EEG-EMG coupling anticipates steering in simulated driving

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Assistive driving technology is an example of vehicle safety standards that can prevent accidents. In order to develop efficient tools with adaptable features, it is fundamental to investigate and characterize the related brain process underlying the driver's actions. We propose a hybrid method to distinguish left from right steering in a driving simulator based on EEG and EMG signals collected during steering actions. In particular, we investigated brain and muscular activity underlying steering behavior during a non-ecological steering task. The extracted EEG features with the EMG activity collected during a session of driving simulation to extend the non-ecological cerebral signatures to a more ecological steering task. Therefore, we aimed to characterize the EEG-EMG coupling associated with the natural and self-initiated execution of steering actions while driving to investigate its predictive power.

Twenty-four participants took part in the experiment consisting of non-ecological and ecological steering tasks. In the former, participants seated in front of a computer screen, and had to turn the steering wheel according to a traffic sign randomly presented on display (44 trials per side). In the latter, participants were seated in a driving simulator and asked to drive naturally on a road circuit with no other vehicle present on the track. Continuous EEG was recorded in the non-ecological task using the 128-channel Geodesic EGI System. The pre-processing comprised line noise removal, bad channels interpolation, and common average reference. Artifacts were rejected by applying a semi-automatic procedure to detect abnormal trends and spectra. Then, we performed an independent component analysis (ICA) to identify and separate neurophysiological brain activities from other noise sources (Delorme et al., 2012). Cluster analysis was used to group components according to their scalp topographies via the k-means algorithm (Vecchiato et al., 2018, 2020). Continuous EMG data from the left and right deltoids - reported to be the main muscles involved in steering actions (Pick and Cole, 2006; Lohani et al., 2019) - were acquired using the Neuroelectrics Enobio in non-ecological and ecological steering tasks. The steering wheel, EEG, and EMG signals were synchronized via Lab Streaming Layer and segmented in trials [-2500, 2500] ms around the steering onset. For each EMG signal and EEG IC, we computed the event-related spectral perturbation (ERSP) as time-frequency decomposition using Morlet wavelets (Makeig et al., 2004). All the statistical comparisons between ERSP panels were performed using dependent sample t-statistics and non-parametric permutation testing, corrected for multiple comparisons by weighted cluster mass correction with randomization of 1000 and a statistical threshold of 0.05 (Hayasaka and Nichols, 2004; Maris and Oostenveld, 2007).

We report that the modulation of the mu rhythm observed during the motor preparation of non-ecological steering discriminates the muscular activity of deltoids, thus anticipating subject steering behavior. The analysis of the EEG activity returned that the mu rhythm modulations measured across sensorimotor areas during the preparation phase in the non-ecological task anticipate the corresponding steering action of 1.5 seconds. In particular, we report the increase of EMG activity of the deltoid anticipating the contralateral steering in non-ecological and ecological steering tasks of 200 and 500 milliseconds relative to the action onset. These results show an asymmetric muscular activity of the deltoids beginning before the action onset remaining steady during the steering execution, i.e. the coordinated increase of power of the right deltoid and the corresponding decrease of power of the left deltoid is associated with the steering action on the left side. The presented findings show that by monitoring the two deltoids' muscular activity, it is possible to discriminate the steering side before the action onset while driving in non-ecological and ecological scenarios. Strikingly, the identified non-ecological EEG feature correlates with the ecological EMG activity of the deltoids, providing an improvement of the discrimination power of the steering side during driving simulation.

The existence of preparatory electrophysiological activity elicited 1 second before the onset of steering action allows inferring the upcoming driving actions in advance relative to the state-of-the-art related to single trial classification (Zhang et al., 2013, 2015). Thus, the reported EEG-EMG coupling is a proof of concept for utilizing hybrid systems for the detection and online prediction of driving actions, exemplifying how it might be possible to complement information from behavioral, physiological, and external sources to control the level of assistance needed by the driver in that context (Chavarriaga et al., 2018). The predictive power of the EEG-EMG coupling demonstrated in a car simulator could be further investigated in a larger sets of actions to extend the validity of this neurophysiological mechanism beyond driving.

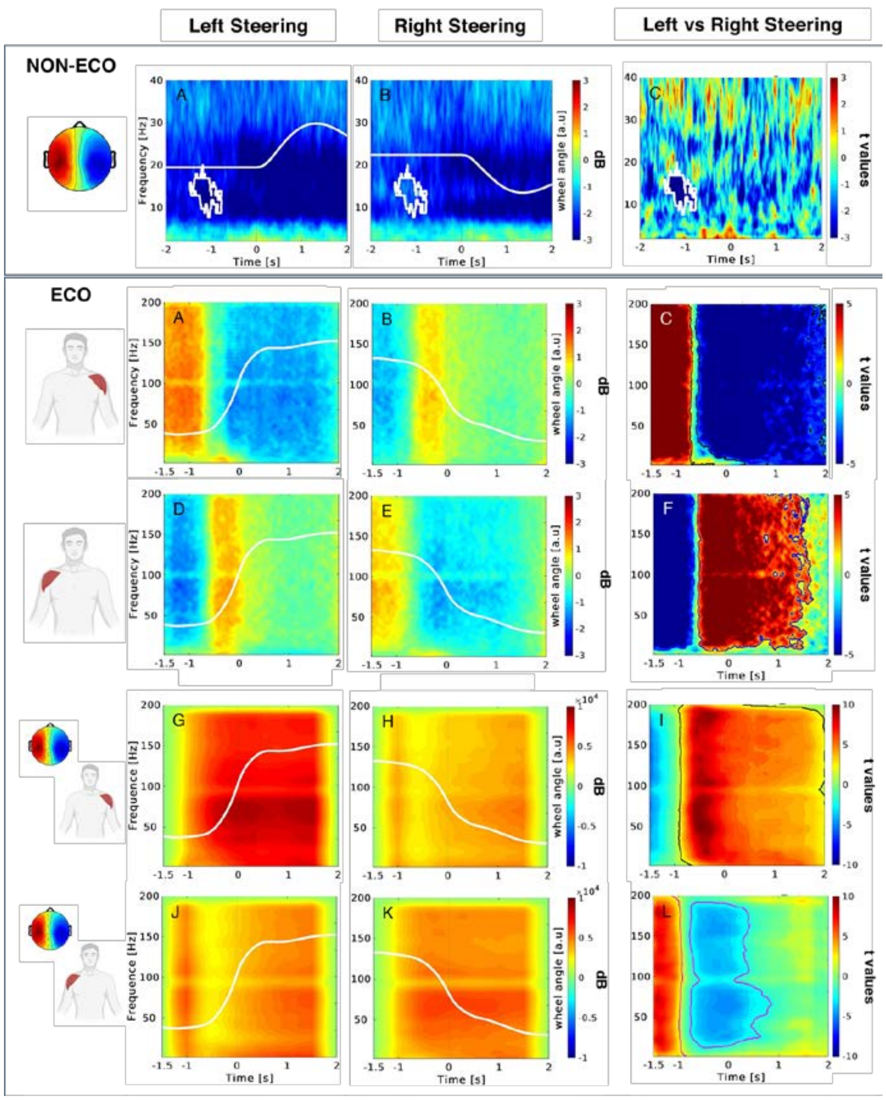

*Figure 1. **NON-ECO frame.** ERSP for the EEG collected during left (A) and right (B) non-ecological steering, as well as their statistical comparison (C). The topography in the left part of the picture shows the average scalp map related to the IC cluster. **ECO frame.** ERSP for the EMG signals collected during the non-ecological steering task (A-F), and cross-correlation results between EEG and EMG data (G-L). The first (second) row (from the top) illustrates the EMG ERSP for the left (right) deltoid during left and right*

steering, as well as their statistical comparison. The third (forth) row illustrates the EEG-EMG cross-correlation values for the left (right) deltoid during left and right steering, and the statistical comparison of the two conditions. White lines depict the left and right steering wheel angle profiles. Colour bars indicate in blue (red) the decrease (increase) of EEG, EMG, and cross-correlation, as well as the statistical differences corresponding to the decrease (increase) of such activity during the left (right) steering. White and black masks delimit the statistically significant portion of the EEG, EMG, cross-correlation panels.

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