A Novel Approach to Auditory EEG-Based Spelling

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Abstract. We investigated whether listener assisted scanning, an alternative communication method for persons with severe motor and visual impairments but preserved cognitive skills, can be used for spelling with EEG. To that end spoken letters were presented sequentially, and the participants made selections by performing either motor execution/imagery or a cognitive task. The motor task was a brisk dorsiflexion of both feet, and the cognitive task was related to working memory and perception of the human voice. The initial results indicate that task related EEG changes could enable auditory spelling independent of any muscle activity or spatial cues, thus complementing existing auditory scanning protocols and spatial auditory paradigms for spelling applications.

Keywords: EEG, Listener assisted scanning, Motor Imagery, Beta rebound, Working memory

1. Introduction

In listener assisted scanning, messages or letter choices are presented to a person acoustically in a sequential fashion until a selection is made. The goal of this work is to investigate whether listener assisted scanning can be used for spelling with EEG. We hypothesize that, when spoken letters are presented sequentially, the participants can communicate the intended letter by performing either motor execution/imagery or a cognitive task. To test this hypothesis we evaluate brisk feet dorsiflexion execution/imagery [Pfurtscheller and Solis-Escalante, 2009; Müller-Putz et al., 2010] and a cognitive task related to working memory [Ruchkin et al., 1992; Klimesch et al., 2001] and perception of human voice [Xu et al., 2012].

2. Material and Methods

Five healthy people (3 male, 2 female, college aged) participated in this ongoing experiment. Participants gave informed consent prior to the beginning of the experiments and received monetary compensation afterwards.

The EEG was recorded with 29 active electrodes overlying the frontal, central, and parietal scalp areas. The EOG was recorded with three active electrodes, and the EMG from both legs. The EEG amplifiers were set up with a bandpass filter between 0.5 and 100 Hz, and a notch filter at 50 Hz. The EEG/EOG were sampled at 512 Hz, the EMG at 2000 Hz.

Spoken letters of the English alphabet, generated by a text-to-speech program, were presented sequentially (SOA 550 ms including 50 ms pause; 14.3 s for the whole alphabet) through a right headphone for one of several predefined words: “brain”,”power”, “husky” and “magic”. For each target letter, the alphabet was presented two to four times. The participants performed one of the following tasks in the copy spelling mode: brisk feet motor execution/imagery triggered by the target letter (ME/MI); discrimination of the target voice’s gender and comparison to the following repetition (i.e. whether the target voice’s gender has changed or it remained the same, reporting through single/double button press) as a cognitive task; mental repetition of the target letter as a control condition.

We balanced the order of motor and cognitive tasks, and voice of presentation. We randomized the order of words, and pseudorandomized the cognitive task and the control condition. Participants received no feedback. We analyzed the central beta rebound and movement-related cortical potential (MRCP) in the motor tasks, and late positive component (LPC), slow negative wave, as well as frontal theta band oscillations in the cognitive task.

For event-related potential (ERP) analysis we defined a single epoch as 1250 ms following onset of a spoken letter, baseline corrected to preceding 250 ms. The epochs were bandpass filtered between 1 and 12 Hz, downsampled by selecting each 16th sample, and the features were extracted from 9 preselected electrodes (F3, Fz, F4, C3, Cz, C4, P3, Pz, and P4). For each task we classified target epochs versus an equal number of randomly selected non-target epochs. To avoid overfitting we used Bayesian linear discriminant analysis (BLDA) as a classifier, and nested blockwise crossvalidation (leave-one-run-out outer fold, 10 x 5 inner fold, ten repetitions with resampled references). To estimate the influence of eye movement artifacts we applied the same procedure to features extracted from the three EOG electrodes.

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To analyze the percentage of power decrease (ERD) or power increase (ERS) relative to a reference interval (0.5 s preceding the stimulus onset), a time-frequency map for frequency bands between 4 and 40 Hz (35 overlapping bands using a band width of 2 Hz) was calculated. Logarithmic band power features, calculated by band-pass filtering, squaring and subsequently averaging over the trials, were used to assess changes in the frequency domain. To determine the statistical significance of the ERD/ERS values a *t*-percentile bootstrap algorithm with a significance level of $\alpha = 0.01$ was applied.

3. Results

The estimated average mean accuracy obtained on outer fold for different tasks is summarized in Table 1. Also summarized in Table 1 are the results of ERD/ERS analysis.

Table 1. *Results of ERP and ERDS analysis. For ERP analysis single trial accuracies (outer fold, mean from ten repetitions) are shown for different tasks. Applying the same ERP analysis procedure to features extracted from the three EOG electrodes only once resulted in significant (p = 0.01) accuracy (marked with an asterisk) . The ERDS analysis for ME and MI task was conducted on a single orthogonal Laplacian derivation centered at Cz electrode position, whereas analysis for COG task was conducted on a single bipolar derivation AFz-Fz.*

Subject	ERP_{ME} [%]	ERP_{MI} [%]	ERP_{COG} [%]	Central β ERS_{ME}	Central β ERS_{MI}	Frontal ϑ ERS
S1	83	59	44	-	-	$+_{p = 0.01}$
S2	75	57	66	$+_{p = 0.01}$	$+_{p = 0.05}$	-
S3	80	54	62	$+_{p = 0.01}$	$+_{p = 0.01}$	$+_{p = 0.01}$
S4	68	45	53	-	-	-
S5	48	61	62	$+_{p = 0.01}$	$+_{p = 0.01}$	$+_{p = 0.01}$
$\mu \pm \sigma$	71 ± 14	55 ± 6	57 ± 9			

4. Discussion

The initial results indicate that task related EEG changes could enable auditory spelling independent of any muscle activity or spatial cues, thus complementing existing auditory scanning protocols [Müller-Putz et al,. 2013] and spatial auditory paradigms for spelling applications[Höhne et al., 2011; Schreuder et al. 2011].

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