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Mental fatigue, motivation and action monitoring

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Abstract

In this study we examined whether the effects of mental fatigue on behaviour are due to reduced action monitoring as indexed by the error related negativity (Ne/ERN), N2 and contingent negative variation (CNV) event-related potential (ERP) components. Therefore, we had subjects perform a task, which required a high degree of action monitoring, continuously for 2 h. In addition we tried to relate the observed behavioural and electrophysiological changes to motivational processes and individual differences.

Changes in task performance due to fatigue were accompanied by a decrease in Ne/ERN and N2 amplitude, reflecting impaired action monitoring, as well as a decrease in CNV amplitude which reflects reduced response preparation with increasing fatigue. Increasing the motivational level of our subjects resulted in changes in behaviour and brain activity that were different for individual subjects. Subjects that increased their performance accuracy displayed an increase in Ne/ERN amplitude, while subjects that increased their response speed displayed an increase in CNV amplitude. We will discuss the effects prolonged task performance on the behavioural and physiological indices of action monitoring, as well as the relationship between fatigue, motivation and individual differences.

Keywords: ERN; Ne; N2; CNV; Event related potential; Fatigue; Motivation; Dopamine; Speed; Accuracy

1. Introduction

1.1. Mental fatigue and action monitoring

Fatigue due to prolonged task performance is a common phenomenon in our everyday lives. When people become fatigued, they usually experience difficulties in maintaining task performance at an adequate level. This can have major consequences: for example, in a recent study by Campagne et al. (2004) in which subject were required to drive a car (in a simulator) for about 3 h, it was found that with increasing fatigue, performance deteriorated. Driving errors such as large speed variations and even running of the road became increasingly frequent. Comparable results have been obtained for truck and train drivers (Kecklund and Akerstedt, 1993; Torswall and Akerstedt, 1987). It seems that the problems that fatigued people experience in these circumstances result to a large extent from the fact that they monitor their actions insufficiently.

To be able to behave in a coherent and adaptive manner, it is imperative to monitor ones actions (MacDonald et al., 2000). In doing so, information is gained which can be used to adjust ongoing behaviour. To keep with our example: if the subjects in the car simulator would have monitored their actions adequately, they would have detected their deviations in speed and position on the road earlier, resulting in less driving errors.

In the present study we examined the effects of fatigue on action monitoring processes, using event-related potentials (ERPs). Different indices of action monitoring can be discerned in the ERP. The error related negativity (ERN) or error negativity (Ne) consists of a large negative shift in the response locked ERP occurring after subjects made an erroneous response. First reported by Falkenstein et al. (1990) and Gehring et al. (1990), the Ne/ERN was thought to be specifically related to error detection processes, in the sense of a mismatch signal when representations of the actual response and the required response are compared.

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Peaking at 50–150 ms after response execution, the Ne/ERN is most prominent at fronto-central scalp positions (e.g., Fz, FCz and Cz). Localization of the Ne/ERN with dipole localization algorithms (BESA) has led most authors to conclude that the Ne/ERN is generated in the anterior cingulate cortex (ACC, Dehaene et al., 1994; Gehring and Knight, 2000; Wijers and Boksem, 2005). These findings are corroborated with results from fMRI studies (Carter et al., 1998; Kiehl et al., 2000; Van Veen and Carter, 2002a).

A second ERP component associated with action monitoring is the N2 (Van Veen and Carter, 2002b). This stimulus locked ERP component has a similar scalp topography as the Ne/ERN and has also been localized in the ACC (Lange et al., 1998; Liotti et al., 2000). In contrast to the Ne/ERN, the N2 occurs prior to response execution on correct trials and is thought to reflect response conflict (Lange et al., 1998; Kopp et al., 1996; Liotti et al., 2000; Swick and Turken, 2002). Response conflict occurs when a stimulus activates more that one response channel (the correct and an incorrect channel).

To resolve the detected conflict, the action monitoring system recruits greater top–down control from other prefrontal structures to improve task performance and thereby reduce conflict (Botvinick et al., 2001; Carter et al., 1998; Gehring and Knight, 2000; Menon et al., 2001). The contingent negative variation (CNV) is thought to reflect anticipatory and preparatory processes, and has been shown to correlate with performance accuracy (Hohnsbein et al., 1998). The CNV is elicited by providing the subject with a warning stimulus (e.g., a cue) followed at some fixed interval by a second 'imperative' stimulus. The CNV is observed as a large negative deflection in the ERP between the warning and the imperative stimulus.

Action monitoring is a prerequisite for the ability to optimize ongoing behaviour. To modify behaviour, remedial actions should be implemented when errors are made. These remedial actions can consist of immediate corrections and/or post error slowing (Rabbitt, 1966). Post error slowing refers to the phenomenon that, after making an error, subjects typically respond with increased reaction times on the following trial. This probably reflects a strategic adjustment in response generation. Gehring et al. (1993) noted that the Ne/ERN was larger on trials in which errors were immediately corrected and that larger Ne/ERNs were related to a slower response on the subsequent trial (see also Scheffers et al., 1996). Moreover, Fiehler et al. (2004) reported a significantly greater haemodynamic response for corrected than for uncorrected errors in the rostral cingulate zone, an area identified to play an important role in error detection.

To investigate whether action monitoring processes are compromised when people are fatigued, we had subjects perform a task in which response conflict was high and required a high degree of action monitoring, for 2 h. The task we used was a modified version of the Simon task. In this kind of task, targets which are assigned to different effectuators (in this case hands) are displayed either left or right of fixation. The Simon effect (or congruency effect), first described by Simon and Small (1969) refers to the phenomenon that people respond faster (typically 20–30 ms; Lu and Proctor, 1995) when the side of stimulus presentation corresponds to the response side. This kind of task induces response conflict as the presentation of the stimulus automatically activates the spatially corresponding response. In the incongruent condition however, one has to override this automatically activated response in order to give the required response, which relies heavily on adequate action monitoring.

1.2. Mental fatigue and motivation

A second important issue we addressed in the current study is the relationship between fatigue and (lack of) motivation to continue task performance. Chaudhuri and Behan (2000) noted that in their patients fatigue is, at least in part, due to a deranged motivation in self-initiated tasks. Tops et al. (2004) proposed that mental fatigue can be viewed as an effort/reward imbalance: as long as one feels that the invested effort in the end will result in sufficient rewards, one will continue working. However, when the perceived effort becomes to great and the reward no longer compares to this, the motivation to continue will dissipate and one will want to disengage from the task, feeling fatigued.

To test this, we manipulated motivation by offering our subjects a certain amount of money if they performed well in the remainder of the task, after they had performed the task for 2 h. If fatigue can indeed be viewed as an effort/reward imbalance, the increased reward should lead to a better balance between effort and reward, thus counteracting the effects of fatigue. However, there are large individual differences in the way people respond to motivation and what kinds of rewards are perceived as motivating. Here, we chose to motivate our subjects by offering them a monetary reward, as well as stressing that their performance would be compared to that of other participants (social comparison). We stressed both accuracy and performance speed, so that subjects were free to choose the way in which they could improve their performance. This allowed us to investigate individual differences in response strategies.

Interestingly, many studies have shown the Ne/ERN to be related to motivational processes: when by task instructions the motivation to perform well is reduced, a reduction in Ne/ERN amplitude can be observed (Gehring et al., 1993). Motivation appears to be essential for observing a robust Ne/ERN (Gehring et al., 1993; Gehring and Knight, 2000; Tucker et al., 1999; Dikman and Allen, 2000; Luu et al., 2000). Bush et al. (2000) argue that Ne/ERN and related ACC activity represent a general evaluative system that processes the motivational significance of events including, but not limited to errors and conflict. In addition, Falkenstein et al. (2003) have shown the CNV to be sensitive to motivational manipulations as well. In their study, CNV amplitude was larger on trials when subjects were asked for an effortful improvement of performance compared to trials when no such performance improvement was demanded.

In this study we will investigate whether the effects of fatigue on behaviour are due to reduced action monitoring as indexed by the Ne/ERN, N2 and CNV ERP components. In addition we will relate these changes to motivational processes.