Evaluation of the workload and drowsiness during car driving by using high resolution EEG activity and neurophysiologic indices

A. Maglione, G. Borghini, P. Aricò, F. Borgia, I. Graziani, A. Colosimo, W. Kong, G. Vecchiato, F. Babiloni

Abstract— **Sleep deprivation and/or a high workload situation can adversely affect driving performance, decreasing a driver's capacity to respond effectively in dangerous situations. In this context, to provide useful feedback and alert signals in real time to the drivers physiological and brain activities have been increasingly investigated in literature. In this study, we analyze the increase of cerebral workload and the insurgence of drowsiness during car driving in a simulated environment by using high resolution electroencephalographic techniques (EEG) as well as neurophysiologic variables such as heart rate (HR) and eye blinks rate (EBR). The simulated drive tasks were modulated with five levels of increasing difficulty. A workload index was then generated by using the EEG signals and the related HR and EBR signals.**

Results suggest that the derived workload index is sensitive to the mental efforts of the driver during the different drive tasks performed. Such workload index was based on the estimation the variation of EEG power spectra in the theta band over prefrontal cortical areas and the variation of the EEG power spectra over the parietal cortical areas in alpha band. In addition, results suggested as HR increases during the execution of the difficult driving tasks while instead it decreases at the insurgence of the drowsiness. Finally, the results obtained showed as the EBR variable increases of its values when the insurgence of drowsiness in the driver occurs. The proposed workload index could be then used in a near future to assess on-line the mental state of the driver during a drive task.

I. INTRODUCTION

World Health Organization (WHO) indicates that road accidents are the ninth cause of death among young people aged between 18 and 29 years. Often this death occurs from a lapse of attention of the driver due to the onset of mental fatigue or induced by high cerebral workload [1-5]. So the workload, fatigue and sleepiness have an important role in road safety. In fact, mental fatigue and drowsiness leading to a lowering of the level of attention and appeared to be among the main causes of road accidents. Several studies have shown a relationship between the cognitive status of the subject and his/her EEG activity during simple sensory - motor or cognitive tasks[1-5]. In particular, the EEG was found to be sensitive to changes in alertness and able to predict a decline in performance due to the increase in mental workload [1-6]. In these studies, it was showed an increase of the EEG power spectral density PSD in the theta frequency band over the prefrontal, frontal and parietal cortical areas, during difficult drive [7][8]. These changes have been often associated to a simultaneous reduction of the EEG PSD in alpha band over the parietal cortical areas [8-10].

From these results provided by the literature it can be hypothesized that the generation of an efficient workload index for the driving task could be based on the simultaneous occurrence of the above mentioned changes in EEG PSD as well as with the use of the other autonomic measurement variables. In fact, other lines of experimental evidences suggested as the heart rate (HR) and the eye blink duration (EBR) measurements could be correlated with the variation of the cognitive efforts during the drive task[4,10]. In particular it is shown that an increase of HR could be indicative of an increased workload while the eye blink is inversely correlated with the changes in mental load of the drivers [4, 10]. Thus, it can be hypothesized that EEG, EBR and HR could be employed in the generation of a workload index that will track the perceived difficulty of the driving task from the drivers. To check such hypothesis, we generated an experimental paradigm in which simulated driving tasks were proposed to a group of normal subjects. Such driving tasks have different level of difficulty or monotony, and the measure of EEG, HR and EBR variables were concurrently performed. The observed results for this experiment reported in the following, suggested that it is possible derive an efficient workload index on the base of such cerebral and autonomic measurements for the drive.

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II. MATERIALS AND METHODS

A. Subjects

The experimental group was composed by 20 healthy subjects (9 female,11 male), all within 24 and 30 years old. All of them usually drive a car with the manual gear, of the same type of the gear proposed during the drive simulations. To all the subjects were prohibited to drink alcohol and to have heavy meals for one day prior to the measurements. Subjects were also asked to avoid caffeine up to 5 hours before the experiment. Each subjects gave his/her explicit informed consent to the experimental procedure.

B. Experimental protocol

The experiments were performed between 2 PM and 5 PM. In this part of the day time sleepiness tends to increase [5]. The experimental protocol is developed along 1 day. The simulated drive game used is Need For Speed and the Spa – Francorchamps (Belgium) track and the car by which performing the driving tasks was the Alfa Romeo – Giulietta QV (1750 TBi, 4 cylinders, 235 HP) have been chosen. The night condition for the drive task was also selected. In order to modulate the difficulty of the proposed driving task, a simultaneous attentional and vigilance task (TAV) was added concurrently to the drive task. This TAV task works as follows: an alert stimuli, a white "X", was presented on a monitor placed about 1 m from the subject, avoiding the interference with the main screen where the game visualized (Fig. 1). Subjects are asked to press the button #1 when the X appears on the screen, during the drive. The audio vigilance stimuli were generated by two speakers placed on the left and on the right side of the driver (Fig. 1). A succession of frequent (with a 95% probability rate) and rare (5% probability) tones at different acoustic frequency were continuously delivered to the subjects. They are asked to press the button #2 when the rare stimulus occurs. These tasks (TAV) could be generated at different levels of difficulty, depending on the overall frequency of the visual and acoustic stimulations. The alternating tone sequence of the vigilance task could simulate the car's radio or engine noise while the target tone sequence could be an unexpected sound (e.g. phone calling). The alert's stimuli simulated instead the traffic jam, for example, the traffic lights, the pedestrians, other cars or other uncontrollable traffic agents [6]. After training of half hour the subject had to drive the simulated cars in two conditions: the first by moving the car in the selected circuit at a predetermined speed. Such condition were named "warm up" (WUP) and serve to collect the baseline for the cerebral and autonomic signals. The second drive condition, named "performance" (PERFO), required to the driver to race at a speed higher than that held on the warm up period. On this driving task it have been superimposed the occurrence of the different TAV tasks. In particular, five TAV tasks with increasing difficulty levels due to the increase of frequency of stimuli were employed during the experiments. Such TAV tasks are presented in a pseudo-random order to the subjects such as: TAV3, TAV1, TAV5, TAV2, TAV4, where TAV1 is the easier task and the TAV5 the most difficult one. Finally, the last condition in which the EEG and autonomic parameters of the subjects were collected was instead a monotonous night driving, in which the subject had to drive, on the same track without exceeding the speed of 70 (Km/h). With the last task we wanted to induce hypovigilance or drowsiness, that effectively occurred in all the subjects during the experiments. At the end of each task of the experiment subjects were asked to fill out the NASA-TLX questionnaire, that provides a standard measurement of the perceived mental load during the task by the subjects. Errors performed by the subjects during the performance of the different TAV tasks during the simulated drive were also analyzed off-line.

C. EEG and physiological recording

A digital ambulatory monitoring system (Brain Products GmbH, Germany) are used to record EEG and physiological signals. The signals are acquired with a sampling frequency of 200 Hz end are collected simultaneously during the experiment. To remove power interference was applied a 50-Hz notch filter. The earlobes are used as reference and the impedances were maintained around 10 (kΩ). The EEG recording was filtered with a band pass filter (1-30 Hz) and then Independent Component Analysis (ICA) was used to remove the artifacts and separate blink component from the data. The blink component are used for the estimation the eye blinks rate (EBR). The EKG raw signal was filtered with pass-band filter (low-pass filter cut-off frequency: 10 Hz, high-pass filter cut-off frequency: 0.5 Hz) used for estimate the heart rate (HR).

Figure 1. Experimental design employed. The pilot drives the simulated car on a circuit that was identical for all the subjects. Five different experimental conditions have been set up for increase progressively the cerebral workload. This was obtained by performing additional tasks beside the car guide as required by the task of Attention and Vigilance (TAV). TAV tasks are proposed to the subjects on the small monitor just below the track images on the wall and by the acoustic stimulations.

D. Neurophysiologic indexes for characterizing drowsiness and mental fatigue.

It has been suggested as the onset of the state of drowsiness could be indexed by the appearance on the EEG traces of the alpha spindles [7]. Such spindles are defined as short bursts in the alpha band of EEG. and consist of 12-14 Hz waves that occur for at least 0.5 (s). It has been also observed as those EEG alpha bursts are also correlated with driving errors. We controlled the occurrences that these EEG events before the driving task in which the drowsiness was induced. In this work, the workload index (IWL) has been defined as the ratio between the EEG PSD in theta band over the central frontal area (Fz) and the EEG PSD in alpha band over the central parietal area (Pz). The EEG bands have been defined by using the Individual Alpha Frequency (IAF) [9-15]. The IWL, HR and EBR values have been subjected to the Analysis of Variance (ANOVA) in order to investigate changes of their values across the modulation of the TAV tasks. Factors for the ANOVA are TASK (with 6 levels) and GENDER (male, female). For HR and EBR indexes are used Z-score value, instead for IWL index are used r-squared values.

III. RESULT

A. Workload index

The group values of the estimated cerebral IWL across the different driving conditions is presented in Fig.2, in which the gender of the investigated sample it is also taken into account. The EEG data are calculated with r-squared. R-squared is a statistical measure computed over a pair of sample distributions, giving a measure of how strongly the means of the two distributions differ in relation to variance.

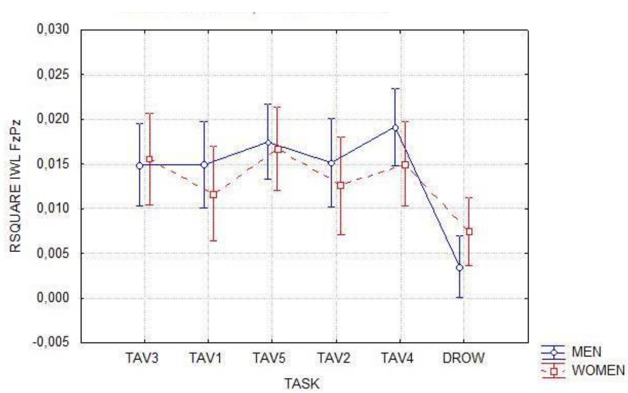

Figure 2. The cerebral IWL for men (blue line) and for women (red line) across the different drivin tasks proposed. For the all population investigated, as the difficult of tasks increases the cerebral IWL increases while it decreases during the drowsy condition (DROW).

Fig.2 shows an example of how the employed workload index changed during the different experimental conditions. Woman and men show the same trend across the different tasks. The TAV tasks are statistically different from the DROW condition ($F=4.54$, $p=0.004$). Application of the post-hoc Duncan tests revealed that the IWL average values for the population investigated discriminate statistically the difficult task (TAV5, TAV4,TAV3) from the easier tasks (TAV1,TAV2), in the female sample population. In the male such trend doesn't reach the statistical significance ($p= 0.1$).

B. Heart and eye blinks rate

The eye blinks rate (EBR) variable shows a statistical significant difference on average between the TAV conditions and the DROW one ($p<0.05$). In fact, Fig.3 shows the EBR average values across the different TAV conditions and the DROW one. Male sample presented EBR values higher in DROW conditions than in the other ($p<0.001$).

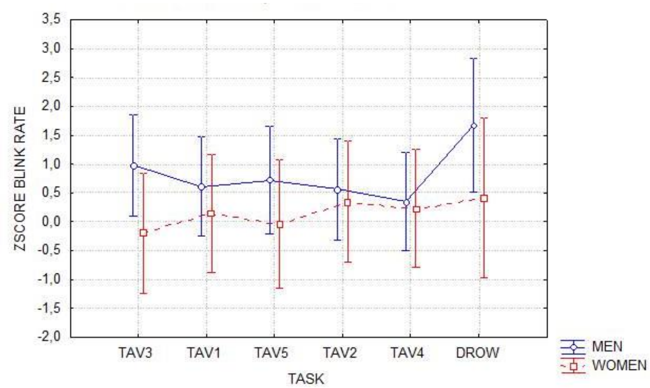

Figure 3. The EBR for men (blue line) and for women (red line) has been demonstrated to be different, especially in the drowsy condition (DROW). The EBR for men is higher in the drowsy condition and smaller in the TAV conditions.

The hearth rate (HR) variable showed a statistical difference between TAV and DROW condition ($p<0.05$), as well as for the gender factor (Fig.4).

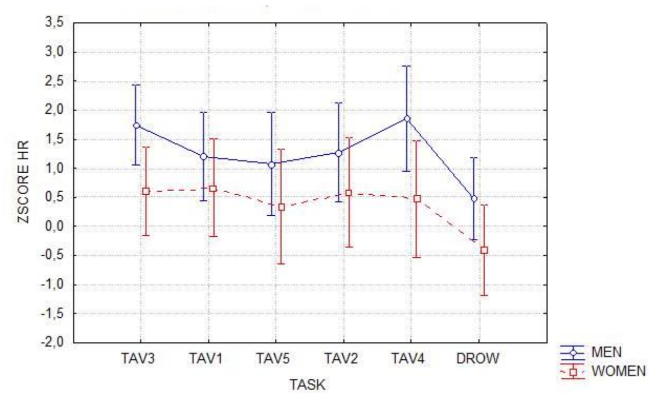

Figure 4. HR average values for the male and female populations across the different TAV and the DROW condition.

In fact, in male population the HR values are higher than in the female population.

C. NASA TLX

The result obtained from NASA TLX test represented in Fig. 5 show that the subjective workload perceived in the analyzed population correlate with the level of the drive difficulty. In fact, such increase occur during the TAV tasks that are more difficult (TAV5,TAV3,TAV4) while it is less prominent during the easier tasks (TAV1,TAV2). Both populations (male, female) show statistical difference between TAV and DROW condition ($p<0.02$).

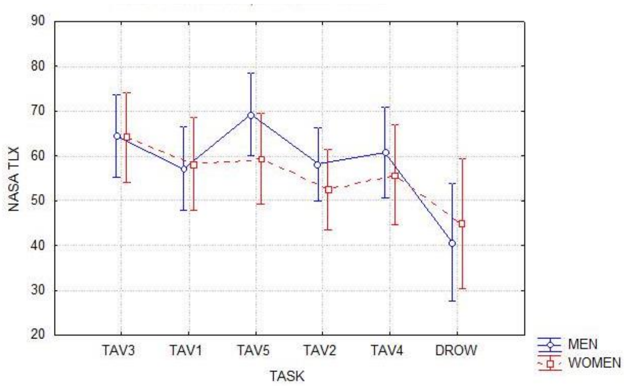

Figure 5. This picture shows the subjective workload evaluation as performed by filling the NASA-TLX questionnaire. The blue line represents NASA TLX results for men and the red line the NASA-TLX for women. The higher the NASA-TLX index the higher the perceived workload. Both women and men feel higher values of workload during the TAV conditions and smaller during the drowsy condition (DROW).

IV. DISCUSSION

In this paper it was showed that different cerebral (IWL) and autonomic (HR, EBR) indexes modulate with the levels of difficulty for a series of simulated drive tasks, at the group level. In addition, it is also observed as such results appear to be dependent to the gender of the relatively young population investigated. A common trend for IWL, HR and EBR indexes has been found; the higher task's difficulty, the higher the IWL and HR values, the NASA-TLX scores, and the driving errors (off road). In addition, the EBR decreased with the increase of difficulty and it decreased during the monotonous condition. However, such differences have been observed at the group level. The female group investigated show less amplitude in each indices considered.

This study suggests that EEG data can be used in the development of an on-line cerebral mental workload index (IWL). It also suggests that the integration of IWL information with those deriving from the autonomic indexes, such as heart rate and the eye blinks rate, could be important. The idea that the workload index could be estimated in a near future in "real-time" by a mixed system that includes EEG, HR and EBR signals inside the car appears feasible in the next few years. Such system will return feedback to the driver about his/her internal cognitive conditions during the execution of the drive task.

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