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Monitoring Driver's Sleepiness On-Board for Preventing Road Accidents

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Abstract. Driver sleepiness due to sleep deprivation is a causative factor of many road accidents. Reducing the extent of the sleepy driving problem by developing a countermeasure device that will monitor the sleepiness level of the driver is crucial to improve the safety of the roads. Among numerous physiological measurements, the electroencephalographic (EEG) signal seems to be the most sensitive to detect sleepiness. Previous studies in the field have found consistent alterations of EEG signal during sleepy driving, though they face methodological limitations. We present here preliminary results from a real-driving experiment in which a more complete experimental setup was followed. The subjects were exposed to driving conditions twice: once after they had a normal sleep during the previous night, and once after they remained awake for at least 24 hours prior to the experiment. Significant alterations were observed in the alpha and beta EEG frequencies bands between the two sessions. Electroopthalmographic (EOG) measurements revealed an increased number of eye blinking during the sleep-deprived session in comparison to the control condition. Both measurements can be used for the successful design of a sleepiness detection countermeasure device.

Keywords. sleepiness, driving, fatigue, EEG, EOG, eye-blinks

1. Introduction

Driving is a complex task involving distinct cognitive, perceptual, motor and decision-making skills [1]. It requires an optimum level of alertness to guarantee the security of the driver and the other road users. Sleepiness at the wheel can significantly impair the driver's alertness causing primarily difficulty in maintaining the vehicle trajectory on the road. It has thus been recognized as the main cause of fatal crashes and highway accidents and it attracts increasing attention in the road safety field [2]. Deprived sleep is the most important factor of sleepiness affecting seriously various aspects of driver's performance and decreasing dramatically his/her level of alertness. While sleepiness at the wheel is a well-known risk factor for traffic accidents, many drivers combine sleep

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deprivation and extensive driving. Reducing the extent of sleepy driving problem is critical to improve the safety of roads and highways.

Sleepiness impairs the drivers' cognitive skills affecting seriously their ability to assess their own alertness level. Serious care should be taken for the implementation of sleepiness technological countermeasures that might be used to provide drivers with useful feedback about the onset of sleepiness leading to improved road safety. The main idea behind the development of a sleepiness countermeasure device is to monitor unobtrusively the sleepiness level of the driver providing feedback about his/her level of alertness [3, 4]. Although numerous physiological measurements can assess the sleepiness and alertness level of the driver, the EEG signal seems to be the most predictive though it presents practical and technical problems [5].

An increasing number of studies examining driver sleepiness are presented the last years. Most of these studies deal with the assessment of EEG signal alterations due to sleepiness (for a review see [6]) and have been performed in driving simulator environments. Therefore, the participants knew that the consequences of their driving errors would not affect their safety. Our group conducted recently a more realistic study in sleep-deprived drivers using an experimental car on road [7, 8]. EEG analysis revealed significant variations in the frequency bands of alpha, beta, gamma, and delta in agreement with previous studies in simulators. The number of eye-blinks as they were captured by camera was increased across driving time.

Despite the inspiring results, our previous study faced one main limitation. It was assumed that increased driving time would impair the driver's alertness and performance and that sleep-deprivation combined with the effect of driving time would amplify the decrease in the level of alertness and induces severe sleepiness [8]. In this sense, there was no control group consisted of non-sleep-deprived subjects. In the present piece of work, we present preliminary results of a real-driving experiment that is an extension of our previous experimental setup. The experiment was performed twice in the same subjects; once after the subjects had a normal sleep during the previous night, and once after remained awake for at least 24h prior to the experiment.

2. Experimental Protocol

Four male subjects (mean age ± S.D.: 34 years ± 5.7) with average driving experience (14.2 years) participated in the study. The investigation has obtained approval from the local Ethics Committee. The experiments were performed using the CERTH-HIT experimental car that is equipped with double support pedals accessible to the driver's instructor. The vehicle is also equipped with the electronic system ELS (Siemens, Germany) that detects the eye-blinking activity. The ELS system consists of a CCIR camera (Figure 1c) with two near-infrared lighting units (Figure 1b). Each subject participated in two experimental sessions: the Control Session (CS) and the Sleepy Session (SS). Both sessions were performed during night. The CS was performed after the subject had a normal sleep during the previous night. For the SS, it was asked from the subjects to stay awake at least 24 hours before the experiment, and then to arrive at CERTH premises around 21:00 o'clock. Upon arrival the subjects passed a standard medical examination test. During the on road experiment, the subject was sat on the driver seat and was driven following the same route (from Thessaloniki to Moudania ~70 km) in both sessions (Figure 1a). An experienced driving instructor was sat at the co-driver's seat insuring safe driving. The mean driving time was 50.4 ± 7.6 min. A similar methodology with our previous studies in the field was followed [7, 8]. Pilot measurements indicated that the measured EEG signal was not contaminated by electrical or mechanical noise of the car or its equipment.

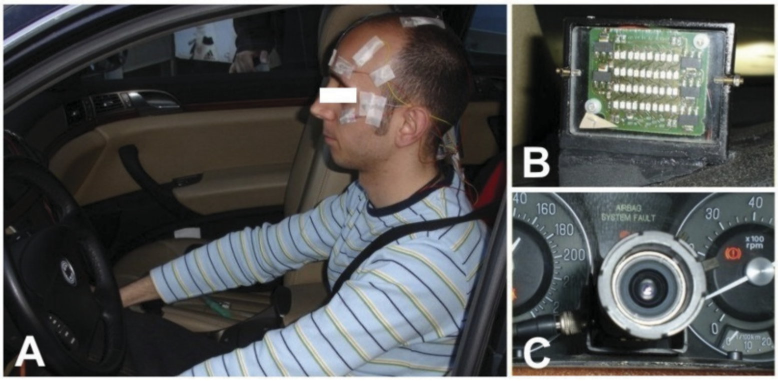

Figure 1. a) The subject sit in front of the wheel with the EEG and EOG electrodes attached b) near infrared lighting unit and c) CCIR camera placed on the car's dashboard

3. Physiological Measurements

Four EEG electrodes were placed on patient's scalp at the positions Fp1, Fp2, C3, and C4 according to the 10-20 International System. EOG measurements were recorded bipolarly using two Ag-AgCl electrodes, one placed medially above and the other laterally below the left eye (Figure 1a). Both EEG and EOG electrodes were connected to an ambulatory monitoring system. A sampling rate of 200Hz was used. The monitoring system hardware filters were adjusted to the band pass filtering option with a frequency range of 0.5 to 40Hz for EEG, and a notch filter at the 50Hz power supply component. The active sites on the scalp were referenced to linked mastoids, and all electrode impedances were maintained less than 10 kΩ.

4. Data Analysis

The EEG recordings were first band-pass filtered (0.5–40 Hz), and then the Infomax Independent Component Analysis (ICA) algorithm was used for removing the ocular artifacts [9]. The EEG data were afterwards divided into one-second segments. Segments contaminated by motion artifacts were rejected. The quantitative analysis was performed on the artifact free EEG segments. For each EEG channel, the relative band ratio (RBR) of the classic EEG frequency bands (delta: 0.5–4 Hz, theta: 4–8 Hz, alpha: 8–12 Hz, beta: 12–30 Hz, and gamma: 30–40 Hz) was calculated. The RBR is estimated by the relative ratio of the power, and it is a unit-less value in the range between 0 and 1. The Shannon Entropy was also estimated for the EEG signal. These quantitative EEG statistics were then averaged in 6-min segments. The number of eye-blinks and their duration was estimated by using an in-house algorithm. Repeated measures ANOVA were applied to the averaged EEG statistics. The independent variables were the session (control or sleepy driving) and the driving time. The means were considered significantly different when the probability of error was less than or equal to 0.05.

5. Results

Statistically significant differences were observed between the CS and the SS for the EEG frequency bands of alpha, beta, theta, and delta (Table 1). The Shannon Entropy was significantly decreased during SS in comparison with the control. Both the number and the mean duration of eye blinks were significantly increased during sleepy driving (Table 1).

Table 1. The mean values (±S.D.) of the RBR for the different EEG frequency bands as well as the mean number of eye-blinks for the two experimental sessions (CS and SS), and the corresponding p-values of the ANOVA analysis.

Statistic	Control Session	Sleepy Session	p-value
Alpha	0.151 ± 0.032	0.168 ± 0.039	0.001
Beta	0.451 ± 0.099	0.354 ± 0.062	<0.001
Delta	0.121± 0.042	0.172 ± 0.080	<0.001
Theta	0.141 ± 0.040	0.176 ± 0.040	<0.001
Eye blinks (Number)	40.83 ± 10.99	52.91 ± 10.51	<0.001

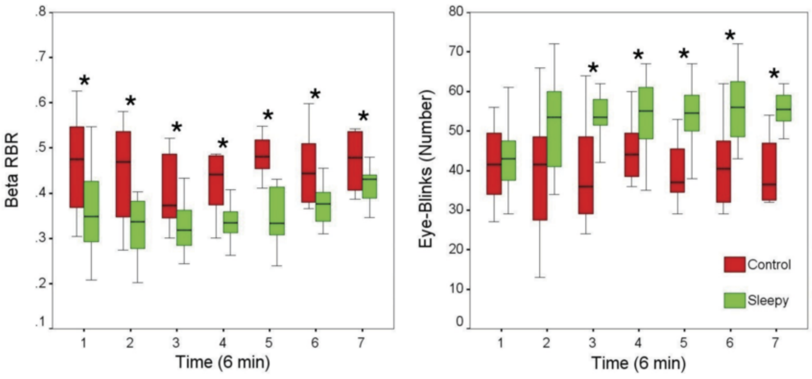

Figure 2. The grand average Beta RBR (left panel) and the grand average number of eye-blinks (right panel) every 6 minutes for the two sessions (CS and SS)

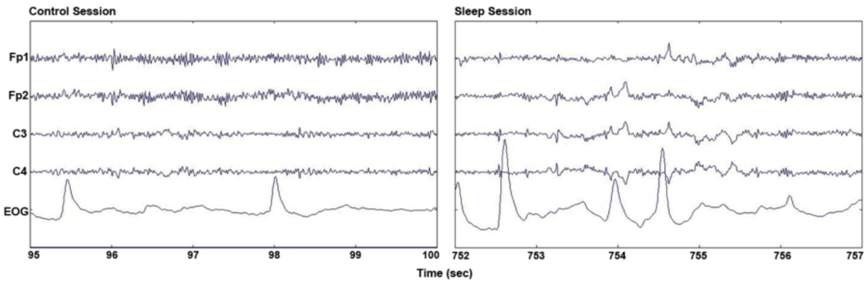

Figure 3. Five-second segments of EEG and EOG measurements during the CS and the SS (Subject 2). We observe a characteristic shift of frequencies to lower bands during sleepy driving.

Statistical analysis revealed a combined affect of driving time and sleepy driving for the frequencies of beta (p=0.001) (Figure 2) and alpha (p=0.027). During sleepy driving, there was a shift of frequencies to lower bands (Figure 3). While the RBR of beta was higher during the CS compared to SS from the first minutes of the experiment, the number of eye-blinks was increased significantly after 12 minutes (Figure 2). The ELS system gave similar results with those provided by the EOG signal for the number and duration of eye-blinks, though it presented some technical problems.

6. Conclusions

Numerous studies have so far investigated the use of EEG or EOG as indicators of sleepiness [6]. What is missing from the available literature is a real on-road driving study comparing the measurements derived from the same drivers after having a normal sleep and after remained awake for at least 24 hours prior to the experiment. Here, we present the preliminary results of such a kind of study. Significant alterations were observed between the two experimental sessions in all frequency bands except gamma. EOG measurements revealed an increased number of eye blinking during the sleepy-deprived session compared to the control. The most interesting finding has to do with the combined effect of driving time and sleepy driving: beta and alpha bands were sensitive to driver's alteration level from the first few minutes of experiment. EEG is thus capable to detect driver's sleepiness level and his/her ability to drive safely. Eye-blinking activity presented a delay of a few minutes in comparison to the EEG signal. Although EEG signal seems to be the most sensitive to sleepiness, it presents serious technological and practical problems if it should be used for developing a sleepiness countermeasure device. Other approaches using peripheral measurements, such as eye-blinking activity through special cameras, should also be considered. We should not forget that the present results are preliminary. Further experiments including more subjects are necessary in order to derive more reliable conclusions.

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