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Error-Related Potentials for EEG-based Typing Systems

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Introduction: RSVP Keyboard™ is a speller that employs rapid serial visual presentation (RSVP) and uses Bayesian MAP inference based on event related potentials (ERP) fused with language models (LMs) to detect user intent [1]. Here, we study the potential benefits of additionally fusing feedback related potentials, a form of error-related potentials (ErrP), in a Bayesian fashion. By appending a prospect symbol (e.g., the top candidate in the alphabet according to the current posterior) to some or all presentation sequences, we expect to induce an EEG response that may be indicative of that prospect's correctness. Existing BCIs that attempt to use ERP/ErrP jointly typically fall into one of these categories: a flag by the ErrP classifier results in (a) the deletion of the last selection made using the ERP classifier [2,4,5,6]; (b) replacing the last selection made using the ERP classifier with the second ranking option [2,3,7]; (c) presenting more stimuli to gather additional ERP evidence, but not use the ErrP to update symbol probabilities over the alphabet [3]. A language model is not fused with ERP evidence in these particular examples, but has been suggested for boosting both ERP and ErrP evidence assessment. Unlike these early attempts to use ErrP evidence, which tend to make hard decisions based on ErrP classifier outputs, we seek Bayesian fusion of ERP, ErrP, and language evidence using probabilistic generative models. The envisioned (and already implemented) system automatically decides to select a letter to type or proceed with more ERP/ErrP evidence collection in a probabilistic fashion. We present simulation based results that suggest this Bayesian fusion process may outperform existing alternatives in the literature. This framework is also applicable to the Matrix Speller [1].

Methods: EEG data to calibrate ERP/ErrP models are acquired using the RSVP Keyboard™ copy-phrase task. Assuming the ERP/ErrP features are not identically distributed, their distributions are calibrated separately (with a process similar to that in [1]). A 6-gram symbol language model (LM) is used for MAP inference with EEG/ErrP gathered from sequences presenting the 14 most probable symbols in the alphabet (of 28 symbols) according to the latest posterior distribution [1]. When the top candidate becomes *somewhat* probable, it is appended to the end of the sequence as a prospect. ERP/ErrP evidences are extracted from the 500ms windows following regular and prospect presentation trial onsets. A decision is made when the top candidate exceeds the required confidence threshold or the number of maximum allowed sequences is reached (time-out); these thresholds are set to 0.9 and 8, respectively. All parameters can be adjusted to optimize performance on an individual user basis (e.g. using simulations).

Results: Results of 25 Monte Carlo simulations of a copy-phrase task with 10 predetermined sentences for which the language model contribution ranges from friendly (correct letters are likely compared to competitors) to adversarial (competitors more likely) were performed as in previous work [1]. These preliminary results summarized in Table 1 demonstrate that, as expected, Bayesian fusion of all evidence (ErrP, ERP, LM) yields faster typing speeds in all participants (without compromising accuracy). The use of ErrP in a suboptimal fashion as has been done in the literature (by allowing ErrP decisions to override ERP) also improves speed relative to not using ErrP at all.

AUC for [ERP,ErrP]	ERP/LM fusion (No ErrP)	ErrP overrides ERP/LM fusion	Bayesian fusion of ErrP/ERP/LM
[0.845,0.865]	531s, *1.00*	454s, *1.00*	421s, *1.00*
[0.846,0.804]	546s, *1.00*	514s, *1.00*	461s, *1.00*
[0.840,0.786]	589s, *1.00*	530s, *1.00*	467s, *1.00*
[0.821,0.777]	542s, *0.99*	519s, *0.99*	497s, *1.00*
[0.775,0.813]	913s, *0.96*	838s, *0.97*	834s, *0.99*

Table 1. Monte Carlo simulation results (expected time to complete task in seconds, *probability of completion*) for five users, using synthetic EEG features from models calibrated with real ERP/ErrP EEG data. Calibration estimate of AUC for ERP/ErrP class-conditional density models (Column 1); average time and probability of completion for no ErrP case (Column 2), typical ErrP application in literature where single ErrP evidence can discard all ERP evidence for last symbol (Column 3; red), and proposed Bayesian fusion of all evidence (Column 4; green).

Significance: As literature suggests, using ErrP evidence may improve performance. However, preliminary results indicate that Bayesian fusion of ErrP with ERP, not treating the former as a de facto superior form of evidence, may yield better outcomes. We will present details and experiment results in a future paper.

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