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Somatosensory P2 reflects resource allocation in a game task: Assessment with an irrelevant probe technique using electrical probe stimuli to shoulders

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ABSTRACT

The present study investigated whether event-related brain potentials (ERPs) elicited by task irrelevant somatosensory stimuli to the shoulders reflect the amount of processing resources allocated to a game task. In the experiment, electrical stimuli were presented to the right (or left) shoulder with a high probability (80%) and to the other shoulder with a low probability (20%) while participants were performing a driving simulation game. The deviant low-probability stimuli elicited somatosensory P2, and this P2 amplitude decreased when the task was difficult. The results show that the ERPs for somatosensory stimuli to the shoulders can reflect the amount of resources deployed even when the stimuli are ignored. This is a useful method for the evaluation of mental workloads in complex circumstances because it does not interfere with inputs of auditory or visual information or operations using the limbs.

1. Introduction

Many psychophysiological studies have demonstrated that event-related brain potentials (ERPs) reflect the deployment of processing resources. This psychophysiological index has been utilized in studies of mental workloads to assess the relative quantity of processing, or attentional, resources that are required to perform a task. A dual task paradigm is one common method for this assessment. It is based on the established idea that processing resources are limited in quantity (Kahneman, 1973; Norman and Bobrow, 1975). Because of this limitation, when more resources are allocated to a primary task, there is lower task performance as well as smaller responses of ERPs in a secondary task.

Previous studies have shown that ERPs elicited in a secondary task provide an indicator of the amount of resources deployed in the primary task (e.g., Wickens et al., 1983). In that study, for example, auditory stimuli (e.g., tones) were presented while participants were working on the main task. Participants were required to respond to the tones at the same time. Under such a dual task condition, performance on the secondary task and responses of ERPs for the auditory stimuli were reduced when the task difficulty was high compared to when it was low. However, although the dual task paradigm has been employed widely, there has been criticism that performing a secondary task could interfere with participants' concentration in the primary task. To resolve this concern, an irrelevant probe technique was proposed as a method that would not cause interference.

The irrelevant probe technique evaluates the amount of resources allocated to a task by assessing the response to a task irrelevant probe stimuli (see Papanicolaou and Johnstone, 1984, for review). In this method, people perform a task while ignoring probe stimuli presented at the same time. It has been shown that several ERP components elicited by the ignored stimuli reflect the amount of resources utilized. For example, Allison and Polich (2008) presented auditory probe stimuli while their participants were performing a computer shooting game. Pure tones were presented in a single-stimulus paradigm in which the inter-stimulus interval of the tones randomly changed. The results showed that even when no response was required for the auditory stimuli (i.e., the ignore condition), the amplitude of most ERP components elicited by the tones decreased with an increase in task difficulty. Allison and Polich's study indicated that the ERPs produced by task-irrelevant auditory stimuli reflect the amount of resources deployed, which vary with task difficulty. The study demonstrated the utility of the method with auditory probe stimuli.

However, there are still issues about which modality would be most reasonable to use for the probe stimuli in various circumstances. Although many other studies have employed auditory stimuli as probe stimuli (e.g., Kramer et al., 1995; Sirevaag et al., 1993), auditory is one of the most utilized modalities in real-world activities. This raises the possibility that auditory probe stimuli could interfere with task-relevant sensory information. For example, in situation where people are engaged in the detection of subtle changes in a sound, auditory stimuli overlapping with the sound could prevent them from getting the proper signal. An equivalent situation exists for visual modalities. For this reason, another modality could be more appropriate for probe stimuli in various circumstances. We consider that the somatosensory modality could be appropriate generally since it does not interfere

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with listening or seeing. Recently, several studies using a dual task have shown that ERPs produced by somatosensory probe stimuli reflect the amount of resources deployed (Kida et al., 2004a, 2012).

Kida et al. (2004a) demonstrated the modulation of somatosensory ERPs with a mental workload by presenting electrical probe stimuli to participants' fingers. The participants were instructed to press a button when infrequent electrical stimuli to the first digit were presented among frequent stimuli to the third digit. At the same time, they performed a force tracking task with the other hand. The difficulty level of the tracking task was defined by the speed and the predictability of the motion of the target line. The results showed that the infrequent somatosensory stimuli elicited the N140 and P3 component. The authors argued that the N140 reflects sensory motor resources and the P3 reflects the cognitive resources allocated to a task.

Although the study of Kida et al. (2004a) showed that the ERP components elicited by somatosensory stimuli provide an estimate of the processing resources allocated to a task in a dual task paradigm, the question remains whether ERPs for task irrelevant somatosensory stimuli reflect the amount of resources utilized. As previously discussed, an irrelevant probe technique would be preferable for a dual task paradigm to prevent interference with concentration on the task. Thus, it is important to examine the feasibility of an irrelevant probe technique with somatosensory probe stimuli as a useful evaluation method for mental workload.

Furthermore, although previous studies often presented the somatosensory stimuli to participants' fingers because they are highly sensitive to stimulation, this presentation precludes operations using that hand. For this reason, we presented the electrical probe stimuli to the participants' shoulders, which allowed operations with both limbs and hands.

In this experiment, we recorded electroencephalograms (EEG) while participants were performing a driving simulation game, and electrical stimuli were presented to their shoulders simultaneously. The electrical stimuli were presented to one shoulder with high probability (standard) and with low probability to the other (deviant). We set two difficulty levels on the game task (easy and difficult conditions). In addition to the game conditions, EEGs were recorded in a condition of a resting state that required no resources for any task (passive condition). We compared the ERPs among these three conditions. We expected that the deviant stimuli elicit the P3 component since we used the oddball paradigm for the stimulus presentation. We examined the influence of task difficulty on the P3, as was done in the previous studies. Although these studies also reported modulations on somatosensory N140, this component was very small when the somatosensory stimuli were ignored (Kida et al., 2004b). Since we adopted the irrelevant probe technique in this study, we did not expect that the probe stimuli would produce distinct N140. We did neither expect to observe earlier somatosensory evoked potentials (SEPs) that can typically be elicited when electrical stimuli are presented to the median nerve at fingers or wrists. Instead, we examined differences of ERPs in the time range of the somatosensory P2 component between the conditions. This component has been reported to vary related to attentional modulation and to rise even when the somatosensory stimuli were ignored (Forster and Gillmeister, 2011; Kida et al., 2006; Miltner et al., 1989). Thus, we expected that the somatosensory P2 should reflect attention resource that deployed for the information processing.

1.1. Purpose of this study

The present study aimed to investigate whether ERPs elicited by task irrelevant somatosensory stimuli to the shoulders reflect the amount of processing resources allocated to a game task. This method has advantages because it does not interfere with concentration on a task, inputs of auditory or visual information, or operations with the limbs and hands. Thus, it could be a psychophysiological evaluation method for studying resource utilization which is applicable to many varied tasks. We expected that the amplitudes of the ERP components elicited by the probe stimuli would decrease in the difficult condition compared to the easy condition reflecting the task difficulties. Furthermore, the amplitudes in these two conditions should be smaller than in the passive condition.

2. Method

2.1. Participants

Thirteen undergraduate and graduate students (5 females, 8 males; 20–27 years of age) participated in the experiment. All but one participant were right-handed. They provided written informed consent. None of them had experience of playing a driving simulation game in last two years. The study protocol was approved by the university's research ethics committee under the Kwansei Gakuin University Regulations for Research with Human Participants.

2.2. Stimuli and procedure

Electrical stimuli were generated by an electrical stimulus generator (Nihon Koden Corporation, SEN-7203) and presented to the participants' shoulders via electric isolators (SS-203J) and Ag/AgCl electrodes. The diameter of the current-carrying parts of the electrodes was 1.0 cm. The electrodes were placed on the participants' shoulders at points 25% of the distance from the spinous process of cervical vertebra CVII to the right and left acromions for cathodes, and 35% of this distance for anodes. The electrical stimuli were single block pulses, with 0.2 ms duration. The intensities were three times as high as the threshold for each participant, which never caused pain. The average intensities of the standard and deviant stimuli among all participants were 5.94 and 5.97 mA, respectively. Standard stimuli were presented to the right (or left) shoulder with a probability of 80%, and deviant stimuli were presented to the opposite shoulder with a probability of 20%. A total of 600 stimuli were presented in each condition block, combining both stimuli. The stimulus interval (SOA) was set to 1 s. Each condition took approximately 10 min.

In the easy and difficult conditions, the participants performed a driving simulation game *Gran Turismo 4* on Play Station 2 (Sony Computer Entertainment Inc.). In the easy condition, participants played the game driving a car (*Honda Fit*) on the course of “High Speed Ring.” This course contained a few curves and the speed of the car was slow. In the difficult condition, they drove another car (*Honda Civic*) on the course of “Nurburgring Nordschleife.” There were many curves in the course and the car speed was fast. Participants performed the task using an analog controller for Play Station 2, and were asked to drive the course at a fast speed and to try not to slide off the course. They were instructed to return to the course and continue driving if they deviated from the track. They practiced the game for more than 30 min at the beginning of the experiment. In the practice, the participants drove the same car as in the easy condition on the course of “Tsukuba Circuit,” which had moderate complexity. The participants were asked not to move their bodies more than necessary to perform the game task.

The images of the game were presented on a 20-inch television screen, viewed from a distance of approximately 1 m. In the passive condition, participants sat at rest in front of the screen and gazed at a fixation point on it. No game task or visual image was given in that time. The participants were asked to ignore the electrical stimuli presented to their shoulders in the easy, difficult, and passive conditions. The order of these three conditions was randomized between participants.

After finishing the three conditions, the participants performed the somatosensory oddball task as an active condition. They were asked to press a button with their right thumb as fast as possible