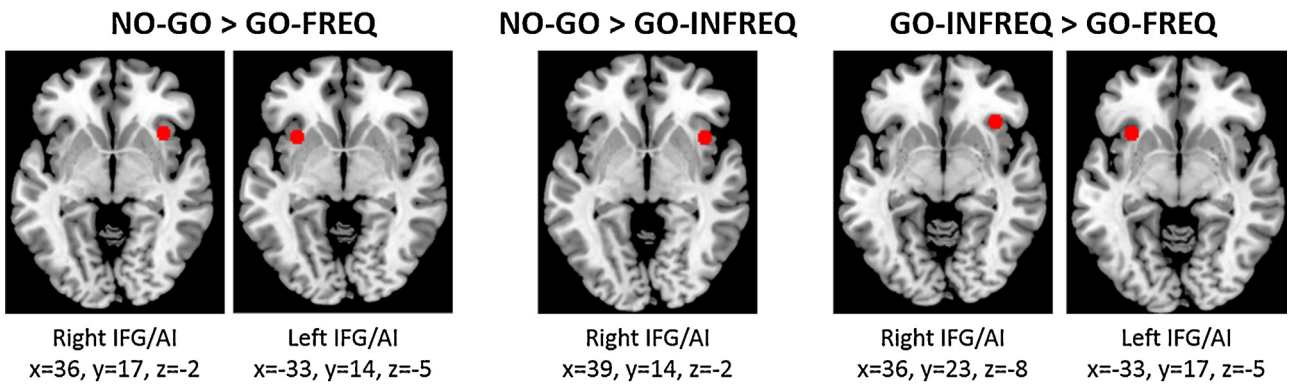

Fig. 1. ROIs defined for the correlation analyses based on the local maxima in whole-brain activation maps. Coordinates are given in MNI space. IFG/AI: Inferior frontal gyrus/Anterior insula.

Hopf, & Woldorff, 2010; Boehler, Schevernels, Hopf, Stoppel, & Krebs, 2014; Kelly et al., 2004; Liddle, Kiehl, & Smith, 2001; Steele et al., 2013), especially in the right hemisphere (Fassbender et al., 2006; Garavan, Ross, & Stein, 1999).

Right IFG activity is sensitive to several factors, such as saliency (Hampshire, Chamberlain, Monti, Duncan, & Owen, 2010), attentional load (Dodds, Morein-Zamir, & Robbins, 2011; Hampshire, Thompson, Duncan, & Owen, 2009), and stimulus frequency (Chikazoe et al., 2009). In this sense, the Go/No-go task designed by Chikazoe et al. (2009) is particularly interesting as it includes a frequent and an infrequent go stimulus that is as frequent as the No-go stimulus. This allows separate analyses of the inhibition and stimulus frequency effects, which can be potentially confounding as No-go and Infrequent-go stimuli are novel and consequently salient during the task. This study showed that different right IFG subregions play distinct roles during cognitive control. A recent study has also shown that the right IFG and the anterior insula play an important role in processing relevant stimuli in cognitive control tasks, including tasks with and without inhibitory demands (Erika-Florence, Leech, & Hampshire, 2014). Accordingly, it has been suggested the IFG is not only involved in inhibitory processes, but also in maintaining task-relevant information, like representations of the different stimulus-response (S-R) mappings involved in the task (see Swick & Chatham, 2014).

Other studies have also revealed that the left IFG plays a key role in the inhibition of dominant responses by showing inhibition deficits in patients with left IFG lesions (Swick, Ashley, & Turken, 2008). The inhibition impairment of these patients may, however, follow a different pattern to that of patients with right IFG lesions (Aron, Robbins, & Poldrack, 2014a). The left IFG is especially relevant when the percentage of No-go signals is low and its role has been related to the semantic representation of task rules (Aron et al., 2014b). Others have associated the left IFG with the efficiency of the inhibition process rather than with inhibition itself (Hirose et al., 2012). So although both regions seem to participate in response inhibition tasks, the specific role of the left and right IFG in the inhibition process remains controversial. The current work focuses on the role of the bilateral IFG in a Go/No-go task adapted from Chikazoe et al. (2009), in which we separately study the effects of stimulus frequency and response inhibition, and how individual differences in reward sensitivity and behavior are related to activity in this region.

Reward sensitivity is a personality trait that reflects individual differences in the sensitivity and reactivity of the appetitive motivation system (Corr, 2004). Individuals with stronger reward sensitivity tend to show more positive affect and are more sensitive to, and more likely to approach, reward (Avila, Parcet, & Barrós-Loscertales, 2008). The effects of reward sensitivity on behavior were initially proposed in the context of appetitive and aversive learning (Patterson & Newman, 1993; Pickering & Gray, 2001), but its influence may extend to more general processing of goal-directed behavior when reward contingencies are absent (Avila et al., 2008; Newman & Lorenz, 2003; Pickering & Gray, 2001). The influence of reward sensitivity on goal-directed behavior can be exerted not only by motivational mechanisms (i.e., increased sensitivity to reward cues), but also by the modulation of the cognitive and neural mechanisms that support goal-directed behavior (Gray et al., 2005). This would be manifested by an association between reward sensitivity and behavior and/or brain activity during cognitive tasks without explicit motivational contingencies. Along these lines, previous reports have tested this possibility and obtained a complex pattern of results. Basically, these studies have shown that individual differences in reward sensitivity are associated with better performance in fast tasks that require continuously changing rules (Avila, Barrós-Loscertales, Ortet, Parcet, & Ibáñez, 2003; Avila & Parcet, 1997) and increased conscious overfocusing of attention on dominant stimuli or response sets when cues bias cognition towards a specific task rule (Avila, 1995; Avila & Parcet, 2001, 2002). Accordingly, reward sensitivity may enhance cognitive flexibility or cognitive focusing depending on the task demands. This view is supported by the opposite effects of appetitive motivation and increased dopamine function on the brain, which favor cognitive flexibility at the cost of reducing cognitive focusing and increasing distractibility, or vice versa, depending on the task demands and the associated neural systems (Aarts, van Holstein, & Cools, 2011). Therefore, reward sensitivity may modulate brain function depending on the task at hand and its neural substrates by either enhancing or impairing task performance.

Reward sensitivity is also associated with increased vulnerability to disorders characterized by poor impulse control, such as Attention Deficit and Hyperactivity Disorder (ADHD, Mitchell & Nelson-Gray, 2006), substance use, dependence or addiction (Knyazev, 2004; Pardo, Aguilar, Molinuevo, & Torrubia, 2007; Yen et al., 2012), eating disorders (Glashouwer, Bloot, Veenstra, Franken, de Jong, & 2007; Matton, Goossens, Braet, & Vervaet, 2013; Matton, Goossens, Vervaet, & Braet, 2014), and cluster B personality disorders (Bijttebier, Beck, Claes, & Vandereycken, 2009; Pastor et al., 2007; Taylor, Reeves, James, & Bobadilla, 2006). Patients with these disorders also tend to show impairments in response inhibition tasks, especially in ADHD, where deficient behavioral inhibition has been considered a core feature of the disorder (Alderson, Rapport, & Kofler, 2007). Meta-analytic studies have shown that these patients have longer latencies to stop signals in the stop-signal task, which is a marker of less efficient response inhibition (Alderson et al., 2007; Lijffijt, Kenemans, Verbaten, & van Engeland, 2005). The same behavioral marker of impaired