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# Towards an Auditory BCI for Binary Communication in the ICU

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***Introduction:*** Brain computer interfaces (BCI) provide means of communication for people with severe speech and motor disabilities. Visual paradigms are broadly employed for noninvasive EEG-based BCIs due to their high classification accuracies. However, they cannot be utilized for users with visual impairments. Auditory presentation techniques can be adopted as a viable alternative for this population [1-3]. We aim to develop a multisensory ERP-based BCI for binary selection to communicate in the intensive care unit (ICU). While designing a paradigm that is intuitive and comfortable for the user is important, physical constraints of the ICU setting must also be considered. Furthermore, we aim to design a paradigm that is applicable with both auditory and tactile stimulation. For the auditory stimulation based realization, we primarily focus on using words as the stimulus, since their meanings are intuitive and we expect them to be less irritating than tones, based on literature on auditory BCIs [1]. We report results for several pilot studies that makes the system suitable for binary communication in the ICU.

***Method:*** EEG signals were acquired using a g.USBamp amplifier. PCA was used for dimensionality reduction, regularized quadratic discriminant analysis (RDA) was employed for feature extraction and a MAP classifier was implemented for classification. We tested the following paradigms using words and tones, each with 100 sequences that contain 16 trials distributed according to:

a) **Random:** Each sequence contains 10 distractors (D) (e.g., *Wait*), 3 *Yes* (Y) and 3 *No* (N) stimuli randomly shuffled. An inter-symbol interval (ISI) of 300ms is used for words and 150ms for tones.
b) **Deterministic with fixed ISI:** Each sequence consists of [D Y D N D Y D N…] with an ISI as in (a).
c) **Deterministic with random ISI:** Each sequence is constructed as in (b) with random ISI chosen in the interval [300,450]ms for words and [150,250]ms for tones.
d) **Simultaneous with fixed ISI:** Two sequences play simultaneously, a *Yes* sequence [YYY..] into the right ear, and a *No* sequence [NNN...] into the left ear, with an ISI as in (a).
e) **Simultaneous with random ISI:** Simultaneous sequences as in (d) with random ISI as in (c).

***Results:*** The results for the different paradigms are summarized in Table 1. AUCs are calculated for 10-fold cross validation. The ERPs corresponding to the target, non-target, and distractor stimuli in paradigm (a) row-2 are shown in Fig. 1.

| Paradigm | Stimuli | AUC |
|---|---|---|
| (a) Random | Y(R), N(L), D(LR) | [0.74, 0.79] |
| | Y(R,M), N(L,F1), D (LR,F2) | [0.79, 0.82] |
| | Y (R,M), N (L,F1), 9 Ds (LR,F2) | [0.64, 0.70] |
| | Y(2kHz,R), N(1kHz,L), D(440Hz,LR) | [0.75 ,0.77] |
| (b) Det. fixed ISI | Y(R), N(L), D(LR) | [0.63, 0.67] |
| | Y(R,M), N(L,F1), D(LR,F2) | [0.76, 0.79] |
| | Y(2kHz,R), N(1kHz,L), D(440Hz,LR) | [0.63, 0.65] |
| (c) Det. rand. ISI | Y(R), N(L), D(LR) | [0.75, 0.76] |
| | Y(R,M), N(L,F1), D(LR,F2) | [0.75, 0.78] |
| | Y(2kHz,R), N(1kHz,L), D(440Hz,LR) | 0.72 |
| (d) Sim. fixed ISI | Y(R,M), N(L,F1) | [0.55, 0.58] |
| | Y(2kHz,R), N(1kHz,L) | 0.60 |
| (e) Sim. rand. ISI | Y(R,M), N(L,F1) | 0.59 |
| | Y(2kHz,R), N(1kHz,L) | 0.55 |

Table 1. Offline classification results in terms of area-under ROC curve (AUC) for different subjects. R/ L are right/left ears, M/F1/F2 are male/female1/female2 voices.

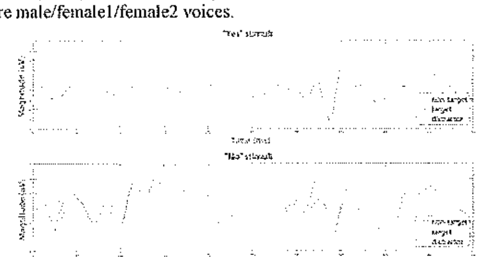

**Fig. 1.** Averaged EEG signals at Cz for the random paradigm with different voices (a) row-2.

***Discussion:*** The best results were achieved with the random paradigm. Playing each stimuli from a specific side (right ear for *yes* and left for *no*), helps the user focus on the target, ignoring the non-target and distractors. Using different voices has the same effect. Observing the ERPs for this paradigm, we can see more separability for the target and non-target stimuli. We also notice that the ERPs for the *yes* and *no* stimuli are different. Hence, our approach for online classification will use a joint classifier that fuses a *yes* classifier (trained only with *yes* stimuli) and a *no* classifier (trained only with *no* stimuli).

***Significance:*** This pilot analysis provides guidance for the development of binary communication BCIs for use in the ICU. A promising paradigm for auditory (and tactile) stimulation that satisfies ICU constraints and considers user experience is identified.

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