 DOI: 10.3217/978-3-85125-467-9-15

Robust, accurate spelling based on error-related potentials

R. Chavarriaga[#,*], I. Iturrate[#], J.d.R. Millán

Defitech Chair in Brain-Machine Interface, Ecole Polytechique Fédérale de Lausanne, Switzerland

[#]Equal contribution. *EPFL-CNBI, Campus Biotech H4 ,Ch de Mines 9, 1202, Geneva, Switzerland. E-mail: ricardo.chavarriaga@epfl.ch

Introduction: One of the principal goals of brain-machine interface systems is provide a communication channel to users with severe motor disabilities. Here, we describe a novel speller paradigm driven by the decoding error-related potentials (ErrP) [1] and the exploitation of shared-control (or context-aware) algorithms.

Methods and Results: The speller is composed of a character matrix, in which a moving cursor automatically scans the available characters (c.f., Fig. 1 *Left*). Contrasting to conventional systems, the cursor does not move in a pre-defined or a random manner. Instead it moves towards the most probable character as inferred based on the decoding of ErrP (c.f., Fig. 1 *Middle*) and a language model. During operation, users simply monitor the cursor movements, which makes discrete steps between adjacent characters in the matrix every 1000 ms. After each cursor movement, EEG is decoded to detect the presence of an ErrP indicating that the user considers the cursor did not move *towards* the intended character. Then, a reinforcement-learning (RL) algorithm re-estimates the probability of each character to be the next one to be written [2,3] based on the classifier output.

The use of a language model and RL to estimate the character's probabilities makes the system less sensitive to misclassification of the ErrP signal. Experimental tests in simulation showed that the system is able to correctly write the intended words even if there are up to 30% of classification errors. Furthermore, the parameters of the RL-based character inference can be tuned depending on the performance of the ErrP decoding (i.e. the RL learning rates can be higher for those users for whom the ErrP decoder is more accurate, and viceversa).

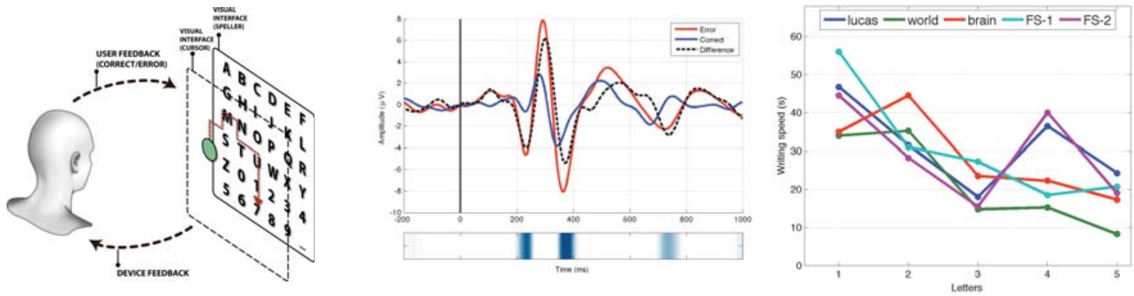

Figure 1. *Left: Diagram of the ErrP-based speller. Middle: ErrPs (FCz electrode) observed in this protocol. Right: Average number of seconds required to write each letter of a five-letter word in the online rund (FS-1,FS-2: Free-spelling runs)*

EEG was recorded using 16 active electrodes over fronto-central, central and parietal areas on healthy subjects (N=4). Signals were filtered in the [1-10] Hz range and decoded using linear-discriminant analysis (same methods as in [3]). Users first went through a calibration period composed of four copy-spelling runs (two five-letter words each), where cursor movements were erroneous 30% of the time. Then, users moved to an online operation phase where they performed 3 copy-spelling runs (words: 'lucas', 'world', 'brain') and two free-spelling runs. ErrPs elicited in this protocol were consistent with previous experiments (Fig. 1 *Middle*). Average decoding performance in the online runs was 0.74, which together with the shared control approach, led to selecting the correct letter 93% of the time for all subjects combined. On average, users took 43.2 s to write the first letter of each word, while this time decreased for subsequent letters (Fig. 1 *Right*). This is due to the use of the RL-algorithm and the language model, yielding an overall average of 28 s per letter (i.e. 2.13 chars/min).

Discussion: The proposed speller paradigm, combining a language model and RL algorithms into a shared-control scheme, allows for efficient typewriting even in case of misclassification of ErrPs. Since the user's task is to monitor the movements of the cursor, (s)he receives immediate feedback on the performance of the system (whether it moves towards the intended letter), as opposed to P300-based systems, where the decoded symbol is only presented after several scanning repetitions. Although evaluation in intended users is yet to be performed, it is worth noticing that ErrP signals have been already reported in subjects with locked-in syndrome [4].

Significance: We present a novel speller paradigm based on decoding error-related potentials. Combination of reinforcement learning and language models yields accurate, efficient typewriting.

Acknowledgements: This work was funded by the Swiss NCCR Robotics & Marie Curie EPFL Fellows programme.

References

[1] Chavarriaga R, et al. Errare machinale est: the use of error-related potentials in brain-machine interfaces. *Front Neurosci*, 2014, 8, 208
[2] Iturrate I, et al. Teaching brain-machine interfaces as an alternative paradigm to neuroprosthetics control. *Sci Rep*, 2015, 5, 13893
[3] Iturrate I, et al. Shared-control brain-computer interface for a 2D reaching task using EEG error-related potentials. *IEEE EMBC*, 2013
[4] Spüler M et al. Online use of error-related potentials in healthy users and people with severe motor impairment increases performance of a P300-BCI. *Clin Neurophysiol*, 2012, 123, 1328-1337