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.

Key words

Cognitive control; Motivation; Proactive; Reactive; ERP; Reward

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, 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 & Behrens, 2008) or spatial attention (Baines, Ruz, Rao, Denison, & Nobre, 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 & 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, Locke, & Braver, 2010; Locke & 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, Paxton, Locke, & Barch, 2009; Braver, 2012; Jimura et al., 2010; Locke & 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 & 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 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, Liu, Van Dam, Hof, & Fan, 2013; Jasinska, Yasuda, Rhodes, Wang, & Polk, 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 & 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, Marco, & Grau, 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, Coles, Sirevaaq, Eriksen, & Donchin, 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, Mathan, & Yeung, 2013; Pierson, Ragot, Ripoche, & Lesevre, 1987; Walter, Winter, Cooper, Mccallum, & Aldridge, 1964) whereas others found no effect (Goldstein et al., 2006; Sobotka, Davidson, & Senulis, 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 & 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).

Participants performed a total of 11 blocks with 80 trials per block. The first 5 blocks were for the non-motivational condition and the last 6 blocks were for the motivational condition. A block was added in the motivational condition as it was anticipated that the participants would physically move more because of frustration and that more trials would be rejected after artefact rejection. The stimuli were pseudo-randomized, whereby each subject had a different random order of stimuli presentation. This was to ensure that there would be no confound due to one particular stimuli randomization. Stimuli were presented on a white background on a 19 inch computer screen, located 20 cm away from the participant. Each trial started with a fixation point (picture of an eye) for 300 ms. This was followed by a white screen for 1000 ms, where the participants were told they could blink. The visual stimulus then appeared for 300 ms and was followed by a white screen that was presented for 1050 ms. Then the sound was presented for 150 ms and therefore appeared 1350 ms after the visual stimulus onset. A response period of maximum 4000 ms followed, and an inter stimulus interval (ISI) white screen was presented again before the beginning of the next trial. The ISI varied from 450 to 550 ms.

As one of the aims was to examine the LRP, vertical spatial orientation (up and down as opposed to horizontal left and right) of the stimuli was used to avoid cofounding ERP activity from the occipital cortex. The response pad therefore had a ‘top’ and a ‘bottom’ button and participants used both hands to respond. Half of the participants were asked to use their right hand for the top button and left hand for the bottom button. The other half were asked to use the opposite configuration.

Before the experimental blocks one practice block was completed with 25 stimuli. The practice block was presented again if the participant did not achieve more than 70% of correct responses. Stimuli were presented using the Neurobehavioral Systems Presentation 11 program.

2.2.2. Stimuli

A visual stimulus (cue) was presented before an auditory stimulus (target) to separate response preparation from response execution; and to examine whether motivational context influences one stage or the other. Instructions designated the meaning of the association between the visual cue and the auditory stimuli in terms of go, stop or switch responses. The difficulty was determined by the association between the visual and auditory stimulus. Within each block, easy and difficult trials were intermixed. In easy trials, the participants always had to press on the response pad that corresponded with the location of the visual stimulus. On difficult trials, participants had to press the opposite response pad, involving switching responses. The time between the visual cue and the auditory stimulus was considered the response preparation phase. The time between the auditory stimulus and the response was considered the response execution phase (see Figure 1).

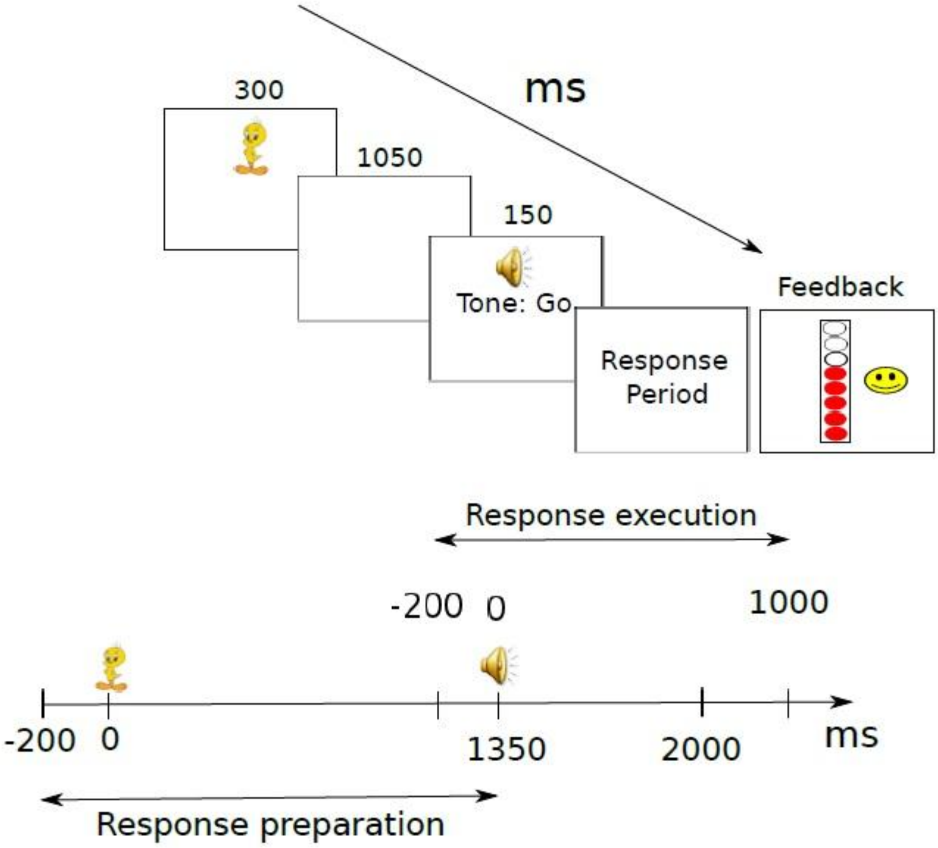

Figure 1: Schematic of a trial. The feedback trial was presented only in the motivation condition, every 10 trials. The Response preparation was analysed between the visual cue and the auditory stimulus (0 to 1350ms relative to the cue). Response execution was analysed between the auditory cue and the response (0 to 1000 relative to the auditory stimulus; 1350 to 2350 relative to the visual stimulus). The Lateralised Readiness Potential (LRP) was analysed in both the response preparation and response execution interval, from 0 to 200ms relative to the visual cue presentation. The -200ms is represented as we baseline corrected the ERP epoch with a 200ms baseline.

Each association between the visual cue and the auditory stimulus was either considered easy or difficult. In easy trials, GO visual stimuli (cue) were followed by either a Go or Switch sound (target); but, the participants were told to always press on the button pad representing the location of the visual stimulus, therefore ignoring the meaning of the sound.

Therefore, if the go visual cue was located at the bottom of the screen, the participants had to press on the bottom button pad, regardless of the sound. In difficult trials, SWITCH visual stimuli (cue) were followed by either Go or Switch sound (target). With the Switch sound, the participants had to press on the button pad representing the opposite location of the presentation of the cue on the computer screen. For instance, if the cue was presented at the top of the screen, the participants had to press on the bottom button pad. With the Go sound (and SWITCH visual stimulus), the participants were required to press on the button pad representing the location of the visual stimulus on the screen. In both easy and difficult trials, the visual stimuli were followed in 10% of the time by a Stop sound, which indicated that the participant had to stop their responses (see Table 1 for a description of the trial types). This was to ensure that all sounds were attended, even in easy trials where Go and Switch sound predicted an identical response. Participants were told to respond as quickly as possible once they had heard the tone, except on Stop trials in which they were to withhold their response.

Table 1: Stimuli Proportions of the cued task switching experiment, representing the different combinations (6 different conditions) of visual and auditory stimuli.

Visual stimuli	Auditory stimuli	% of trials for each condition	%of total trials	% of total trials
GO	go	70% (of Go trials)	35%	50%
	switch	20% (of Go trials)	10%	
	stop	10% (of Go trials)	5%	
SWITCH	switch	70% (of Switch trials)	35%	50%
	go	20% (of Switch trials)	10%	
	stop	10% (of Switch trials)	5%	

Note: GO_go in dark grey represents easy trials and SWITCH_switch in light grey represents difficult trials

Note that amusing characters/sounds were used instead of plain shapes because the task was conducted with children as well as with adults. The visual stimuli represented a cat or a bird, while the sounds were imitations of a cat meowing, a bird chirping and a neutral sound. The sound and visual stimuli were randomised between participants (e.g.. sometimes the cat sound/picture was used for Go trials and sometimes it was used for Switch trials). Stories were told to explain the association between the stimuli and the sounds; and to decrease the working memory load. For example, one story was to help save the bird from the cat by making the bird go home safe (press on same side) and send the cat away (press on opposite side). Both the children and the adults received the same instructions. The children's data are not reported here.

2.3. EEG recording and pre-processing

EEG was recorded by an Electrical Geodesics system with a 129-channel Geodesic Sensor Net. The sampling rate was set at 500 Hz. An on-line lowpass filter of 70 Hz was used. A 50Hz notch filter was applied off-line after recording. The data were band-pass filtered between 0.03 and 30 Hz off-line and were recomputed to average reference. Two types of epoch were computed: one locked to the visual cue and one locked to the auditory cue, in order to look at both the response preparation and response execution intervals respectively. Cue-locked epochs extended from −200 to +2000 ms relative to the visual cue presentation and represented the whole period from the presentation of the cue to the presentation of the auditory target. These were called 'response preparation' epochs. Auditory-stimulus-locked epochs extended from -200 to +1000 ms relative to the auditory stimulus presentation, or +1150 to +2150 relative to the cue presentation. These were called 'response execution' epochs. Data were baseline corrected by a baseline of −200 to 0 ms relative to visual cue and the auditory stimulus presentation respectively. See Figure 1 for a detail of the epochs. Epochs were rejected if they contained ocular artefacts (monitored at electrodes below, above and next to the eyes) or voltage deviations exceeding ±200 μV relative to baseline at any of the recording electrodes. The maximum allowed voltage step was 50 μV /ms. Averaged ERPs were computed for each participant in the four different stimulus conditions: (1) Easy non-motivational trials (Easy nM); (2) Difficult non-motivational trials (Diff nM); (3) Easy motivational trials (Easy M) and (4) Difficult motivational trials (Diff M). Only correct response trials were included in the averaging procedure. Participants with more than 50% of rejected trials were rejected from the analysis. Two were rejected according to this criterion. On average, 74% of non-motivational trials and 77% of motivational trials were retained for the 23 remaining participants.

2.4. Behavioural analysis

Prior to the analyses, we tested whether a practice effect might contribute to any potential differences between the two motivational conditions, as the non-motivational block was always administered first. Specifically, we tested for the presence of a practice effect emerging between the first and second halves of the non-motivation condition. We compared the performances (RT and accuracy) between the beginning and the end of the first non-motivational block of 320 trials (80 (trial per block) * 2 (number of blocks in each conditions) *2 (two conditions) = 320). The paired sample T-tests found no differences between the beginning and the end of the non-motivational block (Easy RT: t=1.57, df= 24, d=0.31, p=.129; Difficult RT: t=2.12, df=24, d=0.42, p=.044; Easy Accuracy: t=-1.12, df=24, d=0.22, p=.274; Difficult Accuracy: t=-.40, df=24, d=0.17, d=0.08, p=.695; Stop accuracy:

t=1.29, df=24, d= 0.26, p=.211; because of multiple comparison, the threshold for p was adjusted to 0.01). This indicates that practice likely had no effect on the potential differences between the motivational and non-motivational conditions.

Second, 2 (trial type) by 2 (motivation) repeated measures ANOVA were conducted on reaction time and accuracy on all trial types.

2.5. Event Related Potential analysis

2.5.1. Contingent Negative Variation: CNV

Deviation from baseline (zero) at the Cz electrode was tested by point-by-point two-tailed one-sample t-tests against zero ($p<.005$) in the 1250-1350 ms interval, which corresponds to the 100 ms interval before the onset of the auditory stimulus. Then, we ran a 2 (trial type) by 2 (motivation) repeated measures ANOVA to evaluate whether there was a difference between the four conditions.

2.5.2. Lateralised Readiness Potential: LRP

The LRP was computed in accordance with Coles' (1989) recommendations: [(ER-EL)left hand response + (EL-ER)right hand response] /2. ER represents the activity from an electrode situated over the right motor cortex (usually C4 in the 10-20 electrode system), and EL represents the activity from an electrode situated over the left motor cortex (usually C3).

We then examined whether the LRP significantly deviated from baseline (zero) at any time point. The deviation of the LRP from the baseline was tested by point-by-point two-tailed one-sample t-tests against zero ($p<.005$) in 50 ms segment intervals. Finally, we ran a 2 (trial type) by 2 (motivation) repeated measures ANOVA to evaluate whether there was a difference between the four conditions.

2.5.3. P3b

2.5.3.1. Cue-stimulus interval (response preparation interval)

P3b mean amplitude and peak latency were calculated in the 350-450 ms time window in the response preparation period, based on the inspection of our grand average waveforms and consistent with previous literature indicating it occurs within the 300-500 ms interval (Best & Miller, 2010; Bryce, Szũcs, Soltész, & Whitebread, 2011; Polich, 2007). The pooling consisted of 10 electrodes (72 77 76 84 90 75 83 82 89 8). These electrodes were chosen based on the topographic observation and on previous literature that has found the P3b to be defined at (centro-) parietal sites (Bryce et al., 2011; Luck, 2005; Donchin, 1981). We conducted a 2 x 2 repeated measures ANOVA, with Trial type (Easy and Difficult) and motivation (motivation and non-motivation) as within subject factors on both amplitude and latency.

2.5.3.2. Stimulus-response interval (response execution interval)

P3b mean amplitude and peak latency were calculated in the 300-400 ms time window in the response execution period, based on the inspection of our grand average waveforms and consistent with previous literature. The pooling consisted of six electrodes (55 62 54 61 78 79). These electrodes were also chosen based on topographic observation and on previous literature (Best & Miller, 2010; Bryce et al., 2011; Polich, 2007). We conducted a 2 x 2 repeated measures ANOVA with Trial type (Easy and Difficult) and Motivation (Motivation and Non-motivation) as a within subject factors. Amplitude and latency were the outcomes

2.6. Correlation between behavioural and neural measures

Pearson's correlations were conducted between (1) the mean amplitudes of the CNV, the mean amplitudes of the LRP, the mean amplitudes and latencies of the P3b in the response preparation and response execution intervals and (2) the RT and accuracy measures in the four following conditions: Easy non-motivational, Difficult non-motivational, Easy motivational and Difficult non-motivational.

3. Results

3.1. Behavioural data

The repeated measures ANOVA showed a main effect of motivation on RT ($F_{1, 24}$ = 48.0, p<.001) and accuracy ($F_{1, 24}$ = 34.0, p<.001). Bonferroni corrected post-hoc t-tests showed that Easy and Difficult trials were responded to significantly faster in the motivational compared to the non-motivational condition ($Mean_{Easy\ nM}$=543 ms; $Mean_{Easy\ M}$=388 ms; p<.001; $Mean_{Diff\ nM}$=578 ms; $Mean_{Diff\ M}$=422 ms; p<.001). However, although trials were responded to faster, participants were less accurate in Difficult trials ($Mean_{Diff\ nM}$=97.4 ; $Mean_{Diff\ M}$=96.2; p=.044), Easy Stop trials ($Mean_{E\ Stop\ nM}$= 92.2; $Mean_{E\ Stop\ M}$=72.5; p<.001) and Difficult stop trials ($Mean_{Diff\ Stop\ nM}$= 94.2; $Mean_{Diff\ Stop\ M}$=89.8; p=.027) in the motivation compared to the non-motivation condition. Figure 2 presents the results.

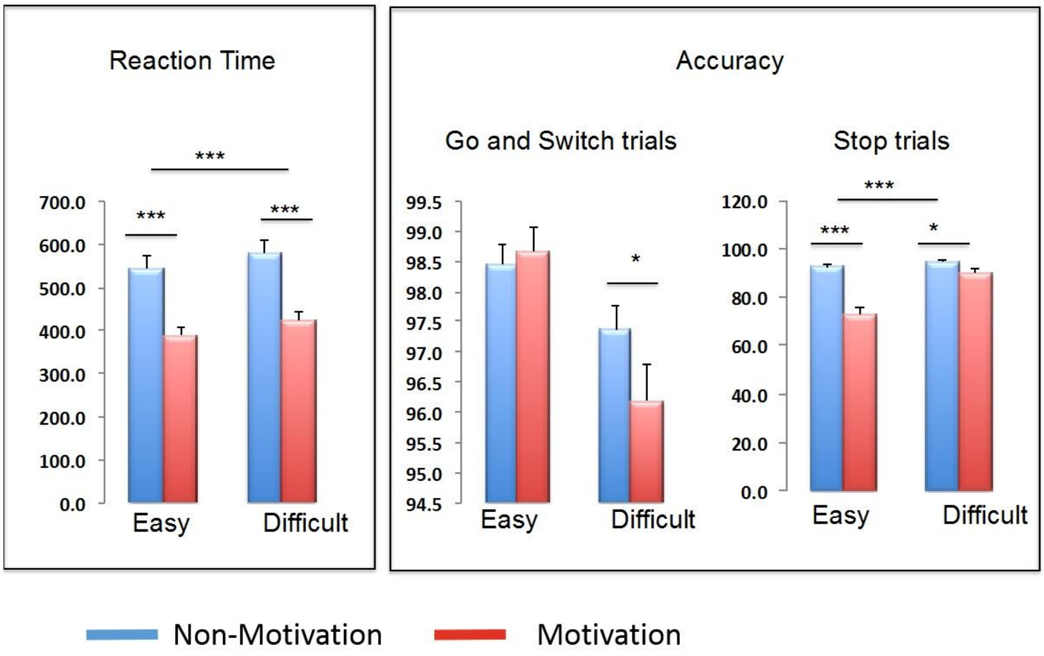

Figure 2: Reaction time and accuracy in the motivational and non-motivational conditions for easy and difficult trials.

***p<.05, *** p<.001**

These results suggest that the participants preferred to use a strategy that would speed their response time but decrease their accuracy in the motivational condition. This seems to suggest that in these trials, the participants used a proactive strategy. Indeed, with a proactive strategy, responses are prepared in advance but when the response has to be stopped or switched it creates a conflict, which can lead to reduced accuracy (i.e. commission errors). Because Easy Stop trials were particularly impaired (not stopping when required), we suspected that the participants predominantly used a proactive strategy in the Easy Motivational trials.

3.2. Event Related Potentials

3.2.1. CNV

Table 2: Mean CNV amplitude (± Standard deviation) in the 1250-1350ms interval just before the auditory stimulus.

	Non motivation		**Motivation**	
	Easy	**Difficult**	**Easy**	**Difficult**
Mean (in µV)	-9.9 (±5.9)	-9.7 (±5.3)	-12.7 (±3.9)	-12.3 (±4.5)
One sample T-test (against 0)	***t=-8.0,df=22, p<.001***	***t=-8.8,df=22, p<.001***	***t=-15.6,df=22, p<.001***	***t=13.3,df=22, p<.001***

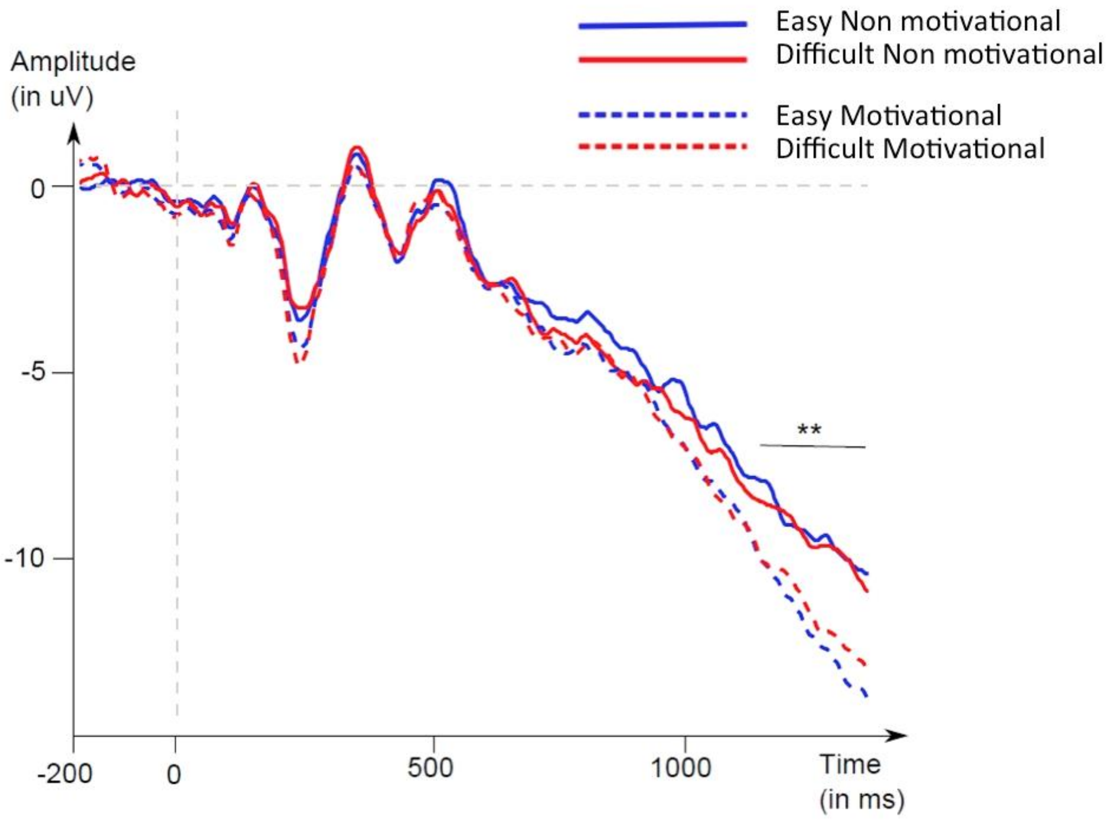

Figure 2: Contingent Negative Variation (CNV) at Cz (central electrode) in the four conditions: Easy Non motivational (bold blue line); Difficult Non motivational (bold red line); Easy Motivational (dotted blue line) and Difficult Motivational (dotted red line). The epoch is cue-locked so 0 is the onset of the visual cue. The auditory stimulus appears 1350ms after the visual cue. The CNV shows a significant deviation from 0 as indicated by the dark line with ** in the 1250-1350ms interval. ** p<.01

The results presented in Table 2 and Figure 2 show that the CNV was significantly different from zero ($p<.001$) in all four conditions which suggests that the participants were alert during the experiment and ready to press the response button, in all four conditions.

The results of the ANOVA showed no main effect of trial type. There was no interaction between trial type and motivation but there was a main effect of motivation ($F_{1, 22}=7.0$, $p=.015$), as confirmed by Figure 2. Bonferroni post-hoc t-tests were conducted to determine the main effect of motivation. The CNV in motivational trials was more negative than the CNV in non-motivational trials (Mean $_{Non\ motivation}$ =-9.8 µV ; Mean $_{Motivation}$=-12.5 µV; p=.007). This suggests that in the motivational condition, the participants were more alert and were more ready to press the response button, as is confirmed by the decreased reaction time in the motivational condition. This increase in alertness was present regardless of the difficulty of the trial.

3.2.2. The Lateralized Readiness Potential (LRP)

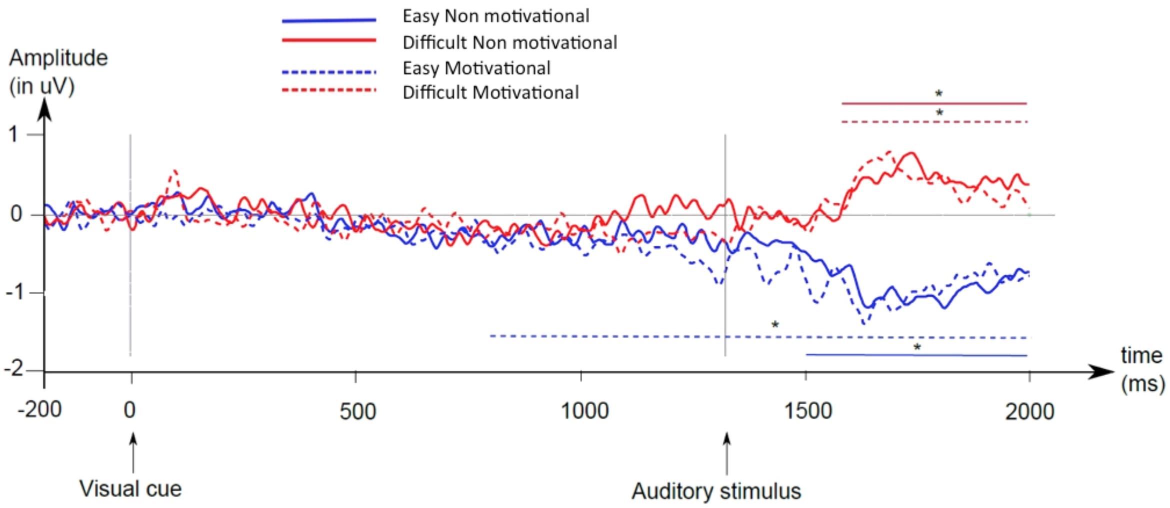

Figure 3: Cue-locked Lateralised Readiness Potential for Easy (blue lines) and Difficult (Diff) (red lines) trials in the non-motivational (nM) (full bold lines) and motivational condition (M) (dotted lines). Note that a negative deflection in the cue-target interval reflects a preparation in the direction of the cue. In the post-stimulus interval, a positive deflection is observed for Difficult trials. This does not reflect an incorrect response but that the response is prepared in the opposite direction to the cue. The horizontal lines denote the interval where the LRP significantly deviated from the baseline (as tested by point-by-point one-sample t tests, p<.05). The blue dotted horizontal line (representing Easy M) goes from 800 to

2000 ms; the blue full bold line (representing Easy nM) goes from 1500 to 2000 ms; the red dotted and full bold lines (representing Diff M and Diff NM respectively) go from 1600 to 2000ms. * p<.05

As shown in Figure 3, the participants started preparing their responses from 800ms after the presentation of the visual stimulus i.e. 550 ms *before* the presentation of the auditory stimulus in the motivation condition for Easy trials only. The participants started preparing their responses 150 ms *after* the auditory stimulus for Easy non-motivational trials and 250 ms *after* the auditory stimulus for Difficult trials (both motivational and non-motivational trials). These results are consistent with the behavioural results suggesting that the participants may have used a proactive strategy in Easy Motivational trials only. They did not seem to have used a proactive strategy in the non-motivational condition, for either Easy or Difficult trials. Difficult trials in the motivational conditions were responded to faster than in the non-motivational condition. However the LRP does not confirm that the participants were preparing their responses in the response preparation interval for such trials.

3.2.3. The P3b

3.2.3.1. Cue-Stimulus interval: Response preparation

A repeated measures ANOVA on the P3b amplitude showed no main effect of trial or motivation and no interaction. However, P3b latency showed a trial x motivation ($F_{1, 22}$=6.4, p=.019) interaction. No significant differences emerged in post hoc contrasts. The fact that the P3b amplitude was similar in all four conditions suggests that the differentiation between proactive and reactive control appears after stimulus processing. The LRP started showing differences from 800 ms onwards after the presentation of the visual cue. It seems therefore that the difference in strategy is implemented in the late stage of response preparation, and the visual cue is processed in a similar manner in all conditions.

3.2.3.2. Stimulus-Response interval: Response execution

Figure 5 represents the topographic maps in the 350-450 ms interval and the grand average ERP. A P3b is clearly present in all four conditions.

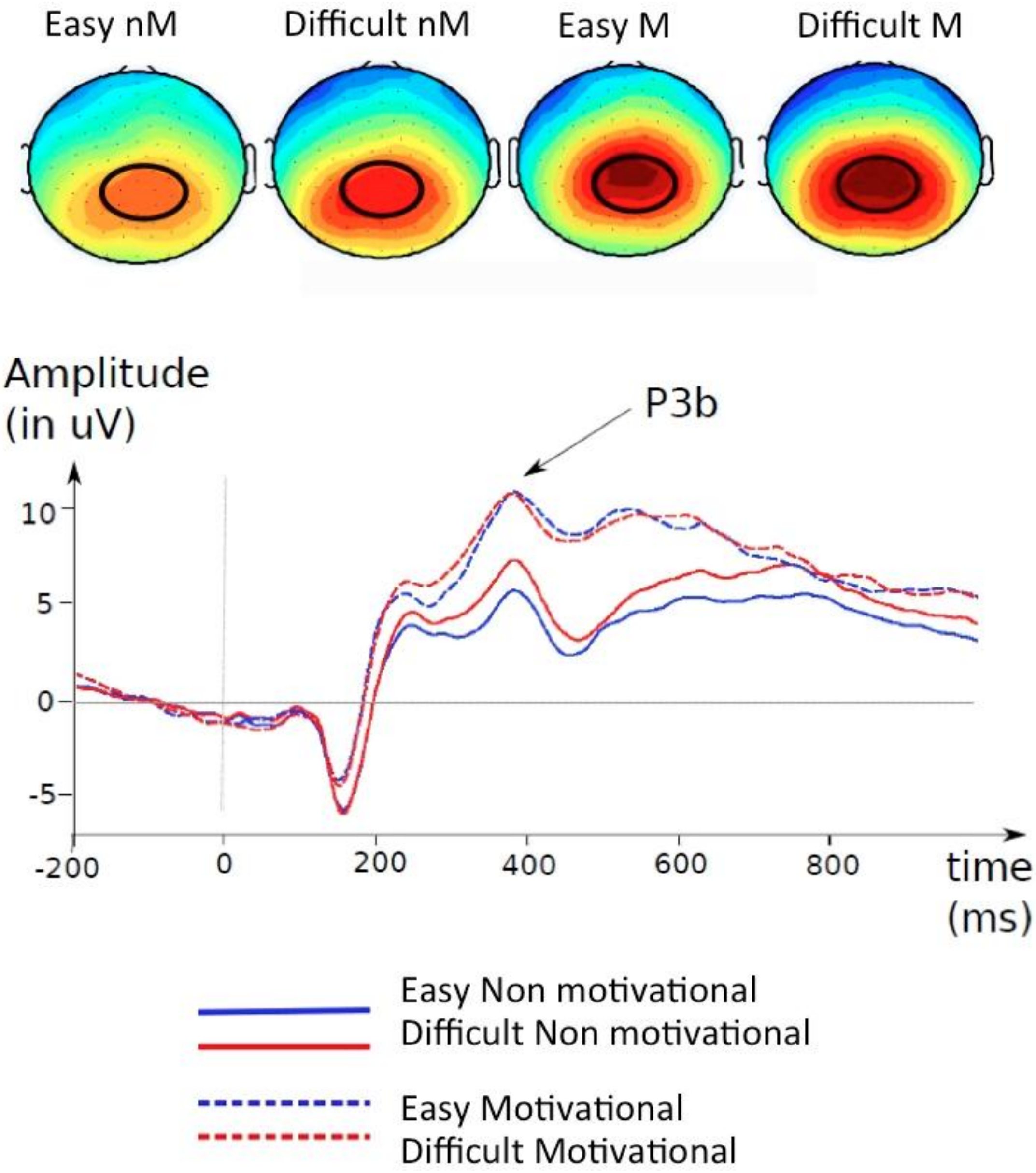

Figure 5: Topographies representing mean amplitudes in the 350-450ms time window in the response execution interval and the Grand-average ERP response for Easy Non-motivational (bold blue line); Difficult Non-motivational (bold red line); Easy Motivational trials (dotted blue line) and Difficult

Motivational (dotted red line) at the site of the pooling as defined by the topographies. The pooling was composed of six electrodes (55 62 54 61 78 79). The Epoch was locked to the auditory stimulus and started from 200 ms before the auditory stimulus and stopped at +800ms.

There were no effects for latency. However, the repeated measures 2 (trial) by 2 (motivation) ANOVA conducted on the amplitudes revealed a main effect of motivation ($F_{1, 22}$=18.0, p<.001) and a main effect of trial type ($F_{1, 22}$=10.7, p=.004). There was no interaction. Bonferroni post-hoc t-test revealed that the P3b in motivational trials had a larger amplitude compared to the P3b in non-motivational trials ($Mean_{Non\ motivation}$ = 6.7μV; $Mean_{Motivation}$= 10.0μV; p<.001). Also, Difficult trials had a larger P3b amplitude compared to Easy trials ($Mean_{Difficult}$ = 9.1μV ; $Mean_{Easy}$=7.6 μV; p=.004). These results suggest that the participants in this study used a reactive strategy in difficult versus easy trials.

3.3. Correlation between behavioural and neural measures

In order to examine the influence of response preparation on behavioural measures, we computed correlations between ERP amplitudes and latencies, and behavioural measures (RT and accuracy). Table 3 shows the correlations between the RT measures of the four conditions (Easy and Difficult in the non-motivational and motivational condition) and the CNV amplitude, the P3b amplitude in the response preparation period and the P3b in the response execution interval. No correlations with accuracy were significant and there was also no correlation with the LRP and behavioural measures so these results are not reported.

Table 3 shows that the amplitude of the CNV significantly positively correlated with RT. As such, more negative CNV (reflecting more preparation) was associated with smaller RT. The P3b in the response preparation interval was not related to any behavioural measures. This is in accordance with the fact that the P3b did not differ across conditions. This seems to confirm that the level of attention placed on stimulus categorisation in the response preparation interval does not influence the final reaction time. The P3b amplitude in the response execution interval was significantly related to RT measures. Larger P3b was associated with smaller RT. The amplitude of the P3b has been shown to index stimulus categorization (Donchin, 1981). P3b latency has been shown to be independent of response execution (McCarthy & Donchin, 1981). This is confirmed by the present results, which suggest that the P3b latency did not significantly correlate with RT.

Table 3: Correlations between the RT measures (in ms) of the four conditions (Easy and non-motivational (Easy NM), Difficult and non-motivational (Diff NM), Easy and motivational (Easy M) and Difficult and motivational (Diff M)) and the mean amplitude of the CNV, the P3b in the response preparation interval (P3b RP) and the P3b in the response execution interval (P3b RA).

		Mean amplitude (uV)		
		CNV	P3b RP	P3b RA
RT (in ms)	Easy nM	*.59****	-.12	*-.48**
	Diff nM	*.50**	-.10	*-.64****
	Easy M	*.49**	.28	*-.58****
	Diff M	*.49**	.16	*-.72****

***p<.05 ; *** p<.001. After Bonferroni correction, only *** were significant.**

4. Discussion

The current study aimed to examine the types of cognitive control strategies that are used in motivational and non-motivational conditions using a cognitive control task with varying degrees of difficulty. Behavioural measures of RT, accuracy and ERP markers were analysed. The CNV and LRP were used as measures of alertness and motor preparation respectively. The P3b was used as a measure of stimulus processing in both the response reparation and response execution stages.

Behavioural analyses revealed that in the motivational condition, the participants responded significantly faster than in the non-motivated condition; as shown by decreased RT. This is consistent with what is generally found in the literature regarding the influence of motivation on performance (Gilbert & Fiez, 2004; Hughes et al., 2013). The behavioural results also showed that accuracy on Stop trials was significantly lower in the motivational condition. We therefore observed a speed-accuracy trade-off, with faster responses but compromised no-go responses on stop trials and in the difficult condition. These results are consistent with the DMC theory (Braver, 2012). According to this theory, participants should prepare their responses in advance (in the cue-stimulus, response preparation interval). Thus, such a strategy would generate lower RTs but induce more difficulties when a conflict arises (such as when they have to press on the opposite side of the presentation of the cue (Difficult trials) or when they have to suddenly stop a response (Stop trials)). The analysis of RT and accuracy alone cannot readily show what the participants were doing in the cue-stimulus interval. ERPs are particularly well adapted to this study as they can investigate mechanisms that are not observable with behavioural measures.

The CNV was examined in order to gain insight into the general awareness and alertness of the participants in the different conditions. We showed that there was no difference between Go and Switch trials. Nevertheless, when both type of trials were included, the CNV was more negative in the motivational condition. Because a more negative CNV has been associated with greater alertness, stimulus anticipation and selective attention (Tecce, 1972), we conclude that the participants were more prepared during the motivational block, probably because they were motivated to earn the reward.

The LRP was used to measure motor response preparation. The results showed that the participants started preparing their response 550 ms before the presentation of the auditory stimulus in Easy trials in the motivational condition only. This fits well with the behavioural results that suggest Easy motivational trials were responded to faster than the other types of trial. Together, these findings suggest that participants used a proactive strategy in Easy motivational trials. The LRP also showed that the participants did not prepare their response to Difficult trials in advance, probably because the response had to be switched in most of the time. Therefore, it is possible that the participants decided to not take the risk of preparing a potentially incorrect response, as this would have led to even more response inhibition (for instance, preparing to press the 'down' button when the correct response is 'up'). Another explanation is that individuals within the group differed in terms of strategies. It is in theory possible that some participants prepared their response in the same direction as the presentation of the target (i.e. preparing the up button for a stimulus being presented at the top of the screen) and that some participants prepared their response in the opposite direction (i.e. preparing the down button for a stimulus being presented at the top of the screen). Such a scenario would have resulted in an average LRP close to baseline (zero). However, we analysed the LRP data for bimodality and we did not find any indication of a bimodal distribution, so we rejected this possibility.

The P3b was analysed in two different intervals: the response preparation interval between the visual cue and the auditory stimulus; and the response execution interval between the auditory stimulus and the response. In the response preparation interval, no difference in amplitude was found between the four conditions. This suggests that the difference in response preparation level between a reactive and proactive strategy (as shown with the CNV or LRP) occurs *after* the stimulus is being processed (as shown with the P3b).

Thus it occurs in the late stage of response preparation. This is the first time that research has differentiated between proactive and reactive types of control with such time precision.

In the response execution interval, we found that P3b amplitude was larger for difficult vs easy trials. This suggests that the participants used a reactive strategy on difficult trials, treating the auditory target as crucial information for these trials. Also, we found that motivational trials had larger P3b amplitude compared to non-motivational trials, confirming previous results found in the literature (Hughes et al, 2006; Goldstein et al, 2006). This suggests that in difficult and motivational trials, more resources are used to treat the last piece of information (the auditory stimulus in this study) necessary to make a response. We did not find any difficulty by motivation interaction.

The correlations between the CNV, P3b and RT show that both the level of alertness in the response preparation interval and the level of attention placed on the stimulus on the response execution interval have a role in behavioural outcomes.

Taken together, these results tend to suggest that a motivational manipulation influences multiple stages of information processing. It seems that motivation increases alertness (as shown by the CNV), promotes a change in strategy as observed with the LRP and increase attention processes in the response execution interval as seen with larger P3b amplitude. These results also confirm that proactive and reactive strategies can be used alternatively depending on the situation; and, that both have their advantages and limitations (Braver, 2012).

Although this study offers insights into the effect of motivation on cognitive control, there are some limitations. First, the fact we had negative feedback with the positive feedback might have created some bias in the experimental condition. It is possible that negative feedback created frustration and therefore the results would not be due only to motivation. However, we suspect that the negative feedback actually improved motivation to gain the reward. Second, the reward did not match the actual performance of the participants, which might have biased the results. However, all participants mentioned that although they might have suspected that the game was rigged, they played their best and felt motivated to earn the reward in case it was not rigged. Third, we did not investigate individual differences in motivation-related traits. Intrinsic motivation has been shown to play a role in how individual view reward and it is possible that the level of motivations varied across our participants. Finally, it was probably not ideal to continuously have the experimental block at the end. However, we reasoned that this design was necessary to keep participants alert and motivated until the end. Because we did not find any difference between the beginning and the end of the non-motivational block, we reason that practice likely had no effect.

5. Conclusion

This study is the first to look at the neural markers of cognitive control across varying levels of difficulty and motivation. This study shows that different types of control are used in different situations. It appears that the motivational situation triggers the use of a proactive strategy when the level of cognitive control is relatively low, speeding up behavioural responses (decrease in RT). This study also shows that although a proactive strategy may reduce response latencies, it can be resource consuming as it involves constant control, inducing more errors. This study also suggests that proactive response preparation appears after the cue has been processed, as indicated by similar P3b amplitudes in the response preparation interval for all four conditions. The LRP and CNV results suggest that this differentiation occurs later on, around 800ms for the LRP and 1250ms for the CNV. Finally, this study demonstrates the utility of using behavioural measures combined with CNV, LRP and P3b to investigate proactive and reactive strategy use.

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