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Electrophysiological assessment of driving pleasure and difficulty using a task-irrelevant probe technique

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ABSTRACT

The amplitude of event-related brain potentials (ERPs) elicited by task-irrelevant auditory probes decreases when more attentional resources are allocated to a visual task. This task-irrelevant probe technique is considered to be useful in assessing the degree of interest in a visual task, as well as task difficulty. The present study examined the amplitude of the N1 and P2 components elicited by task-irrelevant auditory probes during a driving task in a simulated environment. The analysis of ERPs showed that the N1 amplitude decreased when participants drove on the road course that had more frequent and sharper curves, whereas the P2 amplitude decreased when the road contained sharper curves, irrespective of curve frequency. Subjective ratings of driving pleasure and difficulty showed the same variation patterns as the N1 and P2 amplitudes, respectively. These results suggest that use of the task-irrelevant probe technique can assess the degree of driving pleasure and difficulty separately.

1. Introduction

The concept of attentional resources is important in understanding our daily cognitive activities. It is assumed that attentional resources available at a given time are limited and must be deployed to concurrent cognitive processes (e.g., Kahneman, 1973). One of the critical factors affecting the deployment of attentional resources is task difficulty: Performing difficult tasks requires more resources than performing easy tasks. Since depletion of attentional resources is closely related to the occurrence of human errors, assessment of task difficulty, or the amount of attentional resources that are required to perform a certain task in real (or nearly-real) environments, is important to create safe working conditions. Electrophysiological studies have suggested that event-related brain potentials (ERPs) elicited by task-irrelevant auditory probes can be a useful measure of the difficulty of a visual task (Allison & Polich, 2008; Kramer, Trejo, & Humphrey, 1995; Miller, Rietschel, McDonald, & Hatfield, 2011; Ullsperger, Freude, & Erdmann, 2001). For example, Kramer et al. (1995) presented a task-irrelevant auditory oddball sequence while participants performed a radar-monitoring task. They demonstrated that the amplitudes of ERPs elicited by rare, deviant stimuli of auditory probes decreased as the difficulty of the radar-monitoring task increased. The task-irrelevant auditory probe technique assumes that residual attentional resources that can be consumed by the processing of auditory probes are reduced when participants allocate more attentional resources to the visual task, which results in a decrease of the amplitudes of ERPs.

Attentional resources are related not only to task difficulty but also to the affective state of the participant. Recent studies have reported that the task-irrelevant probe technique can be a useful measure of interest in visual environments (Takeda & Kimura, 2014; Takeda et al., 2014). Takeda et al. (2014) asked participants to walk through a simulated shopping mall (i.e., go window-shopping) using a virtual-reality system and measured the amplitudes of ERPs elicited by task-irrelevant auditory probes. The results showed that the ERP amplitudes were lower when participants walked in an interesting environment than when they walked in a boring environment. Similarly, Takeda and Kimura (2014) showed that the amplitudes of ERPs elicited by auditory probes were lower for participants watching interesting video clips than for those watching boring ones. It has been suggested that interest is a basic positive emotion, which facilitates selective attention to particular objects, events, and goals (Izard, 2009). Thus, it is reasonable to assume that attentional resources are consumed when participants are interested in a certain condition, and residual resources available to allocate to auditory probes are reduced.

In our daily life, task difficulty and interest can be derived independently; that is, we can feel interest when the task is not difficult,

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such as going window-shopping (Takeda et al., 2014) or watching a movie (Takeda & Kimura, 2014), and task difficulty does not always accompany our feeling of interest. Nevertheless, these mental states are similar from the viewpoint of attentional resource consumption and may be closely related to each other in certain situations; for example, video-game players should not feel interest if the difficulty of the game is low. To the best of our knowledge, there exists no systematic evidence concerning the consumption of attentional resources when task difficulty and feeling of interest vary in a correlated manner. From an application viewpoint, especially in automotive research, developing techniques to assess task difficulty and the feeling of interest is a pressing concern, because recent developments in autonomous vehicle technology will reduce driving difficulty but may also reduce interest in driving (i.e., driving pleasure).

The present study investigated how the amplitudes of ERPs elicited by task-irrelevant probes are influenced by variations in driving pleasure and driving difficulty. Furthermore, we examined whether or not the degree of pleasure can be assessed separately from the degree of difficulty by means of the task-irrelevant probe technique. Some researchers have proposed that we have multiple attentional resources that can be used at specific processing stages (e.g., Isreal, Chesney, Wickens, & Donchin, 1980). If the mental states of driving pleasure and difficulty consume attentional resources at different processing stages, these mental states may be separately assessable. We used the task-irrelevant auditory probe technique to assess the consumption of participants' attentional resources while they drove a vehicle in a driving simulator system. Four road course conditions were created by manipulating the frequency and mean radius of curves. After driving in each condition, participants were asked to rate subjective driving pleasure and difficulty. Based on previous findings, it was expected that the amplitude of ERPs elicited by task-irrelevant auditory probes should decrease when participants experienced driving pleasure and/or difficulty. In addition, if driving pleasure and driving difficulty consume attentional resources at different processing stages, it is possible that their effects will appear in different ERP components.

2. Methods

2.1. Participants

Seventeen young adults (4 females; age range = 19–36 years old; mean age = 23.9 years old) participated. All participants had driver's licenses and more than one year of driving experience, and all reported normal or corrected-to-normal vision and normal hearing. They were paid to participate in the experiment. The study was approved by the National Institute of Advanced Industrial Science and Technology (AIST) Safety and Ethics committee and was conducted only after each of the participants had given written informed consent.

2.2. Apparatus and stimuli

A high-fidelity driving simulator (Mitsubishi Precision Co.), which provided tactile feedback to drivers by means of a hexapod electric motion platform, was used in the present study (see Fig. 1(A) and (B)). The front and side views were projected on a cylindrical screen surrounding the motion platform with a field of view greater than 180°, and the rear view, which could be seen via the rear-view and side mirrors, was projected on a flat screen located behind the motion platform. The reactive force against the steering action was modulated by a steering control loading system (Moog Inc.). Two different settings of the reactive force were used: light steering (low damping and inertia) and heavy steering (high damping and inertia).

The road courses consisted of combinations of straight and curved sections of two-lane expressways. In the simulation, several vehicles drove in the left lane (i.e., the cruising lane) at a speed of 60 km/h. The length of each course was approximately 10.2 km. There were four course conditions: 2 levels for the frequency of curves (infrequent and frequent) × 2 levels for the radius of curves (sharp and shallow; see Fig. 1(C)). The frequency of curves was manipulated by the length of the straight sections. We set the length of straight sections to 800 m and 200 m for the infrequent and frequent conditions, respectively. The length of each curved section was fixed at 200 m. As a result, the infrequent and frequent conditions contained 10 and 25 curved sections, respectively. The mean radius of curves was 1000 m (SD = 176.8 m) in the shallow condition and 200 m (SD = 35.4 m) in the sharp condition. These curve frequencies and curve radii were determined in a preliminary test, so that driving difficulty and pleasure were induced appropriately. It is known that a curve radius of approximately 200 m is the critical value for increased traffic accidents on urban expressways (Hirai, Makino, Hirasawa, Yamazaki, & Mizutani, 2005). This is also the radius of the sharpest curves found on interurban expressways in Japan.

The auditory probes were presented via over-ear headphones (Sennheiser HD265) controlled by a computer operating Mac OSX, Matlab (Mathworks Inc.), and Psychophysics Toolbox (Brainard, 1997; Pelli, 1997). Following Takeda and Kimura (2014), twelve pure tones were used, with frequencies of 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, 1500, or 1600 Hz. The duration of each tone was 50 ms, which included 10 ms rise and fall times. The stimulus onset asynchrony varied from 400 ms to 800 ms (M = 600 ms). The sound pressure level was approximately 75 dB. Note that we used a variable tone frequency sequence instead of a typical oddball sequence. Takeda and Kimura (2014) identified at least two advantages of the variable tone frequency sequence: (1) a larger number of events (probes) per unit time can be averaged to obtain ERPs, which results in greater reliability of the assessment, and (2) distractions caused by the auditory probes during the main visual task are less likely to occur with the variable tone frequency sequence than with a typical oddball sequence.

2.3. Procedure

After the participants gave their informed consent, the electrodes were attached. The participants then practiced driving on the infrequent-shallow road course. In the experimental session, there were eight driving conditions: frequency of curves (infrequent versus frequent) × radius of curves (shallow versus sharp) × steering (light versus heavy). Each participant performed these driving conditions twice in random order, for a total of 16 driving trials. On each trial, they were asked to accelerate until they exceeded 80 km/h and then to cruise at 80–100 km/h within the right lane. After the travel distance from the starting point exceeded 8 km, the instruction to stop was given. The auditory stimuli (probes) were presented during each driving trial. After each driving trial, participants were asked to rate their subjective driving pleasure (from 1 = "very boring" to 7 = "very pleasant") and driving difficulty (from 1 = "very easy" to 7 = "very difficult").

2.4. Recordings

The electroencephalographic (EEG) and electrooculographic (EOG) signals were recorded with a digital amplifier (BrainProducts, BrainAmp Standard system) and silver-silver chloride electrodes. EEGs were recorded from 23 scalp sites (Fp1, Fp2, F7, F3, Fz, F4, F8, FCz, T3, C3, Cz, C4, T4, CPz, T5, P3, Pz, P4, T6, POz, O1, Oz, and O2,