Monitoring auditory attention with a 6 dry-electrode EEG system in real flight conditions

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Introduction

There is growing interest for implementing tools to monitor cognitive performance in naturalistic environments (Lotte et al, 2009; Debener et al., 2015; Gramann et al., 2017). The emerging field of research known as neuroergonomics, promotes the use of wearable and portable brain monitoring sensors to investigate cortical activity in a variety of human tasks out of the laboratory. Recent technological progress has allowed the development of new generations of portable brain imaging systems to investigate cognition in ecological settings. For instance, electroencephalographic (EEG) pre-amplified dry electrodes do not require any conductive gel on the participant's scalp. Moreover, the use of a wireless protocol (e.g. Bluetooth, Wi-Fi) allows streaming electrophysiological data online, providing freedom of movement for the participants. This technology opens promising perspectives to measure the "brain at work" such as while operating aircrafts. Indeed, flying is a demanding and complex activity that takes place under a highly dynamic and uncertain environment. Recent accident analyses revealed that the occurrence of unexpected events confused the pilots to an extent that they were not able to diagnose the situation despite multiple visual/auditory alerts (BEA, 2013). One solution to prevent such errors is to implement passive brain computer interface (pBCI) to continuously monitor the pilot's performance and to dynamically adapt pilot-cockpit interaction. A first step toward the implementation of such technology is to benchmark dry EEG devices in real flight conditions. Indeed, this environment is known to be particularly noisy (e.g. electromagnetic interferences from GPS antenna, radio communication and engines). Previous experiments have shown the potential of such devices to measure auditory attention in this context with a Cognionics 64 dry EEG systems (Callan et al. , 2015; Callan et al. , 2016). However, these systems are cumbersome and cannot be worn by subjects for long period of time especially with classical pilot's headset. We therefore propose to benchmark a highly portable and comfortable 6 dry-electrode EEG system. We use a classical oddball paradigm and test whether classical features (i.e. event related potential – ERP) could be extracted from the signal. Additionally, we perform off-line single trial classification of brain responses to deviant and frequent sounds.

Material and Method.

The experiment consisted of an auditory odd-ball task in which the pilots were to count deviant sounds (25% of presented sounds). Approximately 220 stimuli were presented every 2 to 5 seconds. A wireless Neuroelectrics EEG system with 6 dry electrodes was used to measure brain activity (10/20 system recording sites: Fz, Cz, Pz, Oz, P3 and P4). The participants wore the Neuroelectrics Headcap Cover R that works as a Faraday protection against external radio-signals. The experiment was conducted in a DR400 4-seat airplane provided by the ISAE-SUPAERO. Seven ISAE student pilots participated in this study and were supervised by a safety pilot. The scenario consisted of two traffic patterns at the Lasbordes airfield (Toulouse, France). The flight lasted approximately 20 minutes. The experiment was approved by the European Aviation Safety Agency (EASA60049235). EEGLAB was used for EEG data analysis. The continuous EEG data was filtered between 0.8-25Hz, and noisy portions of data were removed using the automatic continuous rejection function (default settings). The epochs for deviant and standard stimuli were extracted from the continuous data 0.2 s before and 1 s after stimuli onsets. The trials used for the ERP analyses were baseline normalized using data from 200 to 0 ms prior to the stimulus onset. Statistical significance of the difference between standards and deviants was determined by means of permutation tests adjusted with false discovery rate (FDR). We also performed a single-trial classification to discriminate offline EEG epochs recorded during deviant and standard stimuli.

A shrinkage linear discriminant analysis (sLDA) was performed, providing better results in a high dimensional feature space (Blankertz et al. , 2011). This method has already been applied with success to efficiently classify auditory event-related potentials (Roy et al., 2016). In order to confirm this state of the art, we compared the shrinkage LDA performance with that of a standard LDA, also known as Fisher Discriminant Analysis. Then, feature extraction was similar to that of Debener and collaborators (2015). We computed for each channel 12 consecutive 50 milliseconds (ms) mean windows from 0 to 600 ms after stimulus presentation. This resulted in 72 features per trial (12 features x 6 electrodes). Finally, classification performances of shrinkage and standard LDA were assessed, independently for each subject, thanks to a random 5-fold cross-validation procedure with a balanced number of trials per class.

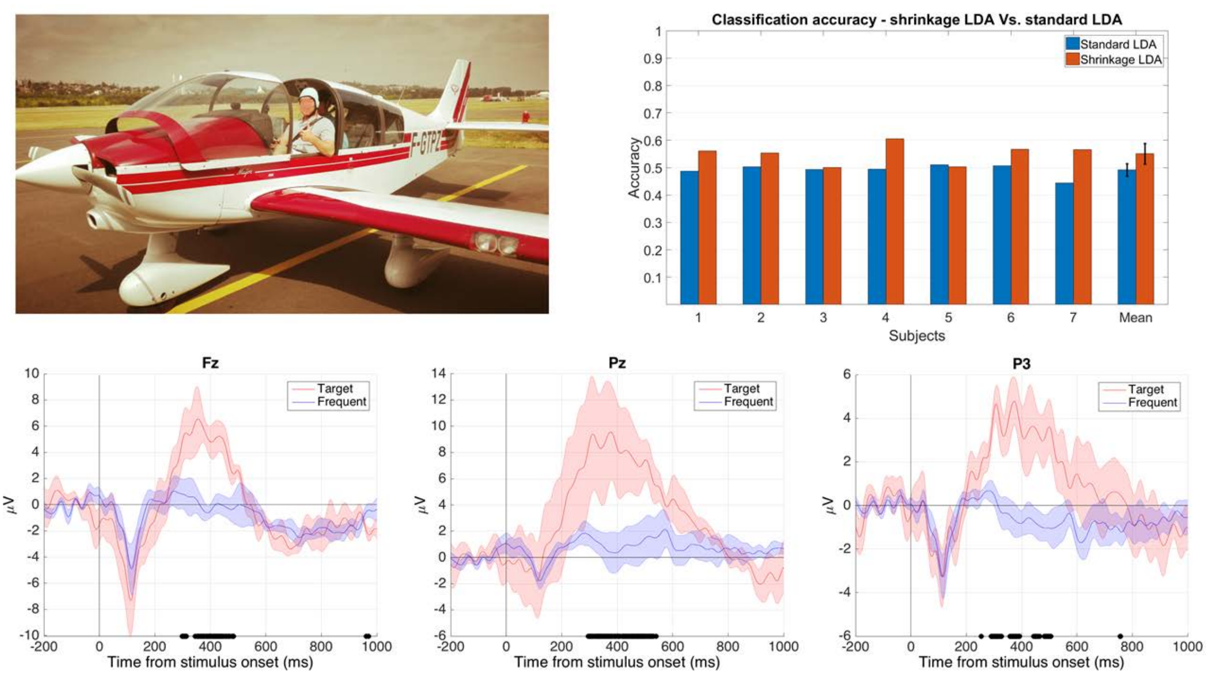

Figure 1: Top left: DR400 light aircraft used for the experiment. The pilot wears a blue headcap that shields against external electromagnetic interferences. Top right: classification accuracy for all participants and mean accuracy. Below (from left to right): Grand averaged waveforms of the ERPs for Fz, Pz and P3 electrodes with standard error. The black bars specify the time range when the ERP amplitudes were significantly different (p<0.05).

Results & Discussion

The statistical analyses disclosed a significant effect of the type of sound on the P300 amplitude for electrodes Fz, Pz and P3 with a significantly higher P300 amplitude for deviant sounds than for frequent ones ($p<0.05$). Top-right part of figure 1 compares balanced classification accuracy from standard and shrinkage LDAs. A two-tailed t-test (p-value = 0.018) disclosed significantly higher performances for the shrinkage LDA (mean=0.55, std=0.04) than for the standard LDA (mean=0.49, std=0.02), corroborating previous results of the literature. The statistical results at the group levels are encouraging knowing that EEG data were recorded in an ecological and so highly noisy environment. However, the classification results did not meet our expectations and more experiments with longer duration has to be carried out to extracts more epochs for classification training purpose.

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