Driver's Mental Workload Assessment Using EEG Data in a Dual Task Paradigm

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Abstract

The integration of physiological monitoring into the human–machine interface holds great promise both for real-time assessment of operator status and for providing a mean to allocate tasks between machines and humans based on the operator status. Our group, aiming to provide a new human-machine interface to improve traffic safety using brain signals, has conducted a number of researches for the driver states monitoring based on EEG data in recent years.

This article presents our study for the representation of mental workload using EEG data. A simulated driving task - the Lane Change Task (LCT), combined with a secondary auditory task - the Paced Auditory Addition Serial Task (PASAT), was adopted to simulate the situation of in-vehicle conversations. Participants were requested to perform the lane change task under three task conditions - primary LCT, LCT with a slow PASAT and LCT with a fast PASAT.

The EEG recordings combined with performance data from LCT and PASAT provided plenty information for comprehensive understanding of driver's workload. The analysis of event-related potentials (ERP) revealed that LCT evoked cognitive responses, such as P2, N2, P3b, CNV, and the amplitudes of P3b decreased with the task load. A crucial benefit of these findings is that the increase or decrease of amplitudes of ERP components can be directly used for representing driver's mental workload.

1, Introduction

Driver's mental workload has been considered as one of the most important contributors to traffic accidents (Verwey et.al., 1993). In the last decades, a large number of researches have been conducted to investigate driver workload using different methods, such as subjective measurement (Pauzié & Pachiaudi 1997), performance measurement (De Waard, 1996), as well as physiological parameters, such as Electroencephalography (EEG), Electrocardiography (ECG), etc (Wilson et al.1988; Piechulla et.al., 2003; Chen et.al., 2005). EEG as the measurement of brain electrical activity recorded from electrodes placed on the scalp

provides a promising approach for driver mental workload monitoring. Characteristic changes in the EEG and event related potentials (ERPs) that reflect levels of workload have been identified (Wilson et al.1988; Gevins et al., 1998; Raabe et.al, 2005). Raabe et.al (2005) revealed the variation of the amplitude of P300 due to the task load or task difficulty. Other researches calculated the power spectral density of EEG signals using the fast Fourier transform (FFT) to examine the change of frequency characteristics. Such an approach allows for understanding how the ratio of a specific frequency band, e.g. alpha band, changes when the mental work level changes (Gevins, et al., 1998).

Our group aims to develop new approaches of driver state monitoring based on brain signals. One of our objectives is to assess the driver mental workload. A simulated driving task - the Lane Change Task (LCT) (Mattes 2003), combined with a secondary auditory task - the Paced Auditory Addition Serial Task (PASAT) (Gronwall, 1977), was adopted in the present study. Both single task condition (LCT only) and dual-task condition (combination of LCT and PASAT) were involved. In the single-task condition, task load levels were manipulated by changing the speed settings (low, moderate, high), while in the dual task condition, task load levels were elicited by the paces of PASAT (a slow PASAT and a fast PASAT). This article concentrates on the results from dual task condition, LCT with two paced PASATs.

2. Methods

2.1 Lane Change Task

The Lane Change Task (LCT) was initiated by the project ADAM (Advanced Driver Attention Metrics) as an easy-to implement, low-cost, and standardized methodology for the evaluation of the attention associated performing in vehicle tasks while driving (for details, see Mattes, 2003; Burns, et.al.,2005).

Fig.1 Lane Change Task

Participants are required to repeatedly perform lane changes when prompted by road signs (Fig.1). The quality of these lane changes can be evaluated by the difference (mainly based on Mean Deviation) between a normative lane change path and the driver's actual lane change path, which is influenced by the drivers' performance of detecting and responding to the road signs as well as their lateral control maintenance. Lane change performance with a secondary task (driving and

using the telematics system of interest) is evaluated against a normative model of single task performance, which enables the possibility to evaluate the extent of distraction due to the dual task condition.

2.2. Paced Auditory Serial Addition Task

The PASAT is a measure of cognitive function that assesses auditory information processing speed and flexibility, as well as calculation ability. It was developed by Gronwall in 1977. The PASAT is usually presented using an audio cassette tape or compact disk to ensure standardization in the rate of stimulus presentation. Single digits are presented every 3 seconds and the participant must add each new digit to the one immediately prior to it. Shorter inter-stimulus intervals, e.g., 2 seconds or less have also been used with the PASAT but tend to increase the difficulty of the task. The digit was randomly arranged to minimize possible familiarity with the stimulus items when the PASAT is repeated over more than one occasion.

3. Driver's mental workload based on EEG

3.1 Participants

Overall, 30 participants between the ages of 20-34 were assessed (M=26.1, SD=11.8). All individuals reported being free of neurological/psychiatric disorders and received a cash payment for their participation.

3.2 Experiment

The experiment involved four blocks. The first block was the primary driving task. Participants were requested to perform the LCT under three different speeds 60 km/h, 80 km/h, 100 km/h, which represented three task load levels (low, moderate and high respectively). The second block was PASAT under two paced conditions: slow and fast (the numbers were presented every 5 and 3 seconds, termed p5 and p3). Participants were requested to calculate the numbers and report the results. The third block was the combination of the primary and secondary task. Participants were requested to do the calculation at two paces while performing the LCT with a fixed speed 80 km/h (80+p5 and 80+p3). However, they were instructed that the primary task was more important. The last block was another dual task. Participants were requested to press a button embedded in the steering wheel when they started to take the action of changing. This block might help us to calculate the reaction time. The whole experiment lasted 3 hours totally. However, the present study concentrates on the dual task condition, the LCT with the secondary task PASAT.

3.3 Recordings

While performing the LCT the brain activity was recorded with 32 Ag/AgCl impedance-optimized electrodes (ActiCap, Brain Products), referenced to the

nasion, sampled at 1000Hz and wide-band filtered. The 32 channels were placed at the positions of the

international 10-20 System. Electromyogram (EMG) was recorded from both forearms with two bipolar electrodes. The horizontal and vertical eye-movement was recorded using the Electrooculogram (EOG). For data recording the Brain Vision Recorder by Brain products was used.

Using the LCT, the information such as the vehicle's position and the steering angle were recorded in order to access the driving performance. The reported digits presented by the PASAT were recorded for the calculation performance evaluation.

3.4 EEG Data analysis

EEG data analysis was performed using EEGLAB 6.03, a freely available open source toolbox running under Matlab 7.3.0. A detailed description about EEGLAB is provided by Delorme and Makeig (2004). For pre-processing, data was down-sampled to 500 Hz to save computation time, and was then digitally filtered using band pass filter (pass band 0.5 to 40 Hz) to minimize drifts and line noise. Then EEG data was average re-referenced, a method to reference the data to the average across all electrodes to avoid the influence of an arbitrary local reference. Finally, data epochs were extracted from 2000ms before stimulus - the command for lane change direction - until 2000ms after stimulus and the average of time range [-2000ms, -1000ms] as the baseline was removed from every epoch. This way, more than 100 trials were extracted for each condition and each subject.

EEG recordings involve plenty of artefacts, such as eye movements, muscle noise, cardiac signals and line noise and many others. In the present study, Independent Components Analysis (ICA) was used to improve the data quality. ICA decomposes EEG data into temporally independent and spatially fixed components, which account for artefacts, stimulus and response locked events and spontaneous EEG activities. Recently, it has been considered as a powerful tool for EEG components identification and artefacts removal (Makeig, et al., 1996; Delorme & Makeig, 2004). After calculation of independent components (ICs), we calculated the correlation coefficient of ICs and EOG, ICs and EMG, and removed the highest correlated ICs.

Analysis of Variance (ANOVA) was employed to verify the significance of difference in amplitude of the component of interest under three conditions and the paired conditions. The Post Hoc Test was used to offer detailed view of the differences among the three conditions.

4 Results

4.1 Driving Performance

Driving performance was evaluated in content of the mean deviation between the real lane change path and normal lane change path. The mean deviation exhibited no difference in driving performance among the three conditions ($F(2,22)=0.43$, $p=0.65$)(see, Fig.2).

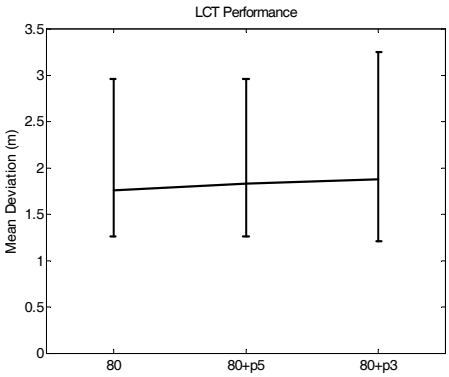


Fig.2.Driving performance

4.2 PASAT Performance

The percentage of the correct reported numbers demonstrated that the participants' performance in PASAT differed among the conditions (Fig.3). The differences between single task conditions (PASAT only) and dual-task conditions (LCT with PASAT) were significant ($F(1,22)_{(p5,\ 80+p5)}=8.18$, $p<0.01$; $F(1,22)_{(p3,\ 80+p3)}=7.28$, $p<0.01$), whereas there were no obvious differences in performance in dimension of paces ($F(1,22)_{(p5,\ p3)}=2.34$, $P=0.13$; $F(1,22)_{(80+p5,\ 80+p3)}= 2.47$, $P=0.12$).

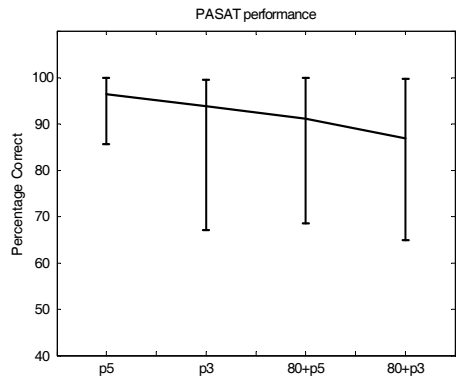
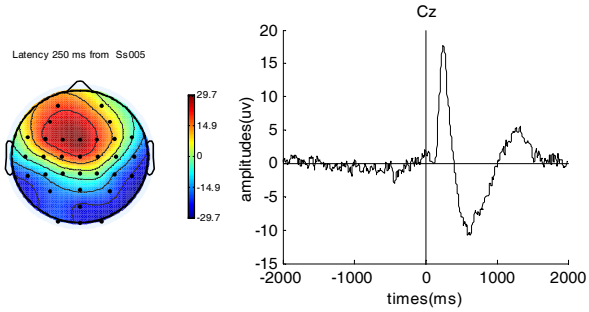


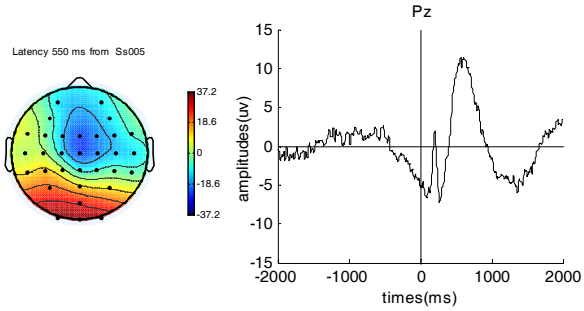
Fig.3 PASAT performance

4.3 ERP

Artefact-corrected ERP showed that the LCT task evoked a P2 (Fig.4 (a)), a positive peak at the latency around 250 ms after stimulus onset in the frontal-central area. This peak had its maximum at FCz and still existed at the parietal area but with smaller amplitude and earlier latency (200ms). Another prominent component was P3b (Fig.4 (b)), a positive peak around 550ms in the central-parietal area, and its maximum appeared at POz. Additionally, there were a obvious CNV and a N2 (270ms) at the parietal-occipital area.



(a) P2 with a positive peak at the latency 250 ms located on the frontal-central area of the brain



(b) P3 with a positive peak at the latency 550 ms located on the parietal-occipital area of the

Fig.4 Event Related Potential

Fig.5 shows the comparison of the ERPs under three task conditions at different locations. Statistical analysis ANOVA revealed that there were no obvious differences in amplitude of P2 among the three conditions at the frontal-central area (Tab.1), whereas, obvious changes in amplitude of P3b were obtained at the central-parietal-occipital area and the difference reached its maxima at Pz.

Post hoc test revealed that the differences between condition 80 and 80+p5, 80 and 80+p3 were significant but no obvious difference between condition 80+p5 and 80+p3 at Pz and POz were observed. Furthermore, the difference between 80 and 80+p5 disappeared at the CPz and Oz. Nevertheless, the differences in amplitude of P3b between condition 80 and 80+P3 existed in the whole central-parietal-occipital area.

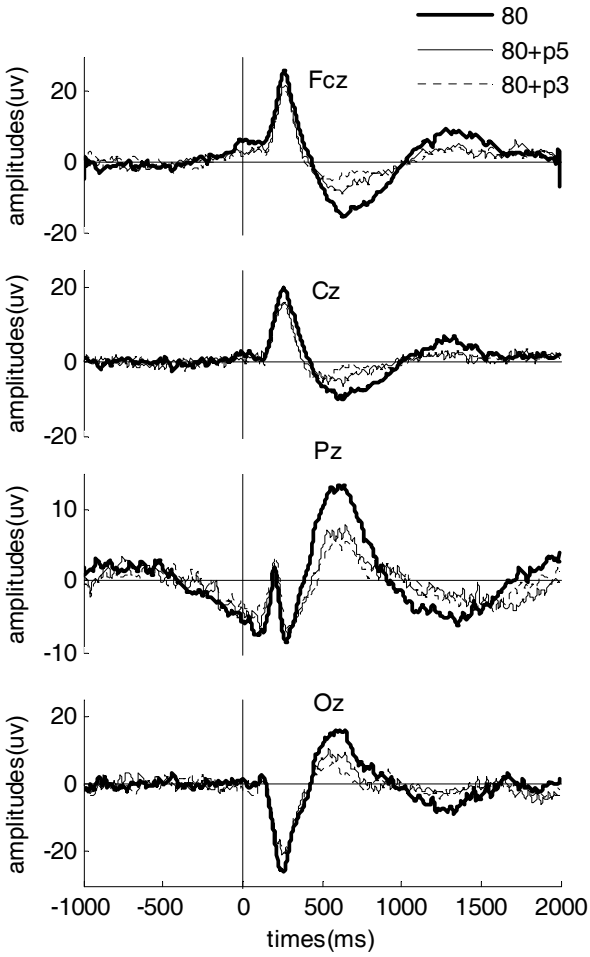


Fig.5. Comparison of the ERPs among three task conditions. For the frontal-central P2 the amplitude was evaluated by the average of 200-300 ms and for the parietal-occipital P3b the amplitude was evaluated by the average of 450ms-650ms.

Tab.1 Statistic Analysis

Post Hoc Test indicates pairs of the condition which differ each other. Condition 1, 2 and 3 represent the workload level low (80), moderate (80+P5) and high (80+P3) respectively.

	Loc.	ANOVA	Post hoc.
Amp. of P2	FCz	F(2,22)=1.99,p=0.14	-
	Cz	F(2,22)=2.96,p=0.06	-
Amp. of P3	CPz	F(2,22)=3.69,p<0.05	1, 3
	Pz	F(2,22)=8.75,p<0.001	1,2 1,3
	POz	F(2,22)=7.13,p<0.01	1,2 1,3
	Oz	F(2,22)=3.65,p<0.05	1, 3

5. Discussion

The results from driving performance analysis indicate that there is no deterioration of performance when the auditory secondary task is added. Two possible reasons might account for the stabilized driving performance. One is that the LCT occupies the visual cognitive resource, whereas the PASAT occupies auditory cognitive resource. Based on the multiple resources theory (Wickens, 1980), the task performance might be insensitive to the task load when the concurrent tasks share difference resources in the dual task condition. However, this theory might not account for the deterioration of PASAT performance when it is combined with LCT. Another possibility is that the concurrent tasks indeed evoke higher task load compared with the single task condition. However, the participants is instructed that to maintain the performance of primary task LCT is more important than the secondary task, which could account for that why there is a deterioration of PASAT performance but no decline of driving performance. Nevertheless, there are no obvious differences in the PASAT performance when comparing the two paced

conditions. This indicates that our manipulation of task load under the two paced PASAT is not successful. However, there is no doubt that the combination of LCT and PASAT elicits higher workload compared with the single task.

The result of ERP analysis reveals a significant decrease in P3b amplitude with the workload level. Previous researches report that the amplitude of the P300 reflects the amount of attention resources allocated (Polich, 2004). A large number of Oddball paradigm researches indicate that the amplitude of P300 for the target is much larger than that of the non-target P300. That is there seems a positive ratio between the amplitude of P300 and amount of attention allocated to stimuli. This theory also could be reasonable for the interpretation of results from some dual-task research. Raabe et.al (2005) reported that the amplitude of P300 decreased with the task load in an oddball paradigm. The P300 was evoked by the secondary auditory task including 96 frequent tones and 24 seldom tones. The primary task was set by two task load conditions, self-paced driving and car-following. Admittedly, the higher workload level (car following) draws more attention of the subject than the low workload level (self-paced driving). That is in high workload level the subject pays less attention to the secondary task, since the primary task occupies a larger amount of attention, therefore the amplitude of P300 decreases. In the present study, the PASAT distracts the participant from LCT and draws a part of attention, which might lead to that less attention is paid for the perception of the road sign. The amplitude of P3b, which is modulated by the amount of attention, therefore is reduced. Nevertheless, there seems no difference in P3b amplitude between condition 80 with p5 and 80 with p3. This might be because that the difference of the mental workload under these two conditions is not distinguishable.

To sum up, the attenuation of the amplitude of P3b with the workload level indicates that EEG is a very effective tool to evaluate the driver's mental workload, and amplitude of P3b is a good candidate for the further study about the attention associated driver's mental workload. However, ERP analysis is based on huge amount of event evoked data and prone to be sensitive to the artefacts, which limits its application in real-time workload evaluation. Thus, further parameters, which are less sensitive to artefacts and relative more stabilized, are still quite necessary for the future research.

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