International Journal of Psychophysiology 72 (2009) 204–211

Contents lists available at ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

Mental fatigue and impaired response processes: Event-related brain potentials in a Go/NoGo task

Yuichiro Kato [a,*], Hiroshi Endo [a], Tomohiro Kizuka [b]

[a] *Institute for Human Science and Biomedical Engineering, National Institute of Advanced Industrial Science and Technology, 1-1-1 Higashi, Tsukuba, Ibaraki 305-8566, Japan*
[b] *Institute of Health and Sport Sciences, University of Tsukuba, Japan*

ARTICLE INFO

Article history:
Received 22 April 2008
Received in revised form 6 December 2008
Accepted 8 December 2008
Available online 24 December 2008

Keywords:
Mental fatigue
Resource
Response inhibition
Response execution
Event-related brain potentials

ABSTRACT

The effects of mental fatigue on the availability of cognitive resources and associated response-related processes were examined using event-related brain potentials. Subjects performed a Go/NoGo task for 60 min. Reaction time, number of errors, and mental fatigue scores all significantly increased with time spent on the task. The NoGo-P3 amplitude significantly decreased with time on task, but the Go-P3 amplitude was not modulated. The amplitude of error-related negativity (Ne/ERN) also decreased with time on task. These results indicate that mental fatigue attenuates resource allocation and error monitoring for NoGo stimuli. The Go- and NoGo-P3 latencies both increased with time on task, indicative of a delay in stimulus evaluation time due to mental fatigue. NoGo-N2 latency increased with time on task, but NoGo-N2 amplitude was not modulated. The amplitude of response-locked lateralized readiness potential (LRP) significantly decreased with time on task. Mental fatigue appears to slows down the time course of response inhibition, and impairs the intensity of response execution.

1. Introduction

Mental fatigue refers to the effect that people experience during and following prolonged periods of cognitive activity that requires work efficiency. Mental fatigue may lead to temporary deterioration of attentional functioning and response readiness, and even to increases in the number of behavioral errors. This phenomenon is common in daily life (e.g., during driving). For instance, Brown (1994) stated that time on task during driving induces a progressive withdrawal of attention from the road and traffic demands, which may impair vehicle control capabilities and the ability to avoid collision. It is therefore important to understand the nature of mental fatigue related deterioration of performance, and its specific effects on brain functioning.

Reaction time is a useful measure for studying information processing. Performing the task for a prolonged period causes a gradual slowing of reaction times on any cognitive-motor task, including switching (De Jong, 2000; Lorist et al., 2000), flanker compatibility (Lorist et al., 2005), and visual attention (Boksem et al., 2005) tasks. These studies indicate that performance deficits due to mental fatigue are associated with deterioration of information processing functions, such as attention and cognitive control. To sustain task performance, subjects are required to regulate their cognitive resources for a given task (Kok, 1997). The availability of resources is important in the continuous planning and monitoring for action. Therefore, it is assumed that mental fatigue is linked to insufficient resource allocation, and to attenuated motivation for preserving the original level of task performance (Fairclough, 2001; Hockey, 1997; Warburton, 1986).

Event-related brain potential (ERP) is an ideal indicator of the structure and timing of the information processing that occurs between stimulus onset and response, owing to its excellent temporal resolution (Coles et al., 1985; van der Molen et al., 1991). A late positive ERP component, namely P3, is thought to reflect the allocation of cognitive resources to a task (Kramer and Spinks, 1991). P3 amplitude is an index of the amount of resources invested to identify a target stimulus (Kramer and Spinks, 1991; Kok, 1997). In addition, P3 latency has been promoted as a measure of stimulus evaluation time that is independent of response selection and execution processes (Duncan-Johnson, 1981; Kutas et al., 1977; McCarthy and Donchin, 1981; Verleger, 1997). Humphrey et al. (1994) reported that P3 latency increased and P3 amplitude decreased with extended wakefulness, and described important effects of wakefulness on early perceptual processes. However, in their study fatigue was induced by sleep deprivation and was therefore distinct from the normal fatigue that occurs during daylight hours. The other ERP studies that have employed a prolonged cognitive-motor task have failed to detect variations in P3 amplitude as a function of time on task (Boksem et al., 2006; Falkenstein et al., 2002; Lorist et al., 2005). Thus, the effect of mental fatigue on the availability of cognitive resources remains to be clarified.

Action monitoring is related in important ways to the motivation that is thought to be responsible for the maintenance of task performance (Boksem et al., 2006; Lorist et al., 2005). The response-locked ERP related to error or action monitoring mechanisms is called

* Corresponding author. Tel.: +81 29 861 6661; fax: +81 29 861 6662.
E-mail address: kidkato@ni.aist.go.jp (Y. Kato).

0167-8760/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.ijpsycho.2008.12.008

error negativity (or Ne; Falkenstein et al., 1991) or error-related negativity (ERN; Gehring et al., 1993). The Ne/ERN shows a negative deflection immediately after erroneous responses to NoGo trials (false alarms) on a Go/NoGo task. Lorist et al. (2005) and Boksem et al. (2006) observed decreases in Ne/ERN amplitude with time on task, using a 2-h flanker compatibility task. They demonstrated that mental fatigue results in compromised error monitoring. In addition, the Ne/ERN is distributed over the frontocentral region, which is consistent with the proposal that the generator of this potential lies in the anterior cingulate cortex (ACC) (Carter et al., 1998; Kiehl et al., 2000; Mathalon et al., 2003; Miltner et al., 2003). Hence, it is assumed that the effect of mental fatigue on Ne/ERN reflects an attenuation of ACC functioning.

On the other hand, response inhibition and execution play important roles in any speeded action. To achieve speed and accuracy stability, subjects must utilize adequate inhibitory control while executing responses. However, little is known about the neurophysiological mechanisms underlying the effect of mental fatigue on response inhibition and execution. These processes can be investigated using the Go/NoGo task, in which subjects have to respond to one stimulus (Go) but not respond to another stimulus (NoGo). Response inhibition has been correlated with two ERP components in a Go/NoGo task. The NoGo-N2 reflects a frontal inhibition mechanism that is active on NoGo trials, and generates a negative deflection between 250 and 350 ms (Eimer, 1993; Falkenstein et al., 1999; Jodo and Kamiya, 1992). Second, the NoGo-P3 is linked to inhibition, which has a more anterior topography than Go-P3, and generates a positive shift between 300 and 550 ms (Eimer, 1993; Falkenstein et al., 1999; Pfefferbaum et al., 1985). Falkenstein et al. (2002) examined the effect of extended work on the inhibitory process in a speeded Go/NoGo task, and observed no effect of time on task on either N2 or P3. They suggested that the inhibitory process is relatively robust against the effects of mental fatigue.

Response activation is assumed to affect the primary output stage (i.e., response execution). Lateralized readiness potential (LRP) provides a specific index for tracing the time course of poststimulus response activation (Coles, 1989; De Jong et al., 1988; Gratton et al., 1988; Miller and Hackley, 1992), as generated in the primary motor cortex (Leuthold and Jentzsch, 2002; Osman and Moore, 1993). The locus of experimental effects can be inferred by analyzing the LRP obtained in waveforms, time-locked to either a stimulus onset or an overt response onset (Leuthold et al., 1996; Osman and Moore, 1993). Response-locked LRP reflects activation of response execution, as determined by the performance of a target movement. Masaki et al. (2004) suggested that the response-locked LRP indicates the beginning of motor programming, and its amplitude reflects the time to peak force. Müller-Gethmann et al. (2000) noted that the response-locked LRP amplitude is sensitive to the preparatory process in the primary motor cortex that concerns the control of response force. If mental fatigue impairs response execution, the response-locked LRP amplitude will be modulated as a function of time on task.

The present study investigated the effects of mental fatigue on resource allocation and error monitoring, as indexed by the P3 and Ne/ERN, respectively. In addition, we examined the effects of mental fatigue on response inhibition and execution in the Go/NoGo task.

2. Method

2.1. Participants

Eighteen healthy subjects (5 females and 13 males) between 19 and 41 years of age ($M=25.4$) participated in the experiment. They were all right-handed, with handedness scores of $+0.76$ or above (Oldfield, 1971), and had normal or corrected-to-normal vision. They were paid for their participation. This study was approved by the Ethics Committee of the National Institute of Advanced Industrial Science and Technology. All the subjects gave written informed consent prior to their participation.

2.2. Subjective measurement

Subjective fatigue was measured using the Fatigue Scale (Chalder et al., 1993). This is a 14-item questionnaire comprised of mental and physical subscales. Each of the 14 items is rated on a four-point Likert scale (0, 1, 2, 3). The subjects completed the questionnaire before and after the experimental session.

2.3. Stimuli and apparatus

A screen (65×90 cm) was positioned 1 m in front of the subjects. Stimulus presentation was programmed on a computer and back-projected onto the screen via a digital light-processing projector. A white fixation cross (0.6×0.6°) was displayed continuously at the center of the black background. The imperative stimulus was a white triangle (Go stimulus) or a white circle (NoGo stimulus), and was presented at a visual angle of 5.7° to the left or right of the fixation cross. The triangle had an equilateral edge length of 1.0°. The circle had a diameter of 0.57°. The stimuli were displayed for 100 ms, with an interstimulus interval of 2500 ms, as shown in Fig. 1. Manual responses were made by pressing a microswitch enclosed within a cylindrical button.

2.4. Procedure

Each subject was seated in a dimly lit, electrically shielded room with response cylinders in his/her left and right hands. Each subject took part in a preliminary session, followed by an experimental session. In the preliminary session, the subjects practiced 120 Go/NoGo trials. The experimental session consisted of twelve blocks of 120 trials, and lasted for 60 min. A 30-s rest period separated the blocks. There were four different types of stimulus in the hybrid Go/NoGo paradigm used here: Go left, Go right, NoGo left and NoGo right. The numbers of Go and NoGo stimuli were 96 (80%) and 24 (20%) per block, respectively, and the sequences of these stimuli were randomized. The subjects had to respond by pressing a button with their left thumb when a left triangle (Go stimulus) was presented or by pressing a button with their right thumb when a right triangle (Go stimulus) was presented, and had to withhold the response when a circle (NoGo stimulus) was presented. The left or right stimuli were presented equally often and in a random order. The subjects were instructed to respond as quickly and as accurately as possible, and were to fixate on the centered cross during a recording epoch.

2.5. Electrophysiological recording

An electroencephalogram (EEG) was recorded from Ag–AgCl electrodes at Fz, Cz, and Pz (according to the international 10–20

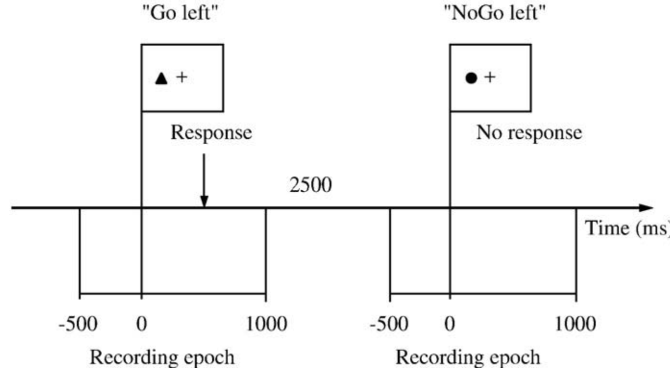

Fig. 1. Temporal sequence of events in task trial.