HIGH FREQUENCY BANDS AND ESTIMATED LOCAL FILED POTENTIALS TO IMPROVE SINGLE-TRIAL CLASSIFICATION OF ELECTROENCEPHALOGRAPHIC SIGNALS

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SUMMARY: Non-invasive brain-computer interfaces are traditionally based on slow, mu or beta rhythms. However, there is mounting evidence that neural oscillations up to 200 Hz play important roles in processes such as attention, perception, motor action and conscious experience. In this preliminary study we propose to extend the investigations to the complete frequency spectrum and to compare the high frequency bands with the usual low frequencies. It appears that the 70–130 Hz band and the 170-230 Hz band performs better than the traditional 2–40 Hz band. In a second step we applied the same analysis to the estimated local field potentials from the scalp EEG. The same frequency bands show the best performances, and the use of eLFP leads to an increase of performances of ∼5%.

INTRODUCTION

Recent experiments have shown the possibility of using the brain's electric activity to directly control the movement of robots or prosthetic devices in real time [1]-[3]. For humans, non-invasive methods based on electroencephalogram (EEG) are preferable because of ethical concerns and medical risks and it's widely hypothesized that EEG signals could form the basis of a brain-computer interface (BCI) in order to provide an alternative communication channel to paralyzed people.
Non-invasive BCIs can be classified according to the electrophysiological signal they use. With some systems the subject learns to modulate the amplitude of mu (8-12 Hz) or beta (16-26 Hz) rhythms [4], while some other systems use slow cortical potentials [5] or the P300 event-related potentials [6]. However, there is mounting evidence that neural oscillations play important roles in processes such as attention and motor action. Recent studies in rats and cats report a correlation between neural oscillations above 100 Hz and extending up to 200 Hz with attentive exploration and visual processing [7]. While human electrophysiology has consistently investigated the functional role of gamma band oscillations, the range of frequencies above 80 Hz remains largely unexplored.
The basic question addressed in this paper is to investigate the potential use of high frequency bands to improve performance and accuracy of a BCI. Therefore we enlarged our investigations to the complete frequency spectrum and we compared the performances of different frequency bands. Furthermore, we also used the previously introduced non-invasive estimation of local field potentials (eLFP) in the whole human brain from the scalp EEG using recently developed distributed linear inverse solution termed ELECTRA [8].

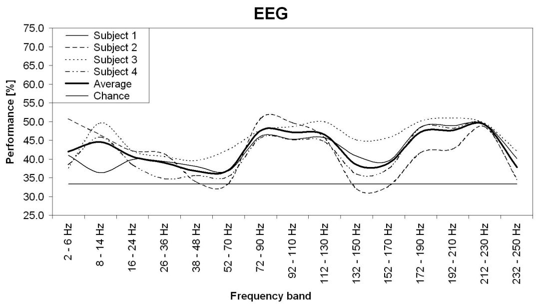
MATERIALS AND METHODS

We recorded scalp EEG from four healthy volunteers (25-31 years, 2 women) performing three different mental tasks. The mental tasks were: imagination of left arm movement, imagination of right arm movement and word association. Subjects had no prior BCI training and did not receive online feedback in order not to bias performance towards any kind of preselected features (i.e., frequency bands or scalp EEG vs. eLFP). Subjects were asked to fixate a central white point and to perform the mental task associated to the visual stimulus that appeared 1.5 s later. In a trial, subjects performed a single task for 5.5 s but, for the analysis of the signals, we rejected the first 1.5 s to avoid the presence of evoked potentials associated to the appearance of the visual stimulus. Each subject performed 15 sessions on 2 different days, one session consisting of 18 trials with a random delay of about 2.5 s in between each single trial.
EEG potentials were recorded at 512 Hz with 64 electrodes covering the whole scalp. For both scalp EEG and eLFP analysis, samples were computed 16 times per second. A sample consisted of the power spectrum density, computed over the last second, at a given frequency for a number of channels. We chose 15 bands of variable resolu-

tion (higher at low frequencies and bands of 20 Hz above 50 Hz): 2–6Hz, 8–14 Hz, 16–24 Hz, 26–36 Hz, 38–48 Hz, 52–70 Hz, 72–90 Hz, ..., 232–250 Hz. Feature selection was then performed for both scalp EEG and eLFP analysis using a variant of the Relief method, which has been successfully applied to the selection of relevant features for a BCI [8]. We applied this method to select the 10 most relevant EEG electrodes out of 64 and the 100 most relevant voxels out of 4024 in the 3D reconstruction of the brain activity.

Each single sample (48 in each trial) was finally fed to a Gaussian classifier [4] for the recognition of the mental task executed by the subject. The output of this statistical classifier is an estimation of the posterior class probability distribution for a sample, i.e., the probabilities that the input vector belongs to one of the three classes.

For each subject, the 30 sessions were split into 6 groups of 5 consecutive sessions each. For each frequency band we performed the feature selection and trained a classifier using the 5 sessions of a group and we evaluated the performance of this classifier on the 5 sessions of the following group.



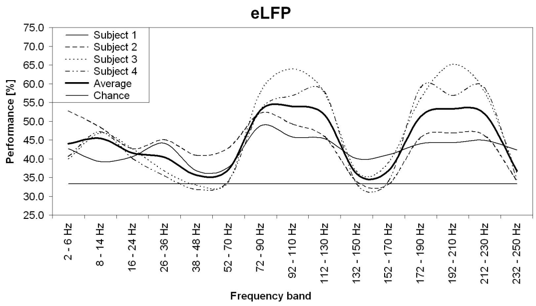


Figure 1: Average of the classification performances for the four subjects plus the average of them using EEG signals and estimated local field potentials for a 3-class BCI. In both cases we can see an increase in performances between 70 and 130 Hz as well as between 170 and 230 Hz compared to the traditionally used 2-40 Hz band. Furthermore, the use of eLFP leads to an increase of performances of ∼5%.

RESULTS

Figure 1 shows the average performance for the four subjects plus the average of them for each frequency band using scalp EEG (top) and eLFP (bottom). For both scalp EEG and eLFP, the best performances are reached for frequencies between 70 and 130 Hz and between 170 and 230 Hz. The peak average performance is 49.2% for the scalp EEG and 54.0% for the eLFP. The high frequency bands perform better than the traditional low frequencies (49.2% vs. 44.6% for scalp EEG and 54.0% vs. 45.5% for eLFP). Furthermore eLFP outperform scalp EEG for all discriminant frequency bands.

In the case of scalp EEG, the selected electrodes are outside the midline and cover also the anterio-frontal areas as expected. Regarding the selected voxels, there are 3 clear clusters in the sensorimotor cortex and the right anterior area.

DISCUSSION

The reported results suggest that high frequency bands carry information that is useful for the classification of mental tasks in a BCI context. Frequencies between 70 and 130 Hz and between 170 and 230 Hz outperformed the traditional 2-40 Hz band. Furthermore, the use of eLFP lead to an increase of performances of ∼ 5%. Performances are not very high for a 3-class BCI, but it should be noticed that we have tried to classify every single sample computed every 62.5 ms and that subjects had no prior BCI training and did not receive any feedback. The combination of several frequency bands could also lead to significantly higher performances. The next important step consists in the online verification of the reported improvements by integration of both high frequencies and eLFP into the BCI.

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