Detecting Cognitive States for Enhancing Driving Experience

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Abstract. Intelligent cars exploit environmental information to support drivers by providing extra information and assisting complex maneuvers. They can also take into account the internal state of the driver by means of decoding cognition-related brain activity. Here we show the feasibility of successfully classify EEG correlates of anticipation, movement preparation and error processing while subjects drive in a realistic car simulator.

Keywords: Anticipation, motion related potential, prediction, slow cortical potentials, error related potential, classification, car simulator

1. Introduction

Intelligent cars are expected to support drivers by extra information (e.g. distance to nearest car) and support complex maneuvers. These systems should take context into account and provide suitable and timely assistance, while seamlessly interact with the driver. Recognition of the driver's cognitive states can be useful to better align the car's behavior to the driver's intention, hence enhancing the overall driving experience. Previous studies have focused on detecting the level of driver's drowsiness and attention, as well as emergency braking using electroencephalogram (EEG) in combination with other physiological signals e.g. [Haufe et al., 2011]. Extending these works, we studied brain correlates of cognitive states in order to predict future actions or to evaluate whether the decisions of the intelligent system are coherent with the user intentions. Specifically, we report single-trial recognition of anticipation- and error-related potentials elicited while driving in a car simulator.

2. Material and Methods

Experiments were performed in a realistic car simulator. Steering angles, brake and acceleration pedals position were acquired at 256 Hz. EEG signals were recorded at 2 kHz from 64 channels (extended 10/20) and spatially filtered using common average reference. We simultaneously recorded EOG and one EMG channel on the driver's right leg. Signals were downsampled to 256 Hz and synchronized with the car simulator data. EMG signals were band-pass filtered (20-50 Hz) and smoothed using a moving average (t = 25 samples).

Environmental cues warn the driver about upcoming situations where an action may be required (e.g. accelerate when a traffic light changes to green). Anticipation processes are reportedly reflected by a slow cortical potential (SCP) that develops between the warning and the anticipated stimuli [Walter et al., 1964]. We tested the existence of such signals in a scenario where drivers ($N = 6$) were instructed to accelerate or brake at specific points cued by visual stimuli. EEG signals were filtered the in the 0.1-1 Hz range and segmented into 1 s trials preceding the moments when the driver has to act (i.e. GO trials), and those when no response is required (i.e. NOGO trials). We then use a QDA classifier to discriminate these two types of trials from the activity of the Cz electrode.

We also studied neural activity preceding self-generated actions. We analyze the EEG activity while drivers ($N = 6$) perform self-paced lane changes in a simulated highway. EEG data was filtered as above and segmented into trials corresponding to straight driving and steering actions. A LDA classifier was trained using the signal at the C1, Cz and C2 electrodes in a 500 ms window ending 700 ms before the action [Gheorghe et al., 2013].

Intelligent cars should be able to infer potential driving behavior from the environmental information and previous experience. Nevertheless, these devices are prone to errors that may hinder their performance. Detection of error-related brain activity can be used to improve the performance of such systems as shown in simpler protocols [Chavarriaga and Millán, 2010]. We studied these signals when a driver assistant provides feedback on predicted turning directions. Seven healthy subjects participated in the experiment where visual feedback (i.e. arrows) was provided 1 s before they reach an intersection. Erroneous feedback, pointing to a different direction, was presented 30% of the times. Features were selected using discriminant analysis and fed to a LDA classifier.

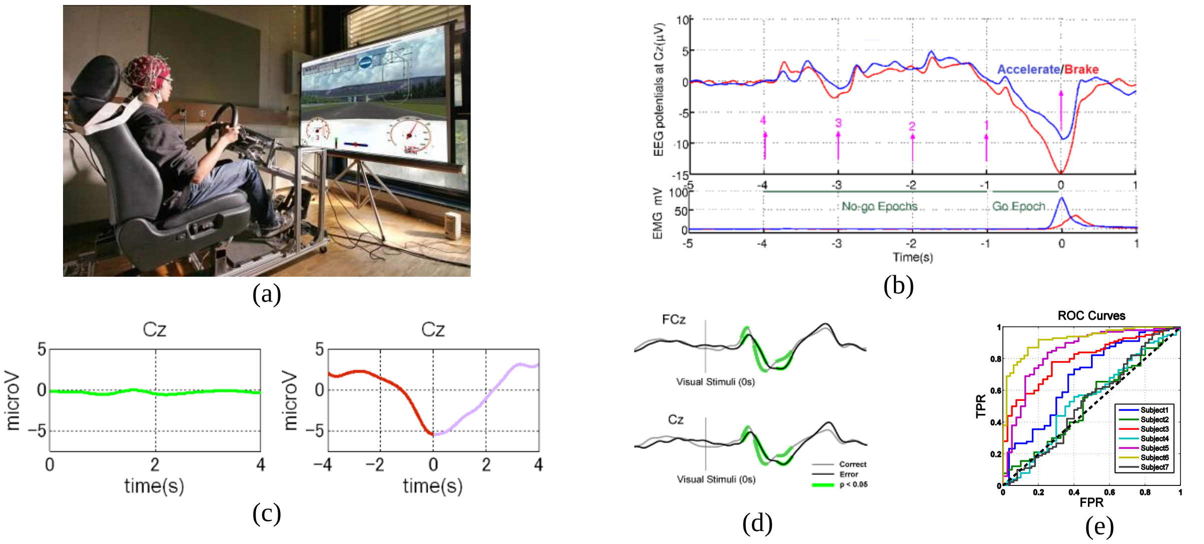

Figure 1. *(a) Experimental setup. (b) Grand average ERP (Cz electrode) for both brake and accelerate conditions. Bottom: EMG. (c) Lane changes. Grand average ERP during straight driving (left) and around lane changes (right). (d) Error-related ERPs after visual stimulus showing predicted directions. (e) Classification of error-related activity.*

3. Results

In the first experiment, we found a centromedial slow negative signal developing well before anticipated actions (accelerate/brake) (Fig. 1b). Average classification performance (AUC) using features up to 200 ms before the action was 0.72 and 0.81 for accelerating and braking actions, respectively [Khaliliardali et al., 2012].

As seen in Fig. 1b, we also found slow negative deflections over central areas–akin to the motion related potentials—starting more than 1 s prior to lane changes. Classification of these actions yields a true positive rate of 68.8 ± 6.6 (5-fold cross-validation), with average detection times of 641 ± 94 ms before the actual steering action. Regarding error potentials, we saw a stereotypic response on frontocentral areas when feedback does not match the user’s intention. Statistical differences between error and correct conditions were observed between 200 ms and 600 ms after feedback. In general, error-related activity was recognized above chance level.

4. Discussion

We consistently found neural signatures of anticipation, movement preparation and error processing while subjects drive in a car simulator. Despite the increased noise that can be expected in this realistic scenario, obtained EEG correlates are well in line with those previously reported in simpler experimental paradigms. These signals can be successfully decode cognitive processes while driving intelligent cars.

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