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Electroencephalogram and electrocardiograph assessment of mental fatigue in a driving simulator

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ABSTRACT

Mental fatigue is a contributing factor to some serious transportation crashes. In this study, we measured mental fatigue in drivers using electroencephalogram (EEG) and electrocardiograph (ECG). Together, thirteen healthy subjects performed a continuous simulated driving task for 90 min with simultaneous ECG and multi-channel EEG recording of each subject. Several important physiological parameters were investigated using preprocessed ECG and EEG signals. The results show that the EEG alpha and beta, the relative power, the amplitude of P300 wave of event-related potential (ERP), the approximated entropy of the ECG, and the lower and upper bands of power of heart rate variability (HRV) are significantly different before and after finishing the driving task ($p < 0.05$). These metrics are possible indices for measuring simulated driving mental fatigue.

1. Introduction

Mental fatigue refers to changes in the psycho-physiological state that people experience during and following the course of prolonged periods of demanding cognitive activity that require sustained mental efficiency (Kato et al., 2009). In other words, mental fatigue is limited solely to a mental state arising from a behavioral situation that includes a long-term continuous, repetitive performance of some mental task. Hulst et al. (2001) thought driving was an example of a complex task that required continuous attention in order to detect possible hazard, and the main time-on-task effect in driving was a progressive withdrawal of attention from road and traffic demands. The deteriorating driver performance associated with driving mental fatigue presents a serious safety risk. According to a report by the Parliament of the Commonwealth of Australia, driving mental fatigue is believed to account for 20–30% of all traffic accidents (The Parliament of the Commonwealth of Australia, 2000). Experts agreed that the actual contribution of a driver's mental fatigue to road accidents might be much higher. Developing and establishing an accurate and non-invasive real-time system for monitoring a driver's mental fatigue are important to reduce road accidents and lower the number of injuries in traffic safety.

Driving simulator studies have dominated the research on driving mental fatigue mainly due to the safe, low cost, well-controlled conditions and ease of data collection (Reed and Green, 1999). In addition, driving simulation allows the evaluation of a wider range of driving situations, especially those that are dangerous or physically threatening. Such situations, which for obvious reasons cannot be tested on the road or even on a test track, include assessing the ability of the subject to avoid collisions, as well as determining the effects of alcohol, drugs and fatigue on driving (Lew et al., 2005). Philip et al. (2005) concluded that fatigue could be equally studied in real and simulated driving environments. Shechtman et al. (2009) found that the same trends existed between driving errors made on the road and in the simulator, thus validating the simulator. Young et al. (2009) validated the Enhanced Static Load Test (ESLT) as predictive of visual event reaction times during open-road driving for the range of experimental conditions and tasks considered.

Previous studies have aimed to find the sensitive indices for evaluating driving mental fatigue based on performance and perceptual, electrophysiological, psychological and biochemical measurements. A number of methods have been proposed to detect mental fatigue. Reimer et al. (2006) tried to establish the validity of driving behavior measures collected during a simulation scenario using self-reported survey indicators of driving behavior. They considered these measures as valid indicators of the behaviors of interest. Lal and Craig (2002) and Lal et al. (2003) used a video image of the driver's face as an independent variable for driver

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