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ERP evidence of cognitive strategy change in motivational conditions with varying level of difficulty

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ABSTRACT

Recent research suggests that motivation improves cognitive functions but the particular mechanisms and precise behavioural conditions involved in such improvement still remain unknown. Particularly, it is unclear when in time and in which conditions these mechanisms are engaged. In the present study, we aimed to look at the neural markers of cognitive control strategies in different motivational conditions (motivation vs neutral) with different levels of difficulty (high vs low). Twenty-five adults completed a newly designed task in the four conditions above. Three ERP components were analysed: the CNV, LRP and P3b. We found that a motivational situation triggers the use of a proactive strategy when low cognitive control is required. A reactive strategy was used in a non-motivational situation and for difficult trials. Our study is also the first to provide evidence that the difference between proactive and reactive strategies occurs after the first stimulus (cue) is processed.

1. Introduction

Individuals perform better when they are motivated. Both the motivation and the cognitive contexts can be diverse (gambling games, University entrance exams, chess competitions etc…), but as long as the salience is motivationally high, cognitive performance is enhanced (see Pessoa and 2008, 2009 for a review of the general relationship between emotion and cognition). Previous research suggests that this is due to modulation of brain activity related to cognitive processes such as decision making (Rushworth and Behrens, 2008) on (Baines et al., 2011). However, the particular mechanisms and precise behavioural situations involved in such improvement still remain unknown. Particularly, an interesting point relates to how task demand influences the effect of motivation on cognitive control. For instance, would motivation improve performance even when the task at hand is very difficult; or actually too easy? The specific contexts under which motivation influences cognitive strategies still needs further investigation. The effect of motivation on cognitive control remains unclear partly because motivation in itself is a complex concept (Ryan and Deci, 2000). Despite the potential implications of extrinsic motivation on success in school or at work, very little research has investigated the neural bases of such effects. Recent neuroimaging data seems to confirm that the improvements in cognitive performance seen in motivational contexts are due to changes in strategy rather than increased efficiency of executive functions (Jimura et al., 2010; Locke and Braver, 2008). However, the exact timing of these changes is not clear and needs to be established. To the best of our knowledge, no study has looked at Event Related Potentials (ERPs) to study the brain mechanisms involved in the cognitive improvements seen in a motivational context, although this technique has the potential to capture changes that occur rapidly with a very high timing precision. The goal of the present study was to determine with more precision how and when motivation affects cognitive control strategies.

The dual mechanism of control (DMC) theory recently developed by Braver (Braver et al., 2009; Braver 2012; Jimura et al., 2010; Locke and Braver, 2008) proposes that cognitive control strategies are flexible and are significantly impacted by specific experimental manipulations, internal goal states and contexts (Braver et al., 2009), such as manipulating the level of emotions encountered. The DMC framework predicts that in a motivational situation, individuals will tend to use a proactive strategy that is characterised by the anticipation of interference before an event occurs (Jimura et al., 2010; Locke and Braver, 2008). Reactive control on the other hand is thought to rely on the detection and resolution of interference after the event happens. These strategies have been differentiated on the bases of the mode of activation of the lateral prefrontal cortex (PFC), before and immediately after the event of interest. The anticipatory activation of the lateral PFC

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used to actively maintain task goals throughout the task and facilitate the processing of expected events is thought to be characteristic of a proactive control strategy (Braver, 2012). In contrast, the bottom-up reactivation of task goals as the interference is processed is associated with only transient activation of lateral PFC, which is characteristic of reactive control strategy use.

Research has shown that task difficulty can modulate the impact of emotions (particularly threat and pain) on cognitive task performance (Gu et al., 2013; Jasinska et al., 2012). For instance, Jasinska et al. (2012) found that the impact of emotional distracters (threat) on the behavioural and neural response in cognitive-control regions as well as in the amygdala is modulated by task difficulty. Gu et al. (2013) found increased reaction times and error rates for painful compared with non-painful stimuli in difficult vs easy tasks. Additionally, Taylor et al. (2004) looked at the effect of monetary rewards on working memory; hypothesising that a more difficult task may motivate subjects more than an easier task. They showed an interaction between motivation and neural activation in the PFC. Nevertheless, no study, to the best of our knowledge, has clearly investigated the effect of motivation and task difficulty on cognitive control strategies.

In order to examine both the cognitive strategies used during different levels of motivation, and how they vary with task difficulty, we designed a conditional task-switching paradigm with two levels of difficulty and two motivational conditions. Three Event-Related-Potentials (ERPs) were used to determine the differences in neural mechanisms associated with different levels of motivation and task difficulty: The Contingent Negative Variation (CNV, Weerts and Lang, 1969); the Lateralised Readiness Potential (LRP); and, the P3b. The CNV and the LRP both relate to response preparation, and are ideal indices to study early differences in cognitive strategies. The CNV corresponds to the negative wave over frontal and central electrode sites that normally precedes response activity. It is thought to reflect sensory anticipation (Gómez et al., 2003) and activation of attentional networks (Fan et al., 2007). The LRP represents the commencement of a motor response as it measures activation of electrodes placed over the motor cortex (Gratton et al., 1988). The LRP, in contrast to the CNV, can give very accurate temporal information about motor cortex activation. A more negative CNV relates to more awareness and readiness to the task and a larger LRP relates to a more significant motor response preparation. Both ERP's therefore have the potential to represent changes in the response preparation stage. The relationship between the CNV and motivational manipulations has been inconsistent. Some studies found that the CNV amplitude in the response preparation interval is related to the level of motivation (Hughes et al., 2013; Pierson et al., 1987; Walter et al., 1964) whereas others found no effect (Goldstein et al., 2006; Sobotka et al., 1992). The differences among the findings might be due to the instruction (responding to accuracy or speed instead of both together), task difficulty, and/or the motivational manipulations, raising the need for additional research.

The P3b is commonly thought to reflect the speed and strength of stimulus categorisation (Donchin, 1981). More specifically, it is thought to originate from temporal-parietal activity associated with attention, and appears related to subsequent memory processing. The P3b is also sensitive to reward (Goldstein et al., 2006), making it an ideal marker to differentiate cognitive control strategies used in motivational and neutral trials, in both the response preparation and response execution intervals. On trials where a proactive strategy is used, the cue should be treated as valuable information, which would be reflected by larger P3b amplitude in the response preparation interval. On the other hand, on trials where a reactive strategy is used, the target and not the cue should be treated as valuable information, which would be reflected by larger P3b amplitude in the response execution stage.

In the present study, we aimed to determine the type of strategy used in different motivational conditions (motivation vs neutral) with different degrees of task demand (easy vs difficult). The DMC framework predicts that a proactive strategy of cognitive control is most likely to be used in a motivational condition compared to a neutral condition (Jimura et al., 2010; Locke and Braver, 2008). Because preparatory processes are more likely to be activated in highly predictable trials, where the participant can anticipate what is coming next, we expect that a proactive strategy will be preferred in such trials. In our design, highly predictable trials are referred to as 'easy' and less highly predictable trials are referred to as 'difficult'. Specifically, and regarding each individual brain activity described above, we expect a proactive strategy to be associated with a more negative CNV, a larger LRP, and a larger P3b in the response preparation interval. A reactive strategy is expected to be associated with larger P3b in the response execution interval for difficult trials.

2. Methodology

2.1. Participants

Twenty-five adults were recruited through advertisements displayed within the University of Cambridge. Before running any analysis, the data from two participants were rejected because of EEG artefacts on more than 50% of the data. The mean age of the remaining 23 participants was 25.1 years (SD = 3.6) and there were 11 males. Participants were paid for their participation and signed a consent form before taking part in the study. This study received the approval of the University of Cambridge ethics committee.

2.2. Task and stimuli

2.2.1. Task

The design was adapted from a procedure developed by Lewis et al. (2006). The task consisted of two main blocks: one neutral and one motivational. In the motivational block, a feedback screen (composed of a happy or a sad face and a counter showing the number of points) was presented every 10 trials, for 5000 ms. Participants were told that they were playing against another player whose scores were saved on the computer. Participants were told that if they were doing better than the (fictional) participant, they would earn points. If they were doing worse, they would lose points. For the purposes of experimental control, the feedback screen was held constant. To make sure participants would not suspect that the game was rigged, feedback were only presented every 10 trials, rather than after each trial. Also, participants were told that blinking at the right moment (when seeing the picture of an eye) and producing no head movements was as important as being fast and accurate to earn points. In addition to helping make the earning or losing points part of the game more real, this instruction also helped to minimise artefacts in the EEG data and prevented the participants to speed up their response in the motivational block just because they wanted to beat the other fictional participant. At the end of the experiment, the participants were debriefed and asked about the deception. The majority said they suspected it might have been set up but explained that they still acted as they were really playing against someone.

To keep the participants motivated, around half of the feedback was negative. For the ease of administration of the task, the motivational block was always presented last. Participants received no feedback in the neutral condition. They were, however, reminded to only blink when the picture of an eye appeared on the screen and were told to be as fast and accurate as possible (without mentioning reward).