Assessment of Drivers' Attentional State Using Event-Related Brain Potentials

Yuji Takeda[1]

yuji-takeda@aist.go.jp
[1]National Institute of Advanced Industrial Science and Technology
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ABSTRACT

This presentation introduces electrophysiological measures: eye-fixation-related potentials and auditory-evoked potentials, which reflect attentional resources allocated to a visual task. Then, I also present our experimental studies assessing drivers' attentional state. The studies demonstrate that these measures are useful for assessing driving pleasure as well as driving workload.

1 Introduction

Objective assessment of attentional state during a visual task is required to develop new devices and working environments, because the allocation of adequate attentional resources is necessary to perform a task successfully. Especially, because of the recent development of semi-autonomous vehicles, many automotive researchers are interested in the assessment of drivers' attentional state while riding in semi-autonomous vehicles. In this section, I introduce event-related brain potential (ERP) measures that allow us to assess the attentional state during various visual tasks.

1.1 Event-related brain potentials

Electroencephalogram (EEG) is a common tool for measuring electrophysiological brain activities in a non-invasive manner. ERPs can be obtained by averaging EEG signals that are time-locked to specific events. Unlike resting-state EEG, ERPs reflect specific perceptual and cognitive processes, and therefore they can be useful measures for assessing operators' (drivers') state of perceptual and cognitive processes. However, there are some difficulties to adopt ERP measures in the real working (driving) environments. Although several dozen or hundred of EEG signals that are time-locked to specific events have to be averaged to obtain reliable ERPs, it may be difficult to collect such event data in the real-world situations. Furthermore, to obtain reliable ERPs, the time onset of each event must be specified within an error margin of a few milliseconds. Beyond these difficulties, eye-fixation-related potentials (EFRPs) and auditory-evoked potentials (AEPs) elicited by task-irrelevant probes are applicable for the assessment of operators' (drivers') attentional state in the real-world environments.

1.2 Eye-fixation-related potentials

EFRP is a kind of ERP, which can be obtained by averaging EEG signals that are time-locked to the termination of a saccadic eye-movements. Because the termination of saccadic eye-movement indicates the beginning of acquisition of visual information at the newly eye-fixated location, EFRPs are considered to reflect visual information processes [1]. The most prominent component of EFRPs is a positive-going wave with a peak at around 80 ms after the termination of saccadic eye-movements (i.e., the P1 component, see Fig. 1). It has been demonstrated that the amplitude of P1 increased when observers paid greater attention to visual information compared with when they paid less attention to visual information [2]. Because most visual tasks require frequent saccadic eye-movements, the assessment of attentional state by using EFRPs is available not only in a driving task [3, 4] but also in various visual tasks [5, 6]. Note that, the termination of saccadic eye-movements can be accurately specified by electrooculogram (EOG) with a high temporal accuracy.

1.3 Task-irrelevant probe technique

Although the P1 amplitude of EFRPs can be a useful index of how much attention is allocated to visual information, it is not sufficient to reveal the overall attentional state during a visual task; that is, the allocation of attentional resources is required not only for visual information processes but also for other higher processes, such as cognition, judgement, and action. A task-irrelevant probe technique has been developed to assess how much attentional resources are totally allocated to a visual task [7].

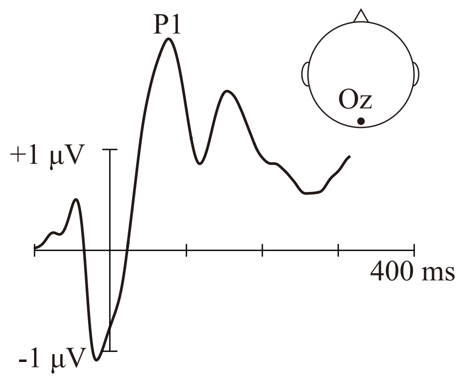

Fig. 1 A typical EFRP waveform

In the task-irrelevant probe technique, auditory stimuli are presented during a visual task, and participants are instructed to ignore these stimuli (i.e., the task-irrelevant probes). It has been demonstrated that the amplitude of AEPs elicited by the task-irrelevant auditory probes would become smaller when participants allocated more attentional resources to the visual task. A typical AEP waveform is shown in Fig. 2. The task-irrelevant probe technique is based on the following assumptions: attentional resources available at a given time are limited [8], and residual attentional resources that can be allocated to the task-irrelevant probes are reduced when participants allocated more attentional resources to the visual task, which results in reduction of the AEP amplitudes. Because the task-irrelevant probes can be presented irrespective of the type of visual task if auditory stimuli are not important to perform the task, this technique is available not only in a driving task [9, 10] but also in various visual tasks [7, 11].

Note that, in a typical task-irrelevant probe technique, an oddball sequence, which includes frequent standard tones and rare deviant tones, was used as the task-irrelevant probes, and AEPs elicited by the deviant tones was measured as an index of the attentional resource allocation to a visual task [7]. To improve the temporal resolution of the assessment, we recently developed a multiple-stimulus procedure, in which multiple auditory stimuli (i.e., 12 pure tones of 500-1600 Hz) were randomly presented as task-irrelevant probes [11]. By using the multiple-stimulus procedure, we can assess the allocation of attentional resources with a temporal resolution of one minute.

2 Assessment of drivers' attentional state

In this section, I briefly introduce our studies regarding the assessment of drivers' attentional state by using EFRPs or AEPs elicited by the task-irrelevant probes with the multiple-stimulus procedure.

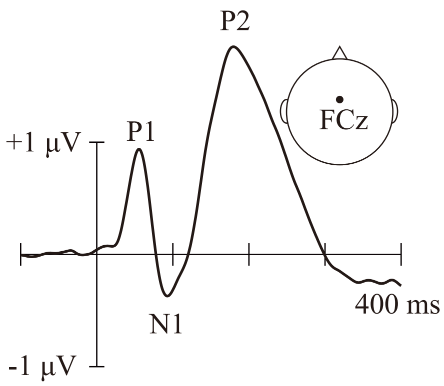

Fig. 2 A typical AEP waveform

2.1 Drivers' attentional state while riding in a semi-autonomous vehicle: an EFRP study

Although the autonomous vehicle technologies have been developed greatly, at present, drivers must take control of the vehicle quickly if it is requested. To ensure safe transition from autonomous to manual driving, it is important to understand how much drivers paid their attention to external visual information (e.g., road environments and other vehicles) during the autonomous mode. Toward this issue, we assumed that the attentional state of a driver in a reliable autonomous vehicle can be equivalent to that of a passenger, and we compared the P1 amplitude of EFRPs as well as the number of saccadic eye-movements measured from drivers and passengers that were riding a vehicle in real road environments (urban roads and an expressways).

The results showed that the number of small saccadic eye-movements (i.e., looking at central objects) was lesser in passengers than in drivers, whereas the number of large saccadic eye-movements (i.e., looking at peripheral objects) was greater in passengers than in drivers. Furthermore, although the P1 amplitude of EFRPs time-locked to the termination of small saccadic eye-movements in passengers was equivalent to that in drivers, the P1 amplitude of EFRPs time-locked to the termination of large saccadic eye-movements in passengers was smaller than that in drivers. These results indicate that, for the central objects, drivers in an autonomous vehicle (i.e., passengers in this experiment) would pay sufficient attention in each fixation, but the frequency of information acquisition was lower than manual drivers. On the other hand, for the peripheral objects, drivers in an autonomous vehicle paid less attention compared to manual drivers, although the frequency of information acquisition was high. The details of experiments and results are shown in [4].

2.2 Assessment of driving pleasure and difficulty by using the task-irrelevant probe technique

Driving pleasure and driving workload (i.e., driving difficulty) are considered to be important factors for the development of attractive and safe vehicles. This study investigated driving pleasure and driving difficulty in terms of the consumption of attentional resources by using the task-irrelevant probe technique. Because it is plausible that drivers cannot feel driving pleasure when the environment is boring, we expected that some degree of attentional resource consumption occurs when drivers feel driving pleasure. Driving difficulty is also considered to be accompanied by the attentional resource consumption, because drivers have to pay their attention to operate a vehicle adequately under difficult situations. Nevertheless, because the mental states of driving pleasure and driving difficulty are obviously different, the patterns of attentional resource allocation can also be different.

In this study, participants drove a vehicle in a high-fidelity driving simulator, and the task-irrelevant auditory probes were presented via over-ear headphones with the multiple-stimulus procedure. There were four course conditions: 2 levels for the frequency of curves (infrequent versus frequent) × 2 levels for the radius of curves (shallow versus sharp). The results of the subjective rating scores showed that participants felt the highest driving pleasure in the frequent-sharp condition than other three conditions, whereas they felt driving difficulty in the sharp conditions irrespective of the curve frequency. The N1 amplitude of AEPs elicited by the task-irrelevant probes decreased in the frequent-sharp condition compared with other three conditions, whereas the P2 amplitude decreased in the sharp conditions irrespective of the curve frequency; that is, the variation pattern of driving pleasure was similar to that of the N1 amplitude, and that of diving difficulty was similar to the P2 amplitude. It is plausible that driving pleasure and difficulty are related to the attentional resource consumption at different processing stages; that is, driving pleasure is related to an earlier processing stage that is reflected in the N1 component, and driving difficulty is related to a later processing stage that is reflected in the P2 component. By using the task-irrelevant probe technique, the states of attentional resource allocation in different processing stages can be assessed separately. The details of experiments and results are shown in [9]. Note that, this study was conducted in the driving simulator, but this technique is useful even in real road environments [10].

3 Conclusions

Here, I introduced two ERP measures for the assessment of attentional states: EFRPs and AEPs elicited by the task-irrelevant auditory probes. Both measures are available in real working environments and can provide different aspects of information about attentional states. Of course, however, they have several shortcomings; for example, they are susceptible to changes in arousal level, and they are not sensitive to the attentional resource allocation in action processes. Further studies are needed to develop the methods to assess the overall attentional state.

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