Use of EEG for Validation of Flicker-Fusion Test

Ronzhina M, Bubnik K, Gajdos M, Kolarova J, Honzik P, Provaznik I

Faculty of Electrical Engineering and Communication
Brno University of Technology
Brno, Czech Republic
+420 54114 3609
xronzh00@stud.feec.vutbr.cz

ABSTRACT

There are many different methods for evaluation of alertness level of a person. The commonly used questionnaires and some physiological test such as flicker-fusion (FF) test are not objective. Other objective methods based on the analysis of biological signals can be used for validation of these tests. The present study is focused on analysis of spectral features of EEG measured in sleep deprived subjects during experiment containing FF test performing. The results of the study show that FF test does not affect electrical brain activity dramatically and, thus, can be used for alertness level evaluation. It is also shown that subjective determination of state using questionnaires can differ from those obtained by objective method based on the analysis of EEG. These results can be useful for correct interpretation of FF test results.

Categories and Subject Descriptors

I.5.2 [**Pattern Recognition**]: Design Methodology – *feature evaluation and selection*, *pattern analysis*.

General Terms

Measurement, Experimentation.

Keywords

Alertness level, flicker-fusion test, EEG spectral features, ANOVA, paired t-test.

1. INTRODUCTION

Alertness is closely related to wakefulness and attention [1], [2]. Inattention accounts for over 25% of the crashes in Europe [3] and over 28% crashes in the Czech Republic [4]. Therefore a big effort has been made to develop reliable systems for detection of the driver's oncoming sleepiness. That is why driver fatigue [5], driver drowsiness [6] or driver alertness [7] are some of currently top keywords in human-machine research studies.

Currently two different approaches are used to monitor the driver: direct and indirect systems [8]. The direct systems measure driver's physiological signals or driver's behavior (e.g. head motion, facial expressions, yawning, eye tracking and blinking, electroencephalogram (EEG), electrocardiogram (ECG), heart-rate variability, pulse-monitoring, galvanic skin resistance, body temperature [5], [6], [9]-[11] etc.). The indirect systems analyze the vehicle's behavior (e.g. steering wheel movements [12], [13], the lateral acceleration [14], [15], pedals acceleration [11]). But all of these systems must be verified and calibrated according to some authority in the alertness level measurement, which is typically EEG. This is due to the fact that the changes in the psychophysiological state of person are manifested in the signals of his brain [16], [17].

In case of indirect systems the majority of experiments is done under laboratory conditions. The test rides are made until the crash occurs. The assessment of the level of driver's alertness is based directly on the EEG or camera record made under static light conditions. The problem arises in case the experiments should be carried out under the real traffic conditions with different drivers in various daytimes. Because monitoring of the driver is not the aim but the source of output variable, the low cost, simple, robust and reliable solution must be found.

In our research we deal with indirect measurement of the driver's behavior based on the data available on the engine CAN-bus of the vehicle [8]. One test ride takes about 20 minutes in the real traffic. We a priori assume that the driver's state changes rather in tens of minutes than in minutes so the state of the driver does not significantly change during one ride. The measurements realized before and after the ride should be the same or very similar. To minimize the influences of the measurement itself, it should be done inside the vehicle right before and immediately after the ride. Furthermore the usage of the test should be very simple and because of many repeated measurements, it should have low learn ability (repeating of the test does not lead to better results). The flicker-fusion (FF) test based on the determination of optical flicker and fusion thresholds [18] seems to fulfill these criteria. Because the experiment described above is not exactly the type of measurement for which the FF test was established (the tests are typically done on fresh persons in morning times), we try to answer the question, whether the making of FF test itself does not influence the level of alertness, especially in tired persons.

Therefore, we propose validation of FF test results and subjective determination of the state by means of spectral analysis of EEG, which is widespread used - next to the other - to study alertness and sleepiness of the person [16], [17], [19].

2. METHODS

2.1 Data Acquisition

Seven healthy deprived subjects (four-hours sleep) were included in the study. For each person, subjective alertness level was determined as:

- S1 - tired,

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- S2 - very tired,
- S3 - extremely tired, but driving is still possible.

Experiments including recording of EEG and performing of FF test were carried out according to protocol summarized in Fig. 1. Each experiment begins with the 5-minutes relaxation phase followed by 5-minutes EEG check phase, 5-minutes control phase and FF test (Vienna Test System, SCHUHFRIED GmbH, Austria) performing (approx. 9 minutes). The preparing of EEG measurement involves setting of EEG headset. Therefore, relaxation phase is included in protocol to give the subject the time to relax after all instruments setting. EEG check phase allows to exclude subjects with different disorders, which can be detected from EEG recorded with closed eyes. Following two parts of experiment (control phase and FF test performing) are used to validate FF test using analysis of EEG.

The sessions started at approx. 10 a.m., 2 p.m. and 5 p.m. During all experiments, EEGs were recorded with EEG system TruScan32 (Ltd. Alien Technik, Czech Republic) with sampling frequency 128 Hz. Recording was performed with a set of 21 electrodes placed in accordance with International 10-20 System of Electrode Placement (see Fig. 2).

Eyes insufficiencies and disturbances were compensated by contact lens instead of glasses to prevent occurrence of additional noise caused by contact of glasses with EEG headset (this compensation is needed for correct performing of FF test).

In addition, contact of some parts of FF test set-up with EEG headset results in artifacts, which are usually present in signals recorded near electrodes F7, R8, T3, T4 and especially near F3 and F4. The position of subjects remained the same during all EEG measurement to prevent distortion of signals by EMG artifact, which has a spectrum overlapping with the lowest frequencies of delta band of EEG (δ band, see below).

Three EEG channels Pz, O1, and O2 (black in Fig. 2) were chosen for further analysis and used, moreover, to derive two additional signals, which are differences Pz-O1 and Pz-O2. This region of brain shows good expression of alpha activity (α, see below), which is an important feature to study alertness level [16], [17], [19]. Furthermore, signals from these channels do not contain blinked related artifact, which is especially characteristic for EEG recorded during FF test.

Two 3-minutes long parts of signals were selected from each EEG for two phases of experiment (before and during FF test) in 2 minutes distance from their beginning (see Fig. 1) to avoid the presence of some transition effects relating to the changes in the state of the subject.

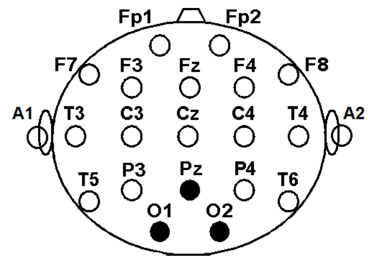

Figure 2. Electrodes placement according to 10-20 System. Black dots denote the electrodes used in this study

For further processing, data were segmented into 30-seconds non-overlapped parts. Thus, six EEG segments were selected from each recording for each analyzed phase of experiment (before/during FF test).

2.2 Data Analysis

EEG is usually described in terms of its frequency components, the main of them are:

- $\delta = (0.5, < 4)$ Hz,
- $\theta = (4, < 8)$ Hz,
- $\alpha = (8, < 13)$ Hz,
- $\beta = (13, 30)$ Hz.

Power spectral density (PSD) of these components (see Fig. 3) can be used to analyze EEG. In this work, nine spectral features were extracted from each signal:

1. *Relative powers* were computed by dividing PSD in certain band (PSD_δ, PSD_θ, PSD_α, and PSD_β for δ, θ, α, and β, respectively) by the total power (TP), which is the sum of PSD of total spectrum (0.5-30 Hz):
   a) $\delta_{rel} = PSD_\delta / TP$,
   b) $\theta_{rel} = PSD_\theta / TP$,
   c) $\alpha_{rel} = PSD_\alpha / TP$,
   d) $\beta_{rel} = PSD_\beta / TP$.
2. *Ratio powers* were computed as ratio of the power in two different spectral bands or their combinations:
   a) $\alpha/\delta_r = PSD_\alpha / PSD_\delta$,
   b) $\alpha/\theta_r = PSD_\alpha / PSD_\theta$,

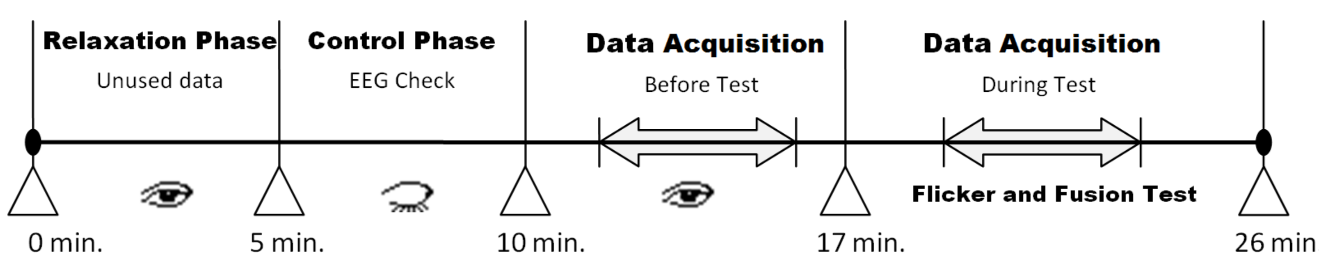

Figure 1. Experimental protocol

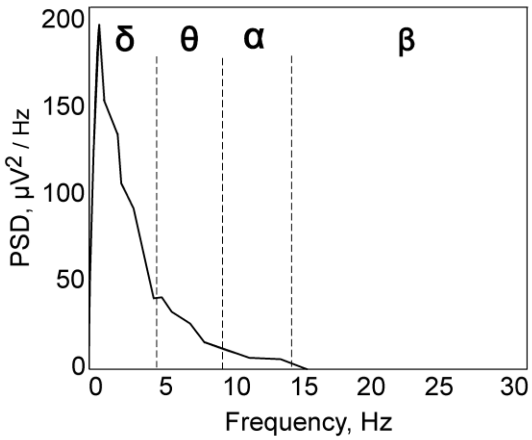

Figure 3. Power spectrum of EEG estimated via Welch method

c) $\alpha/\beta_r = \mathrm{PSD}_\alpha / \mathrm{PSD}_\beta$,

d) $\alpha/(\alpha+\theta+\beta)_r = \mathrm{PSD}_\alpha / (\mathrm{PSD}_\alpha + \mathrm{PSD}_\theta + \mathrm{PSD}_\beta)$,

e) $(\alpha+\theta)/\beta_r = (\mathrm{PSD}_\alpha + \mathrm{PSD}_\theta) / \mathrm{PSD}_\beta$.

The power spectra of EEG (see Fig. 3) were estimated using Welch method with 5-seconds Hann window and 50% overlap.

Analysis of variance (ANOVA), multicomparison test and paired t-test were performed to analyze values of EEG features derived from different channels for certain subjective state (S1, S2, and S3) and phase of experiment (before and during FF test).

Extraction of EEG parameters and statistical analysis were realized in Matlab 7.5 (The MathWorks, Inc.).

3. RESULTS

Spectral parameters derived from EEG recorded using different channels during different phases of experiment (before and during FF test performing) were analyzed statistically with ANOVA, multicomparison test and paired t-test.

Statistical characteristics (median values, the 25th and 75th percentiles, outliers, and the lowest and the highest samples still within 1.5 interquartile range of the lower and the upper quartile, respectively) of two spectral parameters α/θ_r and α/β_r for EEG recorded before FF test performing are shown using box plots in Fig. 4 and Fig. 5, respectively. It is clear from Fig. 4 that the values of α/θ_r derived from Pz, O1 and O2 channels for subjective state S1 are not significant different from state S2. State S3 differs from S1 and S2. Second parameter (see Fig. 5) does not show difference in subjective states.

Box plots correspond with results of ANOVA and multicomparison test, which are summarized in Tab. 1. As can be seen from this table, δ_{rel} and θ_{rel} have the character similar to α/β_r. Thus, there are not significant differences between values of these parameters in different subjective states.

Other spectral parameters show, on the contrary, significant difference between states S1 and S3, and S2 and S3. However, the most of them does not differ for channels Pz-O1 and Pz-O2.

Moreover, only parameters from O1 and O2 are characterized by significant difference in these pairs of subjective states for both experiment phases (before and during FF test).

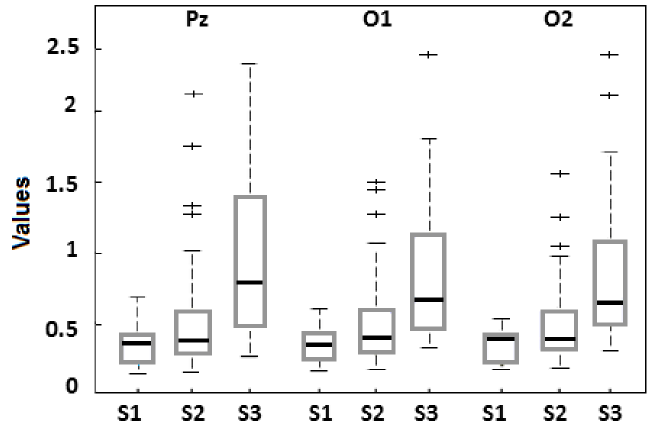

Figure 4. Box plots for α/θ_r derived from three EEG channels Pz, O1, and O2 recorded before FF test performing

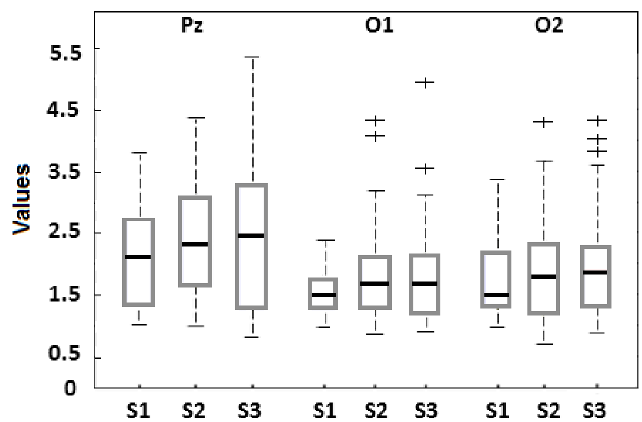

Figure 5. Box plots for α/β_r derived from three EEG channels Pz, O1, and O2 recorded before FF test performing

Increasing of fatigue, which affects the alertness level, is reflected in some features by significant increasing (in most cases)/decreasing of their values from state to state (see Tab. 2).

Paired t-test was used to find out, whether values of EEG parameters do not change significantly by FF test performing, i.e. whether performing of FF test does not influence the state of the person. Results of analysis are summarized in Tab. 3. As can be seen, only some spectral parameters show significant difference in phase of experiment.

4. CONCLUSION AND DISCUSSION

Evaluation of alertness level of the drivers is a relatively difficult task. FF test allows to solve this problem both in laboratory and during real driver task performance. However, results of FF test are difficult to interpret.

The main question, that arises when using some physiological test, is whether its performing does not influence actual state of a subject. Results of the present study show that the values of rest EEG features, which show significant difference in the states, do generally not change significantly by FF test performing. Thus, making FF test itself does not influence the alertness level of a person and so can be effectively used in studies where its determination is needed.

Table 1. Results of ANOVA and Multicomparison Tests for EEG Parameters

Parameter	EEG channels														
	Pz			O1			O2			Pz-O1			Pz-O2		
	S1-S2	*S1-S3*	*S2-S3*	*S1-S2*	*S1-S3*	*S2-S3*	*S1-S2*	*S1-S3*	*S2-S3*	*S1-S2*	*S1-S3*	*S2-S3*	*S1-S2*	*S1-S3*	*S2-S3*
δ_{rel}	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	**/**	*/**	-/-	-/-	-/-
θ_{rel}	-/-	-/*	-/**	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-
α_{rel}	-/-	**/-	**/-	-/-	**/**	**/**	-/-	**/**	**/**	-/-	**/-	*/-	-/-	-/-	-/-
β_{rel}	-/-	*/*	*/-	-/-	**/*	**/**	-/-	*/*	**/**	-/-	**/**	**/**	-/-	**/-	-/-
α/δ_r	-/-	**/-	**/-	-/-	**/**	**/**	-/-	**/**	**/**	-/-	*/-	*/-	-/-	-/-	-/-
α/θ_r	-/-	**/*	**/-	-/-	**/**	**/**	-/-	**/**	**/**	-/-	**/-	-/-	-/-	**/-	-/-
α/β_r	-/-	-/**	-/**	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/*	-/-	-/-	-/-	-/-
$\alpha/(\alpha+\theta+\beta)_r$	-/-	**/-	**/-	-/-	**/**	**/**	-/-	**/**	**/**	-/-	**/-	-/-	-/-	*/-	-/-
$(\alpha+\theta)/\beta_r$	-/-	**/**	**/**	-/-	**/*	**/**	-/-	**/**	**/**	-/-	*/*	-/-	-/-	-/-	-/-

/ Differences before and during flicker-fusion test (before/during). *, ** Significantly different at the 0.05 and 0.01 level, respectively.

Table 2. Changes in Mean Values of EEG Parameters for Different Pairs of States

Parameter	EEG channels														
	Pz			O1			O2			Pz-O1			Pz-O2		
	S1-S2	*S1-S3*	*S2-S3*	*S1-S2*	*S1-S3*	*S2-S3*	*S1-S2*	*S1-S3*	*S2-S3*	*S1-S2*	*S1-S3*	*S2-S3*	*S1-S2*	*S1-S3*	*S2-S3*
δ_{rel}	- / -	- / -	- / -	- / -	- / -	- / -	- / -	- / -	- / -	- / -	↓ / ↓	↓ / ↓	- / -	- / -	- / -
θ_{rel}	- / -	- / ↓	- / ↓	- / -	- / -	- / -	- / -	- / -	- / -	- / -	- / -	- / -	- / -	- / -	- / -
α_{rel}	- / -	↑ / -	↑ / -	- / -	↑ / ↑	↑ / ↑	- / -	↑ / ↑	↑ / ↑	- / -	↑ / -	↑ / -	- / -	- / -	- / -
β_{rel}	- / -	↑ / ↑	↑ / -	- / -	↑ / ↑	↑ / ↑	- / -	↑ / ↑	↑ / ↑	- / -	↑ / ↑	↑ / ↑	- / -	↑ / -	- / -
α/δ_r	- / -	↑ / -	↑ / -	- / -	↑ / ↑	↑ / ↑	- / -	↑ / ↑	↑ / ↑	- / -	↑ / -	↑ / -	- / -	- / -	- / -
α/θ_r	- / -	↑ / ↑	↑ / -	- / -	↑ / ↑	↑ / ↑	- / -	↑ / ↑	↑ / ↑	- / -	↑ / -	- / -	- / -	↑ / -	- / -
α/β_r	- / -	- / ↓	- / ↓	- / -	- / -	- / -	- / -	- / -	- / -	- / -	- / ↓	- / -	- / -	- / -	- / -
$\alpha/(\alpha+\theta+\beta)_r$	- / -	↑ / -	↑ / -	- / -	↑ / ↑	↑ / ↑	- / -	↑ / ↑	↑ / ↑	- / -	↑ / -	- / -	- / -	↑ / -	- / -
$(\alpha+\theta)/\beta_r$	- / -	↓ / ↓	↓ / ↓	- / -	↓ / ↓	↓ / ↓	- / -	↓ / ↓	↓ / ↓	- / -	↓ / ↓	- / -	- / -	- / -	- / -

/ Differences before and during flicker-fusion test (before/during). ↑ Significantly increasing of mean value. ↓ Significantly decreasing of mean value.

Table 3. Results of Paired T-Test for EEG Parameters Derived Before and During Flicker-Fusion Test Performing

Parameter	EEG channels														
	Pz			O1			O2			Pz-O1			Pz-O2		
	S1	*S2*	*S3*	*S1*	*S2*	*S3*	*S1*	*S2*	*S3*	*S1*	*S2*	*S3*	*S1*	*S2*	*S3*
δ_{rel}	*	**	-	-	-	-	-	-	-	-	-	-	-	*	**
θ_{rel}	**	**	**	-	*	-	-	-	-	-	-	-	-	-	-
α_{rel}	-	-	*	-	*	-	-	-	-	-	-	-	-	**	**
β_{rel}	-	-	-	-	-	-	-	-	-	*	*	*	*	-	**
α/δ_r	-	-	-	-	*	-	-	-	-	-	-	-	-	**	**
α/θ_r	-	-	**	-	-	-	-	-	-	*	*	-	-	*	**
α/β_r	-	-	**	-	-	-	-	-	-	-	-	**	-	-	-
$\alpha/(\alpha+\theta+\beta)_r$	-	*	**	-	-	-	-	-	-	*	-	**	-	*	**
$(\alpha+\theta)/\beta_r$	-	**	-	-	-	-	-	-	-	-	-	**	**	-	-

*, ** Significantly different at the 0.05 and 0.01 level, respectively.

Other important question relating to interpretation of results of such experiment is how much alertness levels can be distinguished by certain method. Results of statistical analysis of data show that distinction of states by the set of objective features derived from biological signal of a person can differ from subjective determination of state. According to these results, only two "extreme" states (S1 and S3) are distinguishable adequately and might be thereby taken into account by designing the future experiments. The state S2 can be excluded from the study because of its similarity to S1 in terms of objective physiological parameters (i.e. spectral parameters of EEG).

Using of EEG to validate FF test implies recording and further processing of large quantity of data, which, however, can be reduced by choosing of minimal number of EEG channels and also parameters derived from signals for analysis. The present study shows that signals from O1 and/or O2 can be effectively used to analyze the brain activity by evaluation of alertness level. Statistical analysis of spectral parameters of EEG indicates that changes in power of α band play an important role in evaluation of alertness level of a person. It is in accordance with literature [16], [17], [19].

Thus, results of the present study can be very useful for designing of future experiments and interpretation of results to be obtained.

5. ACKNOWLEDGMENTS

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