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Towards Multimodal BCIs for Access: A Performance & Usability Comparison of Individual Modalities

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Introduction: Individuals with severe motor limitations rely on *access technologies* - tools that assist in translating intent into functional actions – to interact with the world around them. Existing access technologies, such as mechanical switches and eye-gaze devices are designed to harness residual voluntary motor control[1]. However, for many individuals, producing the coordinated movements required by these devices can be fatiguing, unreliable, or impossible[2]. Alternatively, bio-signals such as EOG, EMG, and EEG can register more subtle movements that are easier to produce[3]. Each of these modalities have been investigated independently as access methods, each with their own set of limitations that have restricted widespread adoption[3]. Combining multiple modalities into one hybrid brain- or human-computer interface may help overcome these limitations, yielding an access solution that is more accurate, reliable, and easier to use[4]. As a first step, we present a comparison of the performance and usability of each modality.

Methods: 15 neurotypical adults used eye movements (EOG), facial muscle activations (EMG), and imagined movements (motor imagery, MI/EEG) to complete a simple computer game. Participants were cued to use either their brain/eye/muscle activity to control a virtual character in one of four directions (up, down, right, or left). 400 trials, 100 per direction, were collected over 10 blocks for each modality. Online processing pipelines were implemented to provide real-time feedback and keep participants engaged. EEG data were recorded from 32 saline-based electrodes (RNet, Brain Products), and EOG/EMG data were recorded from 5 pairs of bipolar Ag/AgCl surface electrodes placed around the eyes and over the zygomaticus and frontalis muscles. All data were acquired using a wireless amplifier (LiveAmp, Brain Products). Participants also answered a series of questions on the usability of each modality.

Results: Classification accuracies for each participant and modality were calculated with 5-fold cross-validation using an 80/20 train-test split. Participants achieved similar accuracies using either EMG or EOG, at 82.0% and 82.4% respectively, although there was greater interparticipant variability with EOG control (std. of 18.3%, compared to 10.4% for EMG). MI/EEG was the least accurate modality, with participants achieving an average accuracy of 51.8±17.4%. EMG and EOG were perceived to be the easiest to control (avg. ranking of 7.7±1.9 and 7.5±2.0 on a 10-point Likert scale). EMG was most consistently ranked as the preferred modality (8/15 participants). EMG and EOG were both significantly more physically demanding than MI (p=0.01), while MI was significantly more cognitively demanding (p=0.01). Participants cited fatigue and discomfort as the main limitations of EMG and EOG, and low accuracy as the main limitation of MI. EMG, EOG and MI data were also pooled together for each participant and used to evaluate a simple hybrid classification scheme (ensemble of modality-specific classifiers with majority voting), resulting in a superior average classification accuracy of 85.7±8.4%.

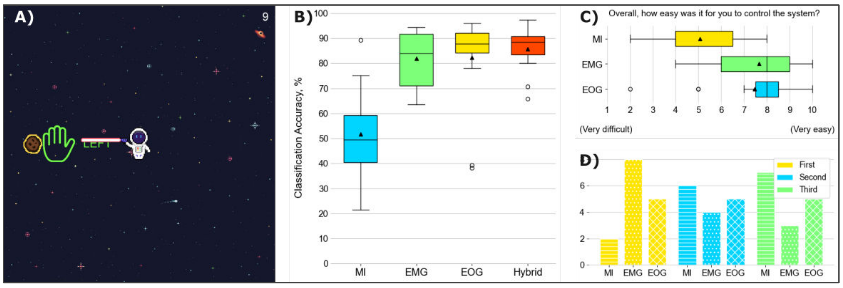

Figure 1: A) User interface of the computer game task; B) Cross-validated classification accuracy scores for each modality; C) Overall ease-of-use rankings for each modality; D) Preference rankings of each modality.

Discussion: Both EMG and EOG offer superior levels of control over MI. The practice of motor imagery is somewhat of a nebulous skill for many users, generally requiring extensive training to obtain proficiency (if it can be reached at all). However, EMG and EOG involve a significantly greater physical demand, and further, require precise timing of these physical movements, which can be considerably difficult for an individual with severe motor impairments. Combining information from each modality will likely improve overall performance and usability - even with a very simple hybrid classification scheme, we already see an increase in accuracy. Next steps for this work will include using the collected dataset of MI, EMG, and EOG samples to design and evaluate a more sophisticated multimodal fusion algorithm for self-paced control in a hybrid human-computer interface system, as well as engaging with potential end-users to gather insights on the opportunities and challenges of such a system.

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