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Towards user-centric BCI design: Markov chain-based user assessment for mental imagery EEG-BCIs

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Introduction: Widespread use of brain-computer interfaces (BCI) is limited by "BCI Inefficiency," a phenomenon where users struggle to produce brain signals that are machine discernible [1, 2]. One avenue to reducing BCI inefficiency to improve user training procedures to enhance user performance. However, current classification algorithm-based methods for user assessment during training yield limited descriptive information about user performance and are prone to misrepresenting user performance progression, thereby hindering training [3, 4, 5]. Here, we propose Markov chain-based methods for user assessment that identify and describe a user's neural modulation abilities.

Material, Methods and Results: First, we used unsupervised clustering methods to segment the electroencephalography (EEG) signal space into regions representing EEG patterns that users had demonstrated the ability to produce. In contrast to supervised classifier-based methods, this approach does not rely upon identifying EEG patterns within trials of a particular task label and, consequently, the user-specific number of pattern states can be independent of the number of mental imagery tasks employed. Second, we modeled users as Markov processes moving through these pattern states (Fig. 1). Using the entropy rate and steady-state distributions of Markov chains, two metrics were developed to assess user ability to (i) maintain consistent patterns during task performance and (ii) produce distinct patterns while performing different tasks. Analysis of motor imagery datasets revealed significant correlations between these metrics and classification accuracy, demonstrating their ability to broadly reflect user skill.

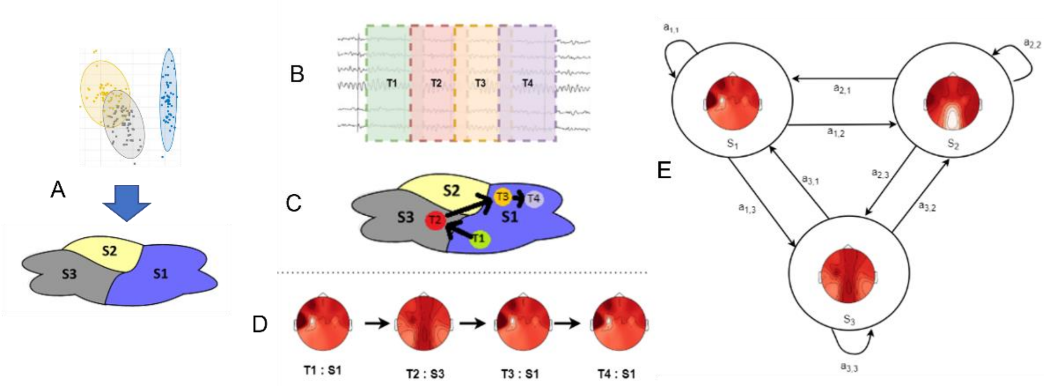

Figure 1. Outline of proposed method. (A) Apply clustering methods to define state space of distinct patterns users can produce, independent of task labels. (B) Segment trials into shorter temporal windows. (C) Observe the pattern state for each temporal window. (D) Represent trials as a stochastic sequence of pattern states. (E) Model transitions between pattern states as a Markov chain.

Discussion: The results indicate that BCI users' mental imagery skills can be estimated using a Markov state space without states or patterns explicitly defined as being associated with a particular task label.

Significance: The proposed metrics provide new avenues to develop (i) improved training schemes that target user weaknesses and enable more exploratory learning and (ii) BCI-design tools that enable the technology to be customized and optimized to leverage the strengths of each individual user.

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