ABSTRACT BOOK

TU Graz

11th International BCI Meeting

Building Momentum: Fostering Collaboration in BCI

June 2-5, 2025

Banff, Canada

BCI SOCIETY

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11th International BCI Meeting

Building Momentum: Fostering Collaboration in BCI

Dear colleagues and participants,

We were thrilled to present to you the Proceedings of the 11th International Brain-Computer Interface (BCI) Meeting in Banff, Canada! As the flagship event of the International BCI Society, this gathering brings together experts from the field to share groundbreaking research, engage in insightful dialogues, and build lasting relationships. Our goal is to inspire and connect you with the latest advancements and opportunities in BCI technology, ensuring we **keep up the momentum and foster collaboration to shape the future of BCIs**.

The International BCI Meeting features dynamic workshops, inspiring posters, and thought-provoking presentations. Special events support growth and collaboration for all expertise levels. Covering foundational, translational, and clinical BCI research, the event drives progress with unmatched energy and enthusiasm. The abstracts collected in these Proceedings highlight the diversity of applications, user needs, and scientific and technological advancements in the field, as presented in the 11th edition.

Conducting research with and for end-users is crucial for developing impactful solutions. Co-development and foundational research must work hand in hand to address challenging research questions and reliably capture and translate brain signals into actionable outcomes. Our distinguished keynote speakers embody this approach. The invaluable experiences and profound insights of Melanie Fried-Oken from Oregon Health & Science University, Juan Gallego from Imperial College London, and Karunesh Ganguly from the University of California, San Francisco, inspire us all to push the boundaries of BCI technology.

In addition to our keynote speakers, we like to take a moment to extend our heartfelt gratitude to everyone involved in making the meeting a success. To our helpers, thank you for your unwavering support. To our reviewers, your insightful feedback greatly enhanced our work. And to everyone involved, your collective efforts truly made a difference.

On behalf of the BCI Society and the Program Committee, we extend our sincere thanks for your interest in the BCI Meeting. We look forward to connecting with you at future instalments of the BCI Meeting Series. Your participation is what makes these gatherings truly special, and we can't wait to see the incredible collaborations and research ideas that will emerge.

Reinhold Scherer
University of Essex, UK
Scientific Program Committee Chair

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Development of a Novel Clinical Outcome Assessment: The Digital Instrumental Activities of Daily Living Scale

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Introduction: With the proliferation of digital technology, previously non-digital activities have come to be performed digitally and new inherently digital activities have become essential to daily life [1]. Digital exclusion is now associated with higher functional dependence [2], and people with motor disabilities are at the highest risk of digital exclusion. People with motor impairments report significantly higher satisfaction and quality of life when they are able to use digital devices to support daily functioning compared to those who don't [3], and continuous access to a digital environment should be considered a basic human right for those with severe disability [4]. However, assessment tools that can accommodate digital performance of instrumental activities of daily living (IADLs) for those living with severe quadriplegia are lacking. This gap was emphasized during the joint FDA and NIH workshop on implantable brain-computer interface clinical outcome assessments held in September 2024. To address this need in-part, our aim was to develop a novel Digital IADL Scale for research and clinical practice.

Materials, Methods and Results: This study comprised a multi-stage methodology, aligned with FDA guidance for the development of clinical outcome assessments. The methodology included: (i) deductive item generation (systematic review), (ii) inductive item generation (survey and interview of people with lived experience), (iii) item refinement and rating (key opinion leaders and people with lived experience), and (iv) focus group discussions (by key opinion leaders and people with lived experience).

71 validated IADL scales were retrieved. 935 items were extracted from the scales identified during database searching, and 315 items were added from grey literature (total n=1250 items). Of these items, 224 were excluded on the basis of being purely cognitive and 260 were BADLs and removed. A further 414 items were removed as they were deemed unable to be performed digitally in their entirety. Remaining items were deduplicated, reducing the number of items to 77. The remaining 77 items were presented in the Delphi process and reduced to 42 items during two survey rounds. People with lived experience inductively generated 152 items, which were reduced to 41 through a deduplication process. 83 items (42 deductive, 41 inductive) were evaluated by experts for representativeness within their domain and eight items were removed. In response to focus group feedback, the list was reduced to 37 items.

Conclusion: The aim of this study was to develop a set of domains, items and accompanying scoring scale that would address an important gap in the clinical assessment of functional independence in a world that can be empowered by digital technologies. This process created an initial draft of a scale to assess digital functional independence, which will be submitted to further validation.

Acknowledgements & Disclosures: We acknowledge the contributions from Maria Nardozzi, OTD, OTR/L, who provided clinical insights. We acknowledge contributions from Professor Todd Little, who reviewed and provided input on our methodology. We acknowledge the assistance of medical librarian Gloria Wilson from Mount Sinai. Support for this project was provided in kind by the Abilities Research Centre. No formal funding was received.

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An EEG Artifact Removal Neural Network for BCI Applications with EEG-ViTNet

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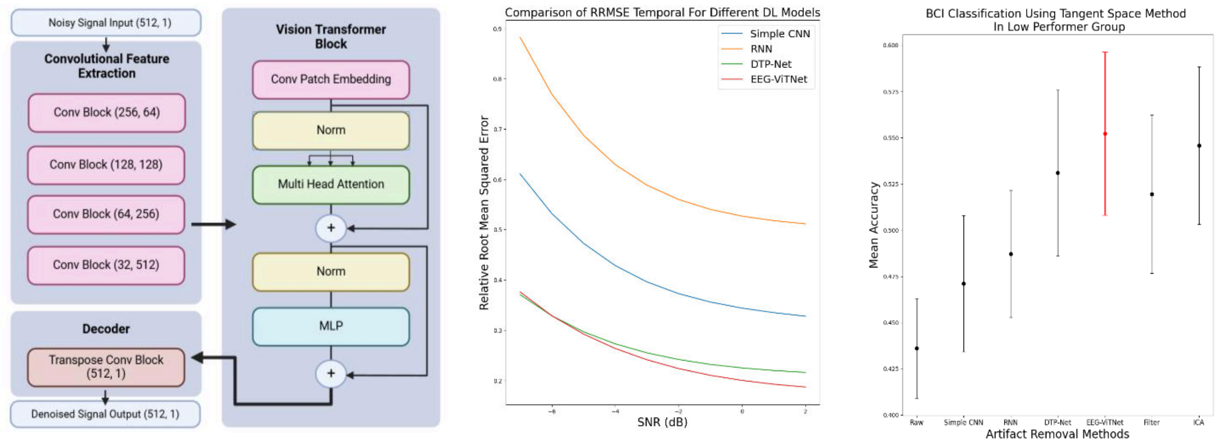
Introduction: Brain-computer interfaces (BCIs) are systems that translate brain activity into commands to control external devices, replacing motor pathways in individuals with disabilities. However, artifacts from eye movements (EOG) [1] and muscle activations (EMG) [2] often contaminate neural signals (EEG) and obfuscate meaningful physiological information. Effectively removing these artifacts from EEG with minimal distortion can enhance signal quality and improve downstream BCI tasks [3]. Traditional blind source separation methods, such as independent component analysis (ICA), are limited in their ability to efficiently denoise EEG in real-time. In contrast, deep learning (DL) techniques, which have shown success in computer vision and medical image segmentation, offer a promising approach for EEG artifact removal, potentially leading to more effective denoising and thus more accurate BCI control.

Methods & Results: An open-access dataset (*EEGDenoiseNet)* was used to train and test the DL models [4]. The dataset consists of 4514 EEG, 3400 EOG, and 5998 EMG segments. Clean and contaminated segments were linearly combined at varying SNR levels (-7 to 2dB) to generate semi-synthetic data, which was then split into training (80%), validation (10%), and testing set (10%). A novel 1D vision transformer-based model (EEG-ViTNet) was proposed and compared with existing state-of-the-art models from literature using metrics such as relative root mean squared error (RRMSE) and correlation coefficient (CC) (Fig A). A second open-access dataset (*PhysioNet EEG Motor Imagery Dataset)* was used to validate the DL models on a real-world BCI task [5]. Data from 80 participants were selected to assess accuracy of a 2-class motor imagery task (hands and feet) using the Riemannian tangent space method and a logistic regression classifier [6]. The novel EEG-ViTNet was used to pre-process the motor imagery data in the classification pipeline, and resulting accuracies were benchmarked against traditional methods, including bandpass filtering, ICA, and other DL models. The novel model achieved a RRMSE of 0.252 (temporal) and 0.272 (spectral), and a CC of 0.955, outperforming the current state-of-the-art model (0.266/0.309/0.950) (Fig B). Furthermore, it achieved the highest classification accuracy (55.2±4.3%) on the validation motor imagery dataset, boosting accuracy for the lowest performers and surpassing the raw baseline (43.6±4.3%), bandpass filter (51.9±4.3%), and other DL models (53.1±4.5%), while displaying comparable performance with the state-of-the-art ICA (54.6±4.3%) (Fig C).



(A) EEG-ViTNet Architecture (B) DL Model Error Comparison (C) BCI Task Accuracy

Discussion & Significance: The preliminary results show strong potential of EEG-ViTNet for artifact removal in BCI tasks. However, the substantial interparticipant performance variability in the motor imagery task suggests the need for larger sample validation. Future work will explore additional BCI tasks (i.e., P300 event-related potential) and consider challenges like single-channel limitations, reliance on semi-synthetic data, and individual EEG variability. Overall, the EEG-ViTNet could be a promising pre-processing step to improve BCI control for people with disabilities.

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Deep learning-based electroencephalic decoding of coherence and direction of the random dot kinematogram

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Introduction: EEG-based mind-reading under covert attention shifts is an essential research topic in brain-machine interfaces (BMI) [1]. Specifically, identifying electrophysiological signatures underlying motion direction perception of moving stimuli with varying motion coherence is crucial for understanding human attentional mechanisms and coherent motion processing [2]. Despite its significance, few studies have explored this area, highlighting the need for further research [3]. This study aimed to determine whether coherence levels and motion direction could be decoded above chance levels using the random dot kinematogram (RDK) task and EEGNet, a deep learning model [4].

Material, Methods and Results: Participants performed a behavioral task that required identifying the direction of coherently moving dots among randomly moving ones under three coherence levels (25%, 50%, and 75%) and two directions (left and right). EEG data were recorded from 25 participants (mean age: 23.8, 16 female) using 63 channels. Ocular artifacts were removed using independent component analysis (ICA), and EEG data were segmented from stimulus onset to 1-second post-stimulus. Artifact-contaminated trials were excluded from further analyses. Data were split 4:1 for training and testing, with 5-fold cross-validation to optimize model parameters. Trained over 500 iterations in a cross-participant setting, the EEGNet model classified coherence (3 classes), direction (2 classes), and combined conditions (6 classes). It achieved accuracies of 0.61 for coherence decoding, 0.77 for direction decoding, and 0.41 for combined classification—all above chance levels (Figure 1A). Additionally, the model achieved AUC values of 0.77, 0.84, and 0.69, respectively (Figure 1B).

Conclusion: This study demonstrated the feasibility of decoding coherent and directed motion perception using EEG signals. The findings highlight the potential of deep learning-based EEG decoding approaches to advance our understanding of human motion integration. However, despite these promising results, the model's performance is currently insufficient for practical applications. Future research will focus on improving decoding accuracy and analyzing decoded EEG components to gain deeper insights into the underlying neural mechanisms.

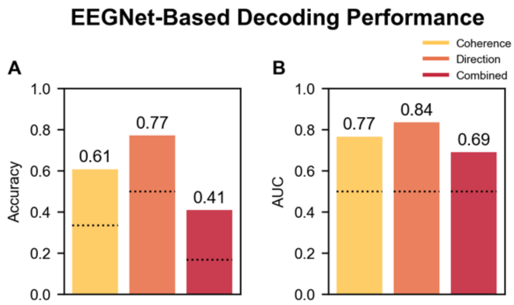

Figure 1: *(A) Accuracies and (B) AUCs of EEGNet-based decoding performance for coherence, direction, and combined classification. The dotted lines indicate the chance level of decoding performance.*

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Evaluation of a P300 BCI for augmentative and alternative communication in children with disabilities

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Introduction: P300 brain-computer interfaces (BCIs) have been previously investigated as an access method for augmentative and alternative communication (AAC) applications. However, the efficacy of P300-BCI-AAC for functional communication in children with severe physical disabilities remains underexplored [1]. In pursuit of practical communication, the present study aims to evaluate event-related potential (ERP) characteristics and user experience in children with motor impairments during a P300 task for functional communication.

Methods and Results: A 16-year-old non-verbal male participant (GMFCS Level III) was recruited for 5 sessions. The participant was instructed to attend to a target button in a personalized 2x2 grid created with the Tobii Dynavox AAC application. In each trial, buttons were flashed in a random order with an inter-stimulus interval of 450 ms until the cumulative probability of any button exceeded a dynamic threshold. Upon successful selection of the target button, a YouTube video was played as a reward for the participant. During each session, EEG were acquired using a 32-channel BrainVision Liveamp with the R-Net system (Brain Products GmbH). Eye gaze data were recorded simultaneously to track visual attention and reject trials where participants did not attend to the target stimuli. EEG signals were bandpass filtered between 1 and 40 Hz, and epochs were extracted from -200 ms and 800 ms around the onset of the visual stimuli. During online trials, Xdawn covariances from single-trial ERPs were classified with a Riemannian geometry classifier using the Mindset BCI system [2]. Figures 1a and 1b show the averaged ERP response for the target stimuli and the eye gaze heat map, respectively, during online trials across all sessions. Table 1 presents BCI performance metrics such as the target button cumulative probability, selection accuracy and information transfer rate (ITR), as well as eye gaze metrics, including the dwell time, continuous dwell time, and trial duration for each session and for all sessions combined. Chance levels for different number of trials were estimated based on simulation results over 10000 iterations with a confidence interval of α = 5% [3].

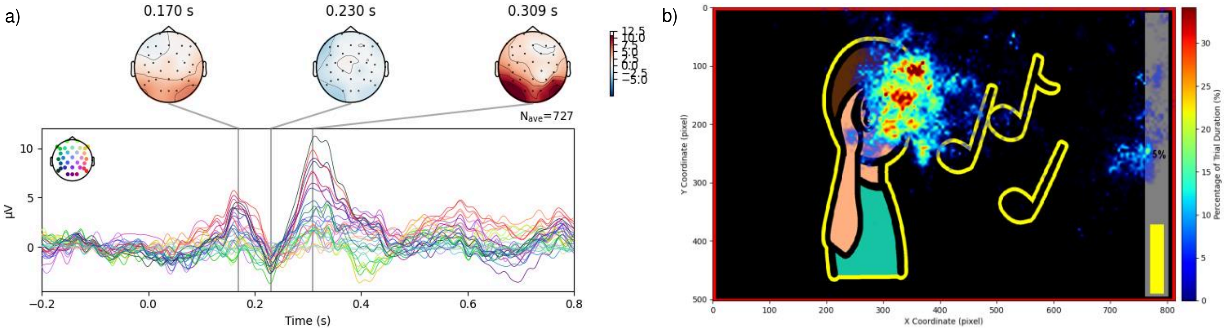

Figure 1: a) Averaged event-related potential during target stimuli across all online sessions; and b) heat map of eye gaze coordinates during online trials plotted over the target button in the 2x2 communication grid presented on the monitor

Table 1: Brain-computer interface and eye gaze performance metrics for online trials

Session	Num. of trials	Stimuli per trial (avg. ± std.)	Target Button Cumulative Probability (%) (avg. ± std.)	Chance Level (%)	BCI Accuracy (%)	BCI ITR (bits/min)	Dwell Time (s) (avg. ± std.)	Continuous Dwell Time (s) (avg. ± std.)	Trial Duration (s) (avg. ± std.)
1	48	18.06 ± 13.58	90.31 ± 4.38	37.50	50.00	1.54	7.51 ± 5.62	6.09 ± 4.87	8.07 ± 6.11
2	52	11.17 ± 10.08	90.81 ± 4.76	36.54	55.77	3.71	4.68 ± 4.52	4.24 ± 4.12	4.99 ± 4.60
3	48	9.96 ± 4.73	91.92 ± 4.08	37.50	75.00	10.79	4.20 ± 2.11	3.72 ± 2.02	4.41 ± 2.13
4	43	18.33 ± 12.37	90.42 ± 4.78	39.53	55.81	2.27	7.12 ± 5.30	6.16 ± 4.85	8.19 ± 5.59
5	57	15.25 ± 10.05	89.39 ± 3.96	36.84	50.88	1.94	6.27 ± 4.07	4.45 ± 2.46	6.87 ± 4.55
All	248	14.45 ± 10.99	90.53 ± 4.43	30.65	57.26	3.14	5.92 ± 4.61	4.88 ± 3.89	6.46 ± 4.97

Note: BCI = brain-computer interface, ITR = information transfer rate

Discussion and Significance: The P300 component was distinctly observed in the ERP plot as a positive peak in posterior channels up to 10 μV in amplitude approximately 300 ms after stimulus onset. A weaker but noticeable P200 component was also observed, potentially indicating some aspect of high-order perceptual processing and attention modulation. These ERP components may have supported online selection with the BCI system. The eye gaze heat map and dwell duration metrics confirm visual attention towards the target button, which likely facilitated elicitation of the visual P300. Although BCI performance varied across sessions, BCI accuracy and ITR reached 75% and 10.71 bits/min respectively in the best performing session. Further investigation into the factors contributing to variability in BCI performances is warranted. Potential factors such as user fatigue as well as cognitive and visual attention levels should be systematically examined to understand their impact. Future research will also include a larger and more diverse participant sample to ensure findings are generalizable to children with other disability profiles. Additionally, further optimization of the BCI system, such as fine-tuning the stimuli and signal processing parameters, will be explored to further enhance BCI performance. This study provides preliminary evidence supporting the feasibility of P300-based BCI access for AAC in children with disabilities. The findings pave the way for refining BCI-AAC systems and broadening their use in functional communication applications.

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A Speech Neuroprosthesis for Decoding High Frequency Activity in Anterior Cingulate and Orbitofrontal Cortices and Hippocampus for Phonemes Articulation

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Introduction: Speech is a main form of communication for humans. Its loss due to injury or disease is terrible. Here, we report a novel speech neuroprosthesis that artificially articulates building blocks of speech based on the high frequency activity, that includes single neuron activity, in the anterior cingulate and orbitofrontal cortices, and hippocampus. These brain areas were never harnessed for a neuroprosthesis before. However, our earlier studies found neuronal populations in these [1] and other [2-5] brain areas that encode these building blocks and demonstrated high accuracy decoding.

Material, Methods and Results: A 37-year-old neurosurgical epilepsy patient with intact speech, was implanted with depth electrodes solely for clinical reasons. He gained control over the neuroprosthesis almost immediately and silently produced two vowel sounds voluntarily [6]. During the first set of trials, the participant made the neuroprosthesis produce the different vowel sounds artificially with 85% accuracy. Performance improved consistently as more trials were conducted. This may be attributed to neuroplasticity, as the decoder remained the same along the experiment. The decoder was trained on overt speech data, but was utilized for silent control over the closed-loop speech neuroprosthesis.

Conclusion: The ability of a neuroprosthesis trained on overt speech data to be controlled silently may open the way for a novel strategy of neuroprosthesis implantation. In ALS patients, for example, the neuroprosthesis may be implanted at early stages of the disease, while speech is still intact, for improved training of the decoder, and be utilized at later stages for silent control. The results demonstrate clinical feasibility of direct decoding of high frequency activity, including spiking activity, in the aforementioned areas for silent production of phonemes that may serve as a part of a neuroprosthesis for replacing lost speech control pathways.

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Ambiguous Text Input for Brain-Computer Interfaces

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Introduction: One of the main driving forces of current BCI research is robust and consistent results with a high information transfer rate (ITR). Code-modulated Visual Evoked Potentials (c-VEP) have been shown to provide high ITR in target-related applications [1]. Our research aims to explore the effect of using an ambiguous text entry method [2] on our system's accuracy and ITR, and its overall efficacy as a communication BCI. We design a system that allows users to input text by selecting a sequence of ambiguous character groups instead of requiring individual character selections.

Material, Methods and Results: Our user interface consists of eight target boxes (Figure 1). Boxes 1–4 in the top row contain ambiguous groups of letters, while boxes 5–8 in the bottom row contain a mode switch, two word suggestions, and backspace. To enter text, a user selects the target box for each letter in their desired word. For example, to type "WORLD", the user would select boxes in the sequence 43321. After each selection, the word suggestion boxes are updated with the most likely words that match the selected group sequence. Users can select their intended word if it appears, or select mode switch to choose specific letters if the system is not able to predict their word. This would replace the existing ambiguous targets with the individual letters from each selected group in turn.

During selection, each target box is replaced by a checkerboard pattern that flickers in a pseudo-random sequence specific to that target. We place electrodes at O1, Oz, and O2 (by the international 10-20 system) to detect the c-VEP produced in response to the attended stimulus. We amplify the EEG signals using the OpenBCI Cyton Board and transmit them to Lab Streaming Layer (LSL) software on a desktop computer. Using Canonical Correlation Analysis (CCA) [3], we compare the recorded signals with the templates produced for each target sequence during calibration to discern the user's target.

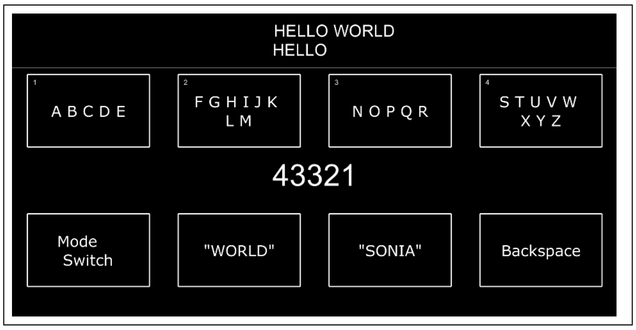

Figure 1: *The user interface for our system. The target and currently typed text are displayed at the top. The selected character groups in the current word are shown in the middle of the screen, surrounded by the eight target boxes.*

To determine the most likely matching words, we leverage a large language model domain-adapted on conversational text [4]. Given the text the user has typed so far, we use the model to evaluate the likelihood of all text that matches the selected letter groups. The two most likely predictions are displayed to the user in boxes 6 and 7. In future work, we seek to extend this algorithm to enable the model to predict words that start with the entered group sequence, allowing it to finish the user's word.

Conclusion: We have designed a preliminary system for ambiguous text input using a c-VEP brain-computer interface. We will validate the efficacy of our system with quantitative data and qualitative feedback from BCI users in the next phase of this project.

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Subject-Transfer Approach based on Convolutional Neural Networks for Classifying Gait-related Motor Imagery

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Introduction: Recently, electroencephalography (EEG)-based brain-computer interfaces (BCIs) for controlling a lower-limb robotic exoskeleton have been developed in several research groups [?]. In particular, gait-related motor imagery-based BCIs have been developed to assist gait in individuals with Spinal Cord Injury. However, the accuracy of classifying gait-related motor imagery needs to be improved to ensure safety. Therefore, we applied the subject-transfer approach, as an advanced algorithm, and compared the performance with the previous algorithm.

Material, Methods and Results: In this study, publicly available gait-related data [?] which is from a total of nine healthy subjects was used to investigate the performance of a subject-transfer approach. The subjects performed gait-related motor imagery while wearing the lower-limb robotic exoskeleton (resting task for 15 sec, and motor imagery task for 24 sec according to voice commands). The subjects repeated the tasks 16 times and the EEG signal was acquired on the 27 electrodes based on the International 10-10 system.
Principal component analysis (PCA)-based spectral feature was firstly extracted and reshaped into a 5×5 matrix for input to the convolutional neural network [?]. The simple CNN classifier was designed (see Fig. 1A) and trained using other subjects' whole data. Then, the trained CNN was fine-tuned using the target subject's training data (see Fig. 1B).
As the results of the cross-validation, the subject-transfer approach showed 87.1±6.4% on average, approximately 6% higher performance than the previous algorithm which consists of the common spatial pattern filtering and linear discriminant analysis classifier [?].

Conclusion: Based on our results, we can confirm that the subject-transfer approach can improve the accuracy of classifying the gait-related motor imagery. As further research, we plan to verify its efficiency via a real-time control experiment of a lower-limb robotic exoskeleton.

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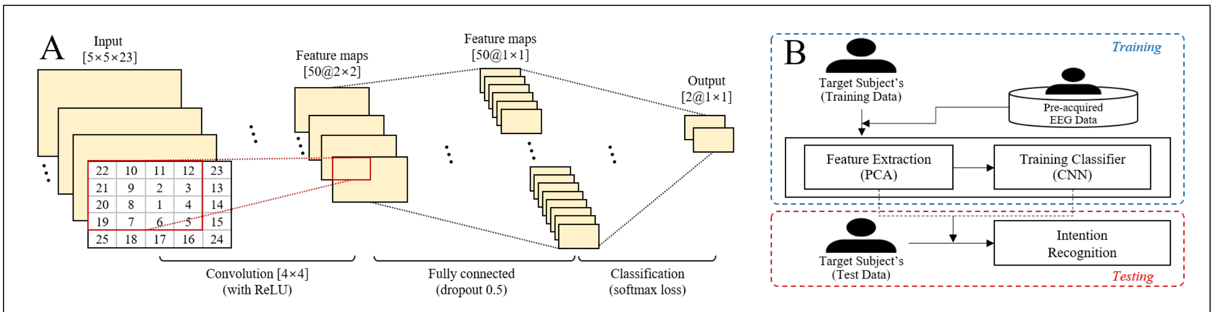

Figure 1: Gait-related motor imagery-based EEG signal processing. (A) CNN structure and (B) Subject-transfer approach

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A Novel Rhythmic Motor Imagery BCI with High Efficiency

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Introduction: Conventional motor imagery (MI) tasks are often abstract, and the current decoding performance of MI-BCIs remains suboptimal. In our previous work, we demonstrated that both rhythmic movements [1] and rhythmic MI [2] can elicit brain activity at the task rhythm and its first harmonic. This novel electrophysiologic feature, which we summarized as steady-state movement-related rhythms (SSMRR), has been shown to facilitate higher decoding accuracy compared to conventional sensorimotor rhythm (SMR)-based decoding. Here, we aim to provide a preliminary validation that this more concrete rhythmic MI paradigm, with the SSMRR feature, can serve as a foundation for developing an efficient online BCI system even for naïve users.

Materials and Methods: Thirty BCI-naïve subjects participated in the experiment (average age 22.03± 3.40 years, all right-handed, 15 female). Four kinds of rhythmic MI tasks (1.0Hz-Lefhand, 1.2Hz-Righthand, 1.4Hz-Lefthand, 1.6Hz-Righthand) were arranged in a block-randomized manner. As shown in figure 1(A), the subjects were instructed to perform rhythmic MI in sync with the video (as if they were controlling the hand in the video). Notably, we informed the subjects that they could associate themselves with the hand on the screen instead of explicitly imagining a hand in their mind, thereby reducing the cognitive load. The experiment consisted of three sessions, each comprising three runs with 40 trials per run. The offline session 1 followed the same design as in our previous work [2]. Session 2 and 3 were designed as online target-selection tasks. Task-discriminant component analysis (TDCA) [3] was employed for online decoding. The data from session 1 was used for initial TDCA training, and after each subsequent run, new data was integrated into the training process. Details of the offline electrophysiologic analysis followed the same methodology as in our previous work [2].

Results and Discussions: As shown in figure 1(B), temporal and spectral-spatial patterns during the task can be clearly observed. By the end of the experiment, 30 BCI-naïve users achieved an average online accuracy of 79.33%±12.85% in the 4-class classification task (figure 1(C)). At the beginning of session 2, the accuracy was relatively low, primarily due to differences in paradigms between sessions. As new training data was accumulated in subsequent runs, the accuracy gradually improved.

Significance: Based on the rhythmic MI paradigm and the SSMRR feature, we achieved nearly 80% accuracy in four-class online motor decoding among 30 BCI-naïve subjects. This novel BCI holds great promise as a new approach for device control and motor rehabilitation.

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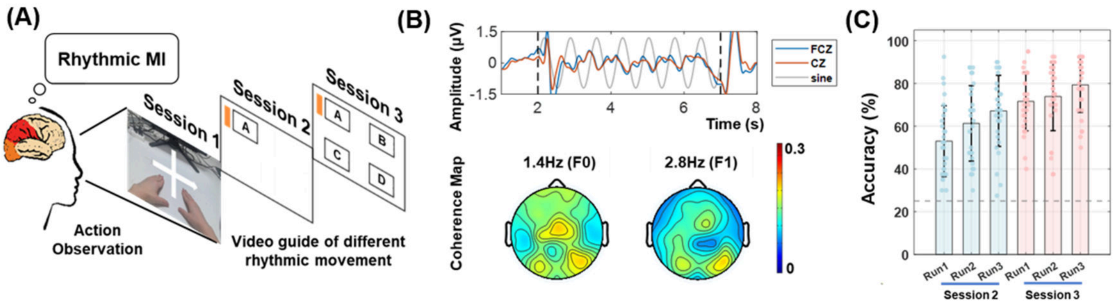

Figure 1. **(A)** *The experimental paradigm. A/B/C/D represent video guides of four different rhythmic movements.* ***(B)*** *The group-level time-series of two selected channels and whole-brain coherence topology of the 1.4Hz-Lefthand MI task in session 3. The black vertical dashed lines in the upper figure indicate the begin and the end of the rhythmic MI. The sine wave at the task-related rhythm (the grey curve) was given as a reference.* ***(C)*** *The 4-class online decoding accuracies. The circular markers represent individual subjects, while the error bars indicate the standard deviation. The grey horizontal dashed line indicates the theoretical chance level (25%).*

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Neural encoding and decoding of multidimensional handwriting movement

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Introduction: The handwriting-based brain-computer interfaces (BCIs) have showed remarkable performance in brain-to-text communication [1], but the capacity to decode intricate handwriting movements, such as trajectories, from brain signals is an area that remains largely unexplored. A significant challenge is the limited understanding of how the brain encodes the nuances of fine handwriting movements.

Material, Methods and Results: We recorded intracortical neural signals from a paralyzed patient during imaginary handwriting of complex Chinese characters (Fig.1A), from which we reconstructed the trajectories of the handwriting and delved into the neural encoding properties. We introduced an innovated decoding framework that accommodates both shape and temporal distortions between movement and neural activity, and reconstructed closely resembled and human-recognizable handwriting trajectories (average CC >0.75, Fig.1B). Utilizing a dynamic time warping approach, we achieved a recognition rate of up to 91.1% within a 1000-character database (Fig. 1C) [2]. Upon examining the neural encoding properties of handwriting, we discovered that the tuning properties of individual strokes aligned with classical motor directional tuning theories [3]. However, the neural encoding of cohesions—air connections between strokes—differed significantly from that of the strokes themselves. Given that the kinematics of handwriting were not available from our paralyzed subject, we recorded multidimensional handwriting movements from healthy subjects to serve as a template, which encompassed 3D velocity of the pen tip, pen grip strength, pen tip pressure on paper, and 8-channel electromyography (EMG) on the forearm (Fig. 1D). Using a neural encoding model, we found that these additional variables accounted for more variance in the neural signals, suggesting that the brain encodes handwriting in multiple dimensions rather than just 2D. When these additional dimensions were decoded and incorporated for handwriting trajectory recognition, the decoding performance could be significantly improved.

Conclusion: We demonstrated a new decoding scheme for BCIs that could accurately reconstruct the imaginary handwriting trajectory, which paves the way for a universal brain-to-text communication system that is translational to any written language. Moreover, our results indicated that the brain encodes handwriting as multidimensional movements, and by leveraging this, we can further enhance the decoding performance for handwriting-based BCIs.

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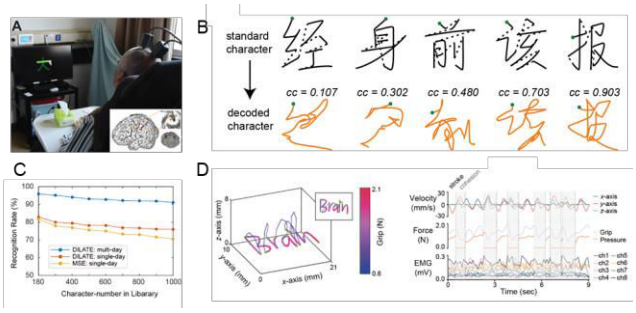

Figure 1: *A, Experimental setup. B, Example decoding trajectories for 5 Chinese characters. C, Recognition rate as a function of character number in the library. D, Multidimensional kinematic and kinetic traces for handwriting of the English word 'Brain'.*

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Quantifying the spatial stability of sensory stimulation projected fields for neuroprostheses

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Introduction: Cutting edge research done in the field of neuroprostheses has demonstrated that electrical stimulation elicits somatosensory percepts in the phantom or paralyzed limbs of individuals with amputations or spinal cord injuries. As the goal is to provide long-term sensory feedback, stability of the percepts has become a key objective for translation to the clinic and users' home. Nevertheless, only a few studies have quantitatively characterized the projected fields (PFs), the locations of perceived sensations elicited by stimulation, and their spatial stability [1–3]. Investigating PF spatial stability over time will confirm that the stimulation design properly serves long-term goals, thus advancing translation for independent use. Here, we present a quantitative framework that determines the spatial stability of PFs and can generalize to PFs collected from different electrical stimulation paradigms.

Material, Methods and Results: We design a graph-based average hand model to represent the recorded PF data. Each node represents a PF element, while each edge represents the average 2-point discrimination threshold at the corresponding region of the human hand. To quantify spatial stability, we combine the frequency of activation of each PF element and its co-occurrence with other PF elements. This characterization reveals percept regions that were consistently elicited together. We use the model to represent PFs obtained from two different electrical stimulation paradigms. The first used non-invasive transcutaneous electrical nerve stimulation (TENS) [2]. Surface electrodes were placed on the residual limb of an individual with upper limb amputation to activate their underlying nerves. The second applied intracortical microstimulation (ICMS) to the primary somatosensory cortex of an individual with spinal cord injury [4]. There were 96 electrodes (3 microelectrode arrays, 32 electrodes each) across the left and right somatosensory cortices.

We find that for PFs that were not frequently elicited, the framework properly distinguished between when PFs co-occurred with other PFs versus when they did not. While co-occurrence values vary for different PFs and electrodes, we use statistical null models to identify PFs that show statistically significant levels of co-occurrence with other PFs. Furthermore, we investigate the spatial stability of functionally relevant PFs, hand contact areas involved in exploration and manipulation tasks. We demonstrate that our method can identify stimulating electrode(s) that elicit percepts in specific regions, such as the fingertips.

Discussion and Significance: The graph model enables representing PFs collected from different sensory stimulation paradigms with the same approach. Therefore, our method can generalize to PFs elicited from different sensory stimulation paradigms. Our framework bridges the gap between the intuition of PF stability and the experimental data towards a more systematic assessment of the efficacy of sensory neuroprostheses for long-term use.

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Mitigating EEG Non-Stationarity in Multi-Session MI BCI with Autoencoder Denoisers

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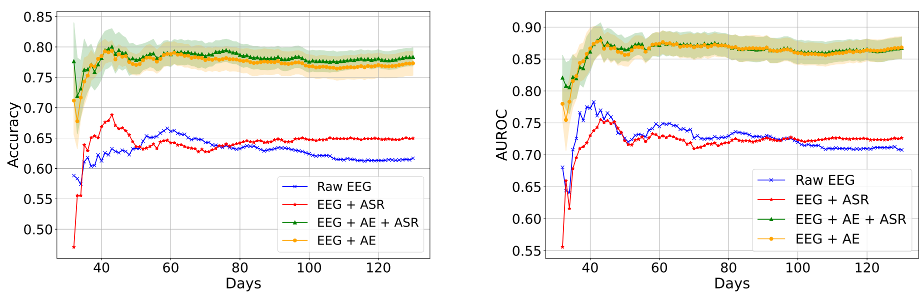
Introduction:
A fundamental challenge in motor imagery (MI) brain-computer interfaces (BCIs) is related to the non-stationary nature of brain signals. This inherent variability undermines the performance of classifiers, as models trained on data from one session often fail to generalize effectively to subsequent sessions. Traditionally, addressing this issue requires recalibrating the model for each session, a labor-intensive process that limits the scalability and practical deployment of BCIs in real-world applications.

Material, Methods and Results:
We propose a preprocessing method to enhance EEG signals using an autoencoder (AE) based on a convolutional neural network (CNN) architecture. The AE captures a low-dimensional latent representation of EEG signals from the initial N days, effectively filtering out noise while preserving essential features. The decoding step reconstructs EEG signals with an enhanced signal-to-noise ratio (SNR), providing stable signals across sessions without the need for recalibration [1]. The reconstructed signals represent a stable, invariant representation of the subject's intent, while the residual signals capture session-specific information. These reconstructed signals are then utilized for feature extraction and classification. When applied to longitudinal motor imagery (MI) data from a stroke patient, the proposed method demonstrates a substantial improvement in performance, as measured by accuracy and the area under the ROC curve (AUC), compared to the same classifier without the AE preprocessing as depicted in Fig 1. Additionally, the application of Artifact Subspace Reconstruction (ASR) does not significantly alter the performance, indicating that the observed improvement arises primarily from addressing non-stationarity rather than artifact removal.



(a) *Comparison of test accuracy across days.* (b) *Comparison of test AU-ROC across days.*

Figure 1: *Performance analysis across* 131 *daily sessions from a stroke patient, trained on the first* 30 *days and tested on the rest.*

Conclusion:
The proposed AE effectively captures a low-dimensional invariant representation of the subject's intent, eliminating the need for recalibration in subsequent sessions. The residual signals, which encapsulate session-specific variations, may offer valuable insights into the underlying sources of EEG non-stationarity.

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Autoregressive model for artifact detection in finger motor imagery decoding for EEG BCI

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Introduction: Invasive recording mechanisms such as electrocorticography (ECoG) achieve high classification accuracy of motor imagery tasks, even for highly correlated signals as elicited by finger movement. The focus of regaining control over fingers, i.e. post-stroke, is on rehabilitation, not substitution, which makes electroencephalography (EEG) the preferred choice. However, EEG suffers from a low signal-to-noise ratio (SNR), which causes significantly lower classification performance. When considering the low-amplitude neural signal of finger motor imagery in EEG, it is crucial to distinguish between event-related neural activity and event-related noise activity. Channels are referred to as bad channels, where erratic waveforms indicate an artifact-heavy recording. SNR can be increased when those bad channels are interpolated to retain their information. The automatic detection of bad channels has been based on a variety of statistical methods, such as standard deviation. Autoregressive model (AR) assesses a given time series considering probable future values, where significant deviations from these values are treated as artifacts [1].

Material, Methods and Results: The dataset was taken from [2] where 256 EEG channels were applied contralateral to the handedness of each subject, where the left-handed subject (S1) was left out for simplicity. Prior to bad channel detection, a bandpass filter (1-40 Hz) was applied. For a z-score greater than 6, as in [2], channels were determined as bad; for AR a threshold of 3 was applied. Bad channels were interpolated, before common average referencing (CAR) and epoch creation. Features were extracted with five component frequency band common spatial patterns (FBCSP), where one subject (S5) had to be regularised at 0.01 post AR.

Conclusion: The findings in table 1 indicate that AR outperforms z-score in bad channel detection where low SNR is precedent. As subjects 2 and 3 performed similar across AR and z-score, subjects with higher variance and lower average with the z-score methodology improved significantly when applying AR. These findings are congruent with previous research on AR for artifact detection and relevant to the current focus on increasing classification accuracy.

Table 1: Classification parametrics of S2-5 comparing z-score and AR model for artifact detection.

Subject	Method	Acc.(%)	A. Dev.(%)	Prec.(%)	P. Dev.(%)
2	Z-Score	92.4	8.8	94.1	6.9
2	AR	93.5	7.4	94.7	6.1
3	Z-Score	93.7	9.5	94.8	8.2
3	AR	93.3	8.4	95.3	5.6
4	Z-Score	66.1	16.5	75	15.7
4	AR	85.4	12.1	88.9	10.1
5	Z-Score	71.2	16.8	76.3	23.1
5	AR	77.4	16.9	81	16.3

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Finding the Groove in Neural Space

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Introduction: A fundamental component of coordinated periodic movements is **rhythm**. From locomotive actions, such as walking or reaching, to more complex actions, such as dancing or playing an instrument, periodic movements require precise synchronization. Although substantial research has explored the neural underpinnings of broad cyclic movements like locomotion in preclinical models [1-3], it remains unclear how rhythms are represented, especially in humans, and what role sensory feedback plays in generating and maintaining rhythms.

Materials, Methods, and Results: In this study, we investigated the neural representations underlying rhythmic hand movements in the human sensorimotor cortex of participants with intracortical implants in the primary somatosensory (S1) and motor (M1) cortices. We sought to understand how M1 encodes rhythm and characterizes the dynamics of this encoding at both the single-neuron and population levels. Participants were instructed to tap their index finger in tandem with an auditory cue presented at different tempos. In the first experiments, participants were presented with both distinct groups of tempos and a continuous range of tempos. In the second experiment, participants performed a similar tapping task but on some trials did not tap a surface and instead tapped with their hand freely, removing sensory feedback. Finally, we asked participants to continue tapping with the same tempo after the cessation of the auditory cue.
At the single-neuron level, we found signatures of entrainment and identified subsets of neurons across M1 and S1 that were phase-locked, frequency-tuned, both, or neither. Examining the population, we identified a low-dimensional representation, or manifold, in neural state space that displayed frequency-dependent rotational dynamics. Within this manifold, oscillations (one per tap) existed along a tempo axis. We quantified the geometry of this manifold by calculating the trajectory speed and diameter of the individual rotations. We found that the geometry and location of these rotations in state space were highly variable during the initial taps of a trial, but became more stable over time as the *groove* was found. This transition functionally distinguished an establishment period from a maintenance period. Lastly, although we observed these rotations in the absence of tactile feedback or auditory cues, the organization of them never fully stabilized, particularly in the absence of tactile feedback, suggesting that the groove was never established.

Conclusion: In this study, we demonstrated that single-neuron activity in the human sensorimotor cortex exhibits signatures of rhythmic entrainment. More importantly, we showed that population activity contains frequency-dependent rotational dynamics that govern the entrainment and maintenance of rhythmic hand movements. However, these dynamics struggled to find the *groove* in the absence of sensory feedback. Future experiments will explore more complex rhythms, such as syncopation.

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Asynchronous Voluntary Self-regulated Near-infrared Spectroscopy Brain-Computer Interface for Children with Cerebral Palsy

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Introduction: Brain-computer interfaces (BCI) hold promise as an access method for children with cerebral palsy (CP) [1]. Challenges such as distinguishing control states with an fNIRS BCI is a challenging task, which involves addressing issues like overlapping neural signals, variability in brain responses, and maintaining a good signal-to-noise ratio to ensure accurate detection and classification of intentional control (IC) versus non-control (NC) states. Previous studies, including Koo et al.[2] developed a hybrid electroencephalography (EEG)-functional near-infrared spectroscopy (fNIRS)-BCI system for self-paced motor imagery, and Millán et al.[3] used an EEG-BCI system with a mixture of Gaussian generative models of multiple IC states. However, none have combined self-regulation with asynchronous algorithms for fNIRS-BCI systems. This research aims to develop an intuitive and user-driven asynchronous fNIRS-BCI for voluntary self-regulation for children with CP.

Material, Methods and Results: Four participants (3 males and 1 female, aged 13-18 years, GMFCS levels III-V) with CP completed four self-regulation sessions on different days. The first two sessions were offline, while the last two sessions used an NIRS-BCI to control a toy car during the online sessions. fNIRS channels were placed on the prefrontal cortex using a wireless Artinis Brite fNIRS headset (Elst, The Netherlands) at 25 Hz. Data from self-regulation and rest tasks were converted into hemoglobin concentrations based on the Beer-Lambert law and baseline correction with noise reduction applied through a third-order Chebyshev type II low-pass filter (passband: $<$6 dB). Features (signal mean, signal slope, signal variance, and root mean square values) were selected through ReliefF. Seven classifiers were tested using a 1000-fold permutation test with 10 by 5-fold cross-validation for each fold, with hyperparameters tuned through grid search (Fig. 1). The offline and online cross-validation achieved average classification accuracies of 85.3±7.17% and 77.2±5.83%, respectively.

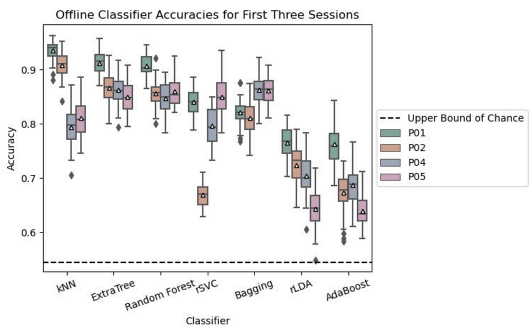

Figure 1: *Classifier accuracies evaluated using 10 by 5-fold cross-validation. White triangles represent the mean accuracy value. The dashed line marks the upper bound, corresponding to the maximum 97.5th percentile of the chance level across all classifiers and participants.*

Conclusion: Our findings show that self-regulated asynchronous real-time fNIRS-BCI is feasible for children with CP. Personalized approaches for channel selection, feature extraction, and classifier optimization may effectively address individual differences. These advances emphasize the potential for translating BCI into clinical or home settings as an access technology.

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The potential of the 1/f EEG slope at rest for predicting BCI performance: a *brain criticality hypothesis for BCI use*

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Introduction: Recently, several studies have highlighted the influence of the *aperiodic*, *scale-free* component, i.e. the *1/f* slope, of the resting-state EEG on subsequent task performance. We investigated this relationship for subsequent BCI (brain-computer interface) performance [1]. We observed two opposing relationships. In a large cohort of healthy participants (n=55, recently reanalyzed in [2]), the BCI performance decreased with a steepening 1/f EEG slope at rest, whereas the opposite was observed in a single *locked-in* (LIS) patient with *amyotrophic lateral sclerosis* (ALS). To reconcile these conflicting results, we referred to the *brain criticality hypothesis* (see e.g., [3]). Brain criticality has been related to the 1/f EEG slope, where a flatter slope typically indicates greater criticality. According to the brain criticality hypothesis, cognitive processing capacity is optimal at the point of criticality, with reduced performance in subcritical and supercritical states. This nonlinear relationship helped us explain our findings and formulate *the brain criticality hypothesis for BCI use* that is presented here.

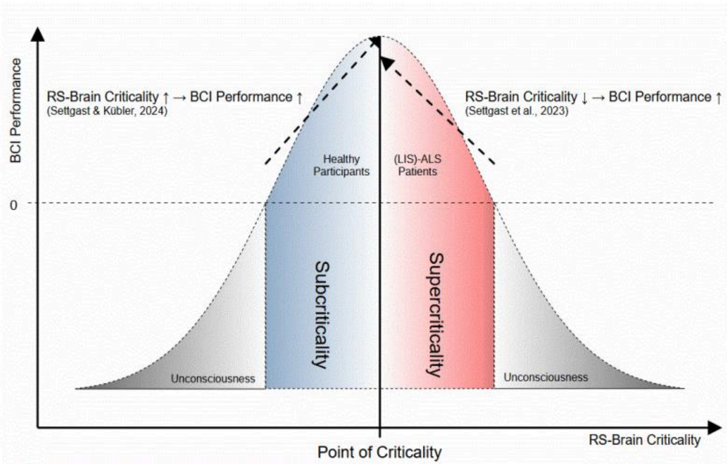

Figure 1: *Hypothetical relationship between resting-state (RS) brain criticality and BCI performance. The relationship is shown exemplarily for healthy participants (left; as found in [2]) and a LIS-ALS patient (right; as found in [1]).*

Hypothesis: Resting-state brain criticality predicts subsequent BCI performance. Performance improves as the brain approaches the point of criticality at rest, regardless of whether the starting point is subcritical or supercritical.

Initial evidence: Our results [1, 2] suggest that both healthy participants and a LIS-ALS patient benefit from approaching the point of criticality at rest for subsequent BCI performance. While BCI performance increases with increasing resting-state brain criticality in healthy participants (Figure 1, left), the opposite occurs in the LIS-ALS patient (Figure 1, right). In both cases, however, performance increases as one approaches the point of criticality at rest. The underlying assumption that brain criticality in ALS patients is generally elevated – eventually even being super-critical (Figure 1, right) – was recently supported by Trubshaw and colleagues [4] who showed the flattening of the 1/f EEG slope, consistent with increased criticality, in a large cohort of ALS patients.

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Speech mode classification from electrocorticography signals

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Introduction: Speech processing involves distributed networks across the brain with similarities observed across speech modes. However, the interplay among these modes remains elusive. In this study, we classified 5 different speech modes: speaking, listening, imagining speaking, reading and miming.

Materials, Methods and Results: Electrocorticography signals were recorded from 27 participants using one of two paradigms. In the *sentence* paradigm, 19 participants were asked to speak, listen and imagine speaking 20 Dutch sentences. In the *navigation* paradigm, 8 participants first either read or listened to a word (*up*, *down*, *left*, *right*, *stop* in Dutch) and then spoke, imagined speaking or mimed the word. Hilbert envelopes were computed for 7 different frequency bands from delta to high gamma. Linear discriminant analysis (LDA) classifiers were trained to classify trials (1 second epochs) of different speech modes. Statistically significant accuracies were observed at both electrode- and subject-level when concatenating the features from all channels of each subject. Figure 1a shows the distribution of the electrode-level normalized accuracy. The highest performance was achieved in the sensorimotor cortex and superior temporal gyrus. We did not observe an increased performance in the left hemisphere compared to the right hemisphere. This might be attributed to a stronger engagement of all speech modes in the language-dominant hemisphere (left hemisphere for most participants) not helping the classification due to shared patterns across modes. Figure 1b displays the confusion matrix of the speech mode classification at subject-level, averaging predictions from subject-specific models. The overall accuracy was 69.54% (chance level: 20%).

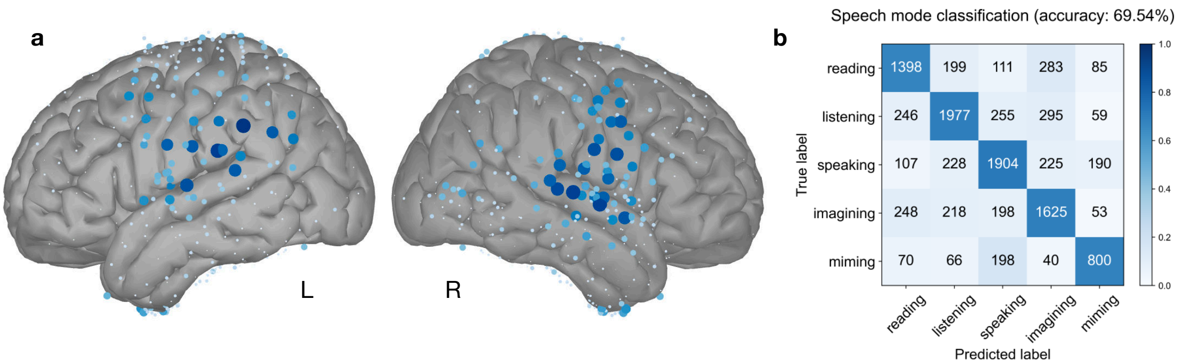

*Figure 1- **Speech mode classification a** Electrode-level: The size and color of the electrodes are proportional to the normalized accuracy (see color bar in b). **b** Subject-level: The confusion matrix shows the labels predicted by subject-specific models against the true labels for all trials.*

Conclusion

High performance could be achieved using a simple linear model. The results confirm the importance of the sensorimotor cortex and superior temporal gyrus in speech processing and highlight their role in differentiating between speech modes. In a self-paced speech brain-computer interface, a speech mode classifier would prevent spurious output while the patient is engaging speech-related brain areas through activities such as reading or listening to speech.

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Beyond Single Datasets: Transfer Learning for iBCI Decoding

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Introduction: Implanted brain-computer-interfaces (iBCIs) using (high-density, HD) electrocorticography (ECoG) grids have successfully been used to help individuals with severe motor paralysis interact with their environment via synthesising speech or translating their movement intent into functional outputs. Due to differences in grid placement and interindividual variability, these high-performing systems usually need to be trained from scratch to be tailored to each user, which requires large amounts of labelled data. Acquiring that labelled data takes a lot of time and effort from iBCI users. In this work, we aim to create a model that can leverage unlabelled neural data, pooled from several HD ECoG participants and datasets. If successful, such a model can be used to reduce iBCI training time for new users (and tasks), create meaningful neural representations, and improve closed-loop, continuous iBCI decoding.

Material and Methods: One approach to transfer learning and dealing with ECoG grid placement variability was demonstrated with HT-Net [1], which classified neural data as either rest or task-related activity. Beyond pooling different datasets, we expand on their work in several ways: 1) We filter and reconstruct the data in 3 individual frequency bands to capture the movement-relevant high-frequency parts of activity. 2) We build three model variations, all based on the auto-encoder structure to compress and reconstruct neural data:
a) linear, b) recurrent and c) convolutional recurrent models. 3) We define a denser set of common sources aligned with HD grid spacing in sensorimotor regions following the Human Connectome Atlas.
Our dataset consists of two finger movement experiments, totalling two hours across 14 able-bodied participants, who were being monitored for medication-resistant epilepsy and had 64- to 128-channel HD ECoG grids implanted. The models are trained on time-domain data sampled at 250 Hz, fed into the model in 500-ms windows, and band-passed into 0-12, 12-24, and 24-125 Hz bands. Our models consist of an encoder, which extracts spatiotemporal features and compresses the 500-ms window into a bottleneck representation, and a decoder, which mirrors the architecture of the encoder and reconstructs the three frequency bands from the bottleneck. The models are optimised by reducing the mean-squared error between reconstruction and input signal for each band. The model performance is assessed on unseen data: 1) in-participant: the models are trained on one run of the task and are tested on an unseen run; 2) across-participants: trained on multiple participants (from one or several datasets), tested on an unseen participant.

Results: The convolutional recurrent model outperformed the linear and recurrent models by a significant margin in baseline tests, for both in-participant (correlation of reconstruction: 0.543, compared to 0.221 & 0.238 for the linear and recurrent models respectively, $p < 0.0001$) and across-participants evaluation (0.576, vs 0.338 & 0.526, $p < 0.0001$). Adding the projection matrix (ECoG channels to common sources), and bandpass filters to the model yielded further improvement for in-participant reconstruction (0.628 correlation on test set).

Conclusion: We are introducing a novel approach for transfer learning in iBCI development, combining data across several datasets to learn motor-relevant neural dynamics that are applicable to unseen participants. Our study showcases a potential avenue to lower the hurdle of training iBCI devices for new users. In further evaluation, we will assess the performance of this method for fine-tuning to an individual participant, explore what dynamics & features the model extracts from the data, and employ it to decode motor intent when applied in a closed-loop setting.

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Task-Based Functional Network and Topological Data Analysis of Event Related Potentials in Chronic Tinnitus

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Introduction: Brain network analysis, powered by advancements in network science and graph theory, provides crucial insights into the neural mechanisms underlying mental disorders and brain pathophysiology. In tinnitus, characterized by the perception of sound without an external source, investigating altered brain networks is essential to understanding its pathophysiology. Graph-theory-based functional networks enable comparisons of the small-world organization characteristic of healthy brain networks with the disrupted architecture observed in tinnitus patients. However, constructing brain networks is often hindered by the lack of standardized criteria for threshold selection, which impacts network topology and interpretation. Persistent homology, a topological data analysis (TDA) method, addresses this challenge by quantifying topological features across multiple scales without relying on arbitrary thresholds.

Material, Methods and Results: Seventy participants, including 38 tinnitus patients and 32 healthy controls (HCs), underwent audiological evaluations and EEG recordings during a cognitive auditory oddball task. P3 components were extracted from midline electrodes (Fz, Cz, and Pz). Neural sources were reconstructed using a minimum-norm imaging technique, and current source density was estimated within predefined functional brain regions. Functional connectivity was computed using wPLI to construct adjacency matrices. Persistent homology was derived from the adjacency matrices to compute Rips complexes, quantifying topological features such as connected components (β0) and higher-order loops (β1). Subsequently, persistent topological features are visualized using persistence diagrams. Persistent entropy, derived from these diagrams, quantifies the complexity of topological features by measuring the distribution of interval lengths. Higher entropy values indicate greater diversity and uniformity in the persistence of features, while lower values reflect dominance by a few significant features, suggesting simpler underlying structures. Bottleneck and Wasserstein distances are used to assess the stability and similarity of topological features, with Bottleneck capturing localized differences and Wasserstein reflecting global variations [1]. Using the random forest algorithm, we employed a filter-based feature selection method utilizing the Fisher score combined with leave-one-out cross-validation. With functional network features from each frequency band, the model achieved a maximum accuracy of 67.14% using 13 selected features. In contrast, incorporating non-linear topological features from each frequency band improved the model's performance to 77.14% with only 5 selected features, highlighting the efficiency and discriminative power of topological features in the classification task.

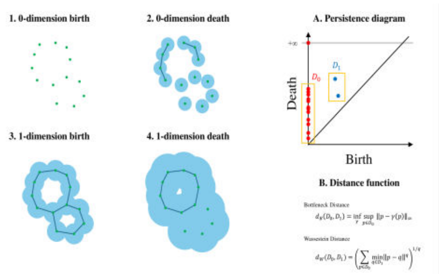

Figure 1: Comprehensive representation of a persistence homology, with A. persistence diagrams and B. the mathematical formulations for persistence distances.

Conclusion: The experimental results demonstrate that persistent homology effectively captures the non-linear and non-stationary topological features of brain networks, which are inadequately characterized by conventional linear graph-theoretical approaches. This study establishes a comprehensive framework for modeling complex brain dynamics in topological systems, offering deeper insights into their nonlinear behaviors and enabling more robust analyses and predictions. It particularly highlights the utility of identifying higher-order topological structures in nonlinear brain functional networks.

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Towards the Clinical Translation of Implantable Brain-Computer Interfaces for Motor Impairment: Research Trends and Outcome Measures

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Introduction: Implantable brain-computer interfaces (iBCIs) translate neural signals into motor commands, such as the movement of a device or synthesis of speech, offering potential to restore function in patients with severe motor impairments. This systematic review provides a comprehensive analysis of the evolution of implantable BCI research so far, as well as the need for robust, clinically meaningful outcome measures to enable clinical translation.

Material, Methods and Results: A sensitive search strategy was developed and applied across MEDLINE, Embase, and CINAHL databases. Studies involving iBCIs with intracranial sensing and external effector components were included. Records were screened by two independent reviewers. Data was extracted using a piloted proforma, and the risk of bias was evaluated using the Mixed Methods Appraisal Tool (MMAT). A total of 112 studies met the inclusion criteria, with a significant proportion published since 2020, accounting for 49.1% of included studies (n=55). Most research was concentrated in the United States (83.0%; n = 93), with notable contributions from Europe, Australia, and China. Over the past decade, electrocorticography (ECoG)-based devices have increasingly emerged alongside micro-electrode arrays (MEAs) as the sensing devices in iBCI studies. This coincides with a shift in focus from exclusively decoding individual neuron spiking activity to also incorporating spectral features derived from the oscillatory activity of large populations of neurons. iBCI devices are now being used to control an increasingly diverse range of effectors, including robotic prosthetic limbs and consumer digital technologies. Although most (69.6%, n = 78) studies reported outcome measures prospectively, these most commonly related to decoding (69.6%, n = 78) and task performance (62.5%, n = 70). Clinical outcomes were rarely reported, with only 20 studies (17.9%) reporting a use of clinical outcome measure. These measures were heterogenous and most often were related to robotic prosthetic upper limb functions, or the completion of activities of daily living.

Discussion and Conclusion: The clinical and engineering focus of iBCI studies has rapidly evolved since the first human studies, and fully implantable devices have now emerged which may enable clinical translation. This review highlights the dominance of U.S.-based research, the shift towards ECoG-based systems, the expanding array of controllable effectors and the predominance of engineering-related outcome measures. iBCI systems have the potential to restore functional independence at scale, however challenges remain regarding cross-subject generalisation, scalable implantation of devices, and standardisation in the reporting of clinically-meaningful outcomes. Development of novel outcome measures should involve engineers, clinicians and individuals with lived experience of motor impairment.

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Understanding Patient Preferences for Implantable Brain–Computer Interfaces in Motor Neuron Disease: A Cross-Sectional Survey

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Introduction: Motor neuron disease (MND), often presenting as amyotrophic lateral sclerosis (ALS), leads to profound motor and communication deficits. Implantable brain–computer interfaces (iBCIs) that decode cortical signals to drive assistive devices represent a promising avenue for restoring functional independence. However, patient preferences and tolerances regarding iBCI risks, training burdens, and desired outcomes remain incompletely understood. This cross-sectional survey sought to characterize these preferences in people with MND (pwMND) in the UK.

Material, Methods and Results: A web-based survey was disseminated by the MND Association (30 September–15 December 2024). Thirty-nine pwMND responded (32 complete responses, 7 partial), encompassing varied ages and disease severities. Most (66.7%) used digital devices hourly, although 30.8% could not operate these devices by hand and relied on assistive technologies such as eye tracking. Self-reported familiarity with BCIs was generally low, but individuals with more advanced disease tended to have slightly higher awareness.

Asked which functions they would most like an iBCI to restore, participants prioritised mobility, communication, and arm/hand control. Among digital-specific applications, communication tools, work/employment, and entertainment/leisure emerged as the top three preferences. Other activities, such as managing finances and controlling smart home environments, were also mentioned as top priorities.

Respondents were generally open to neurosurgical implantation if it led to meaningful functional benefits (80% “Agreed” or “Strongly Agreed”). However, only 60% accepted implantation if the device would remain effective for just one year. Respondents were also willing to receive a device in the context of higher surgical risk (1% risk of death), with 80% of patients again indicating they would accept implantation to restore meaningful functions.

When asked about post-implantation training, participants reported a median upper limit of 12 total sessions if they could be conducted at home, but only 5 sessions if they required travel to a clinical site. Almost half (48.5%) indicated that each session should not exceed two hours, and most participants preferred infrequent device recalibrations (ideally once every few weeks or months). These findings suggest tolerance for a training and recalibration burden lower than is required in most iBCI academic studies.

Accuracy, ease of use, and long-term reliability were top priorities when deciding whether to receive an iBCI, surpassing raw speed in importance. More than 90% wanted guarantees of ongoing technical support to minimise the risk of device abandonment.

Conclusion: This survey offers new insights into the real-world priorities of pwMND regarding surgically implanted BCIs. Whilst there is a clear willingness to accept neurosurgical risk for potentially life-enhancing gains in mobility and communication, participants desire robust device accuracy, reliable technical support, and minimal training burdens. The absence of any iBCI background knowledge indicates that patient groups may benefit from the delivery educational workshops or materials where individuals are being recruited to iBCI studies. These patient-informed preferences should help guide clinicians, researchers, and industry partners in designing and evaluating iBCIs that align with the practical realities and aspirations of individuals living with MND.

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Automatic EEG Channel Optimization Based on Integrated Gradients for Auditory Attention Tasks

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Introduction: Humans have the ability to focus on the specific speaker's voice in a noisy environment, and the attention could be decoded from neural signals, such as Electroencephalography (EEG) [1]. To achieve high accuracy, EEG-based auditory attention decoding studies often employ dozens of electrodes, which increases the complexity of the system and reduces its portability [2]. Previous channel pruning algorithms typically relied on prior assumptions or require additional costs [3]. This work proposed to employ integrated gradients (IG) and directly infer the channels related to auditory tasks without extra training and learning costs.

Material, Methods and Results: EEG data from 16 subjects with 32 channels were collected under an auditory attention paradigm. IG performs Riemann integration on the gradients along the path between the EEG signal and the reference baseline to stably quantify channel contributions, guiding channel pruning. IG significantly outperforms random channel selection (see Fig. 1). The top 20 selected channels achieve similar decoding performance to using full channels. Even with just 5 channels, accuracy remains above 80%. Additionally, the task-relevant channels identified by IG are located in the prefrontal cortex, which is involved in attention allocation and decision-making.

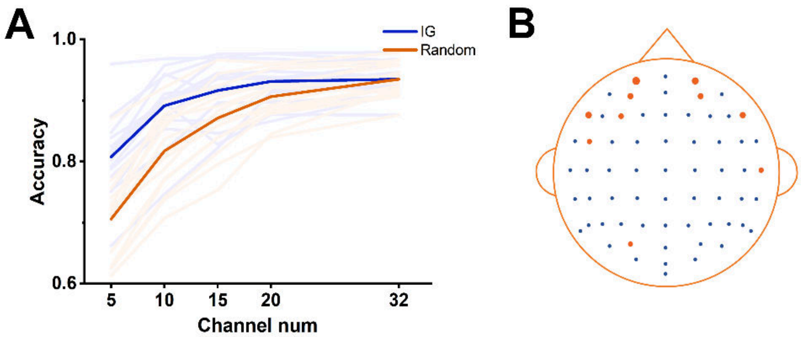

Figure 1: *(A) The impact of channel count on decoding performance. The dark lines show average decoding performance, while light lines represent individual results for 16 subjects. (B) Top 10 electrodes identified by IG, with orange dot size indicating contribution level.*

Conclusion: IG incurs a small causal inference cost, reducing over half the channels while maintaining performance, and successfully identifying channels related to the neural mechanisms of auditory attention. These results support neuro-guided hearing device applications.

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An SSVEP Regression Network for Cross-stimulus Transfer in SSVEP-BCIs

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Introduction: SSVEP-based BCIs achieve high information transfer rates (ITR) over 300 bits/min but require prolonged calibration time. Cross-stimulus transfer addresses this by enabling models trained on a subset of classes (seen classes) to decode both seen and unseen classes. Existing approaches obtain templates of unseen classes for decoding using common components from seen class templates [1]; however, these templates suffer from class-relevant activities, leading to degraded performance. This study proposes a neural network to directly map visual stimuli (sine-cosine reference signals) to SSVEP responses (SSVEP templates). Moreover, a novel framework is introduced by combining the proposed regression network and spatial filtering to identify targets from both seen and unseen classes.

Materials and Methods: A public SSVEP dataset comprising 35 participants was utilized [2]. Each participant completed six blocks, each containing 40 trials representing 40 classes/visual stimuli. A k-fold cross-validation scheme was implemented, with one block as the test set and the remaining as the training blocks. In the training blocks, 32, 20, and 8 classes were chosen as the training set, i.e., the seen set, with the remaining classes as the unseen set. The network employs three modules: (i) an Embedding block, embedding sine-cosine reference signals into high-dimensional features; (ii) a Spatial-temporal Extraction block, using 1D convolutional layers and residual connections to extract spatial and temporal features; and (iii) a Bi-direction block, using recurrent layers to further extract temporal features. As shown in Figure 1(A), with obtained SSVEP templates of all classes, spatial filters mapped multi-channel data into 1D vectors, followed by correlation analysis for target prediction.

Results and Discussions: Figure 1(B) shows that the regressed SSVEP templates closely align with the true templates, indicating that the proposed network captures frequency and phase information. Moreover, Figure 1(C) shows that the framework outperforms existing approaches by a 10% improvement.

Significance: The proposed network can regress SSVEP responses of any class without collecting corresponding training samples. Integrated with the spatial filtering technique, the proposed framework enhances decoding performance and facilitates practical applications of SSVEP-based BCIs.

Acknowledgements: The Science and Technology Commission of Shanghai Municipality (STCSM, Grant No. 24YL1900200), and the National Natural Science Foundation of China (Grant No. 52175023 & No. 52227808).

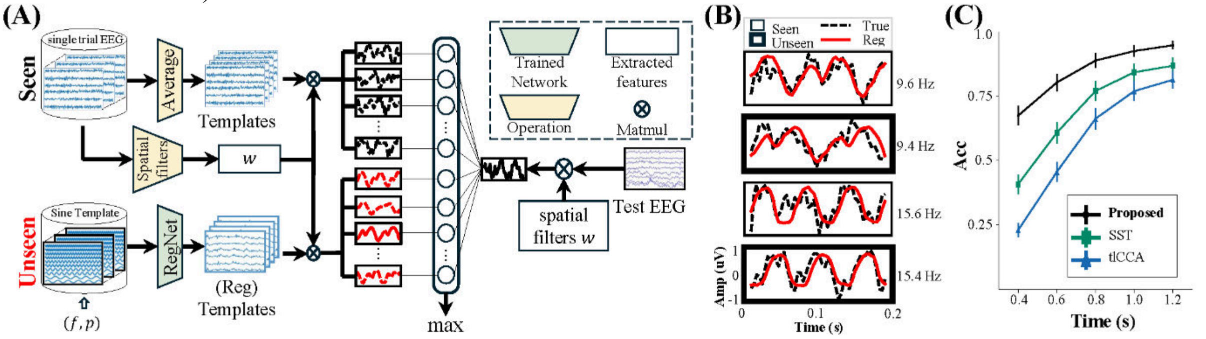

Figure 1. **(A)** *Overall scheme of the proposed framework. SSVEP templates of seen classes, spatial filters* w*, and RegNet are derived from the training set. SSVEP templates of unseen classes are regressed by the RegNet using sine-cosine reference signals as input.* ***(B)*** *Comparison between true SSVEP templates and regressed SSVEP templates.* ***(C)*** *Accuracies of different approaches under eight unseen classes.*

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A novel method for visual cortical prosthesis

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Introduction: Visual cortex stimulation is a cutting-edge technique in neuroscience that targets the primary visual cortex (V1) to modulate visual processing. It utilizes various forms of electrical stimulation which has attracted attention for its potential to restore visual perception in blind patients, regardless of the underlying cause, and possibilities for enhancing and augmenting visual processing in individuals with intact vision. The devices are designed to bypass damaged visual pathways by directly stimulating the brain's visual processing areas and reactivate neural circuits, induce artificial visual experiences, promote neuroplasticity, and assist in rehabilitating individuals who have lost their sight due to impaired visual pathways while retaining their brain's capacity to process visual information. In the past decade, interest in developing cortical stimulation prostheses has surged, largely driven by developments in cortical stimulation waveform design [[1,2]] that have been demonstrated in humans and primates, brain command connectivity [[3]], advanced visual mapping techniques [[4,5]] and the apparent shortcomings of retinal prostheses in offering a comprehensive solution. Projects such as the Orion and Chicago ICVP systems that cover a limited central field of view with low resolution utilizing penetrating or surface epicortical electrodes have advanced to the point of clinical research.

Material, Methods, and Results: While still in the experimental phases, the CortiSight technology adopted recent advances in neurotechnology, high capacitance electrode design, application of AI-based algorithms for image-brain-computer interfaces, and advanced electrode arrays deployment surgical techniques, and not only aims to provide basic visual sensations but also aspires to facilitate chronic complexed functional vision experiences for individuals with blindness and deepen our understanding of brain function and sensory restoration. The device uses wide multiple electrode arrays embedded within flexible intra-cortical threads to enable an extensive and effective number of cortical neurostimulation signals. The four electrode arrays aim to cover a large visual field on both hemispheres. The 386 distinct electrodes controlled by a single implant case can be used for both active stimulation and local return to localize the affected Phosphene. The electrodes are coated with non-faradic TiN highly porosive deposition, which allows for safe, long-lasting stimulation with minimal gliosis. The implant is wirelessly linked to a headset unit to receive power and stimulation instructions. The headset uses a camera to capture images of visual scenes and provide stimulation directions that consider the patient's gaze direction as well as audio commands for zooming and brightness adjustments. The optimal wide spatial distribution of electrode arrays is achieved using a rigid *comb-like* delivery tool. The accurate and robust delivery of the tool in close proximity to the target cortical cell layer was demonstrated in a sheep model following a 3x3cm craniotomy. Lateral introduction aimed to cover the foveal visual region, while the medial introduction was applied along the calcarine sulcus to enable the activation of para-foveal visual regions (fig. 1). This approach minimizes the risk of accidentally interacting with the superior sagittal sinus vein.

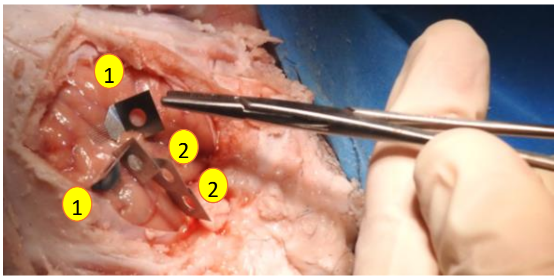

Figure 1: *A sheep brain with several orientations of the comb-like introduction tool: 1. Lateral cortex surfaces; 2. Medial cortex surfaces.*

Conclusion: A unique method of visual cortical prosthesis that may allow significant spatio-temporal resolution to blind patients has been developed and an early demonstration was performed.

Acknowledgement and Disclosures: R.Gefen and D. Rigler are personnel of CortiSight Medical Ltd.

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Adaptive EEG-Based Brain-Computer Interfaces for Stroke Patients: A Scoping Review

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Introduction: EEG-based brain-computer interfaces (BCIs) have gained attention for their potential to enhance post-stroke rehabilitation through motor imagery tasks. By dynamically tailoring the system to individual neurophysiological responses, adaptive BCIs promise more personalized rehabilitation, potentially improving patient engagement and intervention outcomes [1,2,3]. However, given the diversity in post-stroke motor impairments and neuro-rehabilitation approaches, the comparative efficacy of adaptive versus non-adaptive BCIs remains unclear [4, 5]. Hence, the current study aimed to systematically evaluate empirical evidence on adaptive EEG-based BCIs, focusing on their benefits, challenges, and effectiveness in post-stroke rehabilitation.

Material, Methods and Results: A scoping review was conducted following the PRISMA-ScR protocol to investigate the benefits and effectiveness of adaptive EEG-based motor imagery BCIs for post-stroke patients. A systematic search of 3 databases (Scopus, PubMed and IEEE Xplore) with the query "(BCI OR Neurofeedback) AND stroke AND EEG AND adaptive AND motor" provided 62 original publications, 13 of which met the predefined inclusion/exclusion criteria. Data extraction from these 13 studies highlighted that adaptive BCIs can effectively address challenges such as inter-user variability and EEG non-stationarity through real-time adaptation of the feedback and model recalibration. For instance, personalized calibration could enhance classification accuracy for stroke patients by up to 13.5% when adapting to inter-session signal fluctuations [3, 5]. Additionally, real-time feedback mechanisms were shown to promote cortical reorganization. One study reported a 15% improvement in Fugl-Meyer Assessment scores for upper extremities when combining adaptive BCIs with virtual reality and functional electrical stimulation [3]. Therefore, positive trends in motor recovery and user engagement were identified [3, 6], yet direct comparisons to non-adaptive systems were considered limited. Variability in study designs and outcome measures further constrained definite conclusions about the comparison between adaptive and non-adaptive systems [4, 5, 6].

Conclusion: Our scoping review shows that while adaptive BCIs offer significant promise in stroke rehabilitation by personalizing feedback and addressing EEG signal variability, limitations exist in comparative studies and standardization, highlighting the need for further research. Future studies should prioritize direct comparisons between adaptive and non-adaptive systems, alongside longitudinal designs to assess long-term impacts on motor recovery and daily functioning.

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Movement-based navigation of a matrix-speller via EEG

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Introduction: Restoring communication for locked-in patients is an important task to improve their quality of life [1]. Although invasive methods have demonstrated great advances, they are associated with surgical implantation and therefore not feasible for all patients. Non-invasive methods such as electroencephalography (EEG) can offer an alternative. The current study investigates the implementation of a training paradigm and online matrix-speller to restore communication via movement detection using EEG. Such spellers offer an alternative to P300-spellers for locked-in patients or people with cerebral palsy [2]. The paradigm was designed to enable fast, cue-based data collection. This preliminary study explored the general feasibility of the approach with five healthy participants.

Material, Methods and Results: Participants executed two paradigms: a training paradigm and an online spelling task. The training paradigm consisted of three cue-based runs and one run of self-paced movement execution. During cue-based runs, participants executed finger flexion whenever a rotating cross overlapped a static cross. Each run lasted $330\,\mathrm{s}$ during which 100 movements were executed. In the self-paced run, participants executed movements at times of their choosing. The online spelling task contained six runs with matrices of size 3×3 (run 1-3) or 5×5 (run 4-6). Row-column scanning was implemented by sequentially highlighting the rows until a motion was detected and the currently highlighted row was selected. Subsequently, columns were highlighted until another motion was detected and the highlighted tile was selected. In runs 1 and 4, tiles were empty and the current target tile was marked with a red dot. In runs 2,3 and 5,6, participants spelled two five-letter words with upcoming letters being highlighted in red (runs 2,5) or participants having to locate the letters themselves within the matrix (runs 3,6). Runs 1-3 and 4-6 had timeouts of 3 and $4\,\mathrm{min}$, respectively, after which the next word was displayed. Five participants (3 male, 2 female) completed the study. All participants were equipped with 60 EEG electrodes and 4 EOG electrodes for measuring eye movements. Movement onsets were tracked via motion capture software. EEG data was bandpass-filtered between 0.5 and 70 Hz and eye-artifacts were removed using the EOG channels [3]. Features were extracted by lowpass-filtering the data (cutoff frequency: 3.5 Hz), downsampling to 10 Hz and re-referencing to the common average. A shrinkage linear discriminant analysis (sLDA) was trained on data from the training paradigm to detect movement onsets from neural signals. The model was evaluated on data from the self-paced movement execution and the probability threshold of the sLDA was adapted to result in a maximum of one false positive per minute (FP/min) while achieving the maximal true positive rate. The grand average true positive rate over all matrix modes in the online spelling task was 59.1 % with a grand average of 0.87 FP/min. 65.8 % of all words were correctly completed within the timeout period.

Conclusion: The results from the spelling task show that the introduced training paradigm and the utilized model lead to an online performance feasible for spelling complete words. The success rate of 65.8 % within the timeout period shows that a useful communication can be achieved. Future work will investigate the performance of the model in people with motor-impairments and the possible adaptations of the algorithm required for these patients.

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Transparent c-VEP-based passive BCI to probe spatial attention

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Introduction: Code Visually Evoked Potentials (c-VEP) have garnered significant attention within the Brain-Computer Interface (BCI) community. Traditionally employed for enabling hands-free interactions in reactive BCI systems, c-VEP present a novel application within passive BCI systems, aimed at spatial attention tagging. Our team has innovatively developed transparent textured flickers to seamlessly integrate attention tagging without causing distraction or eye strain, achieved by carefully adjusting contrast and intensity to remain at the threshold of conscious perception [1][2].

Material, Methods and Results: In this study, we aim to extend the current paradigm to more ecologically valid settings, using the Multi-Attribute Task Battery (MATB), which includes three subtasks: Monitoring (responding to visual alerts), Tracking (maintaining a crosshair in the center), and Communications (reading back radio communications) – see Fig. 1a. Three stimuli were presented imperceptibly across these subtasks. These stimuli, flashed aperiodically with unique binary codes (sequences of 1 – on, and 0 – off), are designed to minimize correlation. By reconstructing the observed c-VEP codes in real time, we achieved predictions of participants' spatial attention targets at ~30 Hz. We tested our approach on 10 participants using the LiveAmp EEG system, alongside an eye tracker as ground truth for spatial attention. The session included an 80s calibration followed by 300s of passive supervision of cued MATB subtasks. The results are displayed on Fig. 1b.

Conclusion: The results demonstrate that our system successfully generated continuous predictions that were consistent with the output of the eye tracker, validating the effectiveness of our pBCI with its short calibration time and nearly invisible flickers. Future research will focus on the real-time integration of EEG and eye-tracking data streams to provide a more comprehensive understanding of the user's state. By leveraging neural responses as indicators of cognitive processing depth, this approach aims to enable cooperative and synergistic use of neural information, enhancing human-computer interaction.

Acknowledgments and Disclosures: This work is part of the PROTEUS Project (ANR-22-CE33-0015)

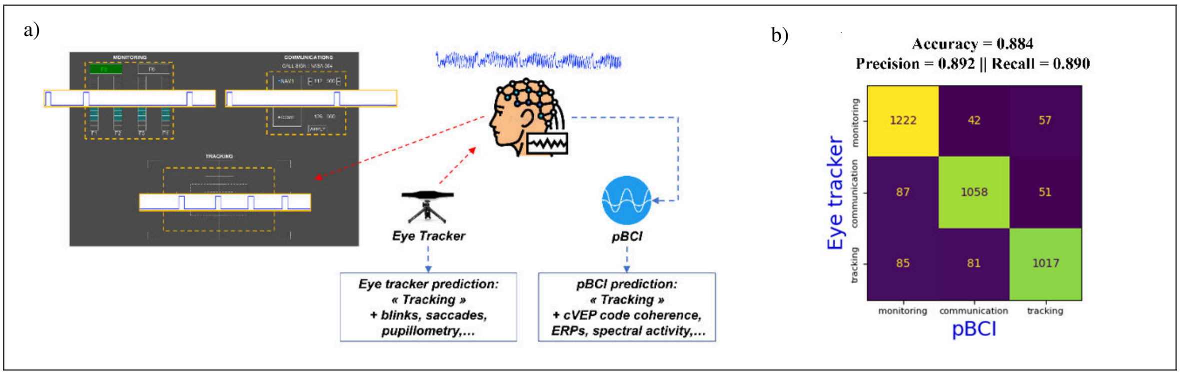

Figure 1: a) *Implementation of the c-VEP based BCI and the eye tracking system to tag spatial attention; b) Confusion matrix of pBCI predictions and Eye Tracker predictions and related Accuracy, Precision and Recall;*

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A non-invasive brain computer-brain stimulation interface to enhance motor rehabilitation

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Introduction: Rehabilitative brain-computer interfaces (BCI) improve motor function by inducing neuroplasticity [1]. Typically, these BCIs either use neurofeedback or neuromuscular electrical stimulation to induce neuroplasticity in the motor cortex, both of which don't directly stimulate the brain [1]. A rehabilitative BCI that directly stimulates the brain on movement-intention may cause greater motor cortex activity, amplifying the magnitude of Hebbian plasticity (Fig 1.). In this way, a direct brain stimulation BCI may induce greater neuroplasticity than standard rehabilitative BCI, enhancing motor recovery. Thus, we set out to develop and test the effects of a BCI that triggers a burst of gamma frequency repetitive transcranial magnetic stimulation (rTMS) when movement intention is detected (Fig 1.).

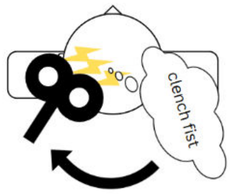

Figure 1: *Proposed Hebbian plasticity through co-incident movement-intention and brain stimulation.*

Material, Methods and Results: The BCI is trained on a participant's electroencephalography (EEG) data recorded during 30 trials of cued right-hand clenching. Specifically, the BCI uses 9 sensorimotor electrodes (FC3/z/4, C3/z/4, CP3/z/4) that are bandpass filtered between 8-40Hz. The data are split into noise [-3, -1] and movement [-1, 1] epochs. A common-spatial pattern (CSP) is fit to the epochs and a support-vector machine (SVM) is trained on the CSP transformed data. Five-fold cross-validation is then performed on the training data and the elbow of the receiver-operating characteristic (ROC) curve obtained from the fifth fold of cross-validation is used as the threshold in testing. We tested the BCI in pseudo-real-time using a 2s sliding window with a step-size of 83ms and a 2s window jump when the BCI detects movement regardless of whether movement truly occurred. We computed the true-positive and false-positive rates, where a true positive is defined as being within 1s of movement intention. Across 2 healthy adults and 2 fibromyalgia patients we achieved an average true-positive rate of 83% and false-positives/minute of 6.34/min with a mean latency of 123.7ms. In practice, real-time data will be streamed to a custom Python script running the tuned BCI that triggers an rTMS 100Hz triplet over the right-hand representation of the participant's motor cortex (Fig. 2).

Conclusion: We have successfully developed and obtained pilot validation data for a BCI that can trigger rTMS 100Hz triplets when movement intention is detected. This work introduces a novel form of rehabilitative BCI that directly and non-invasively stimulates the brain. This novel rehabilitative BCI has the potential to significantly enhance motor recovery through greater motor cortex plasticity. Our next steps are to test BCI performance in real-time and determine the effects of this BCI on motor cortex plasticity in healthy adults.

Acknowledgments and Disclosures: We have no conflicts of interest to disclose.

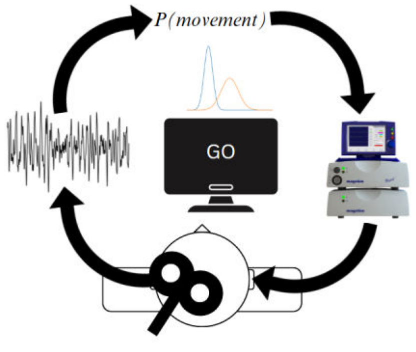

Figure 2: *Diagram of real-time implementation BCI-rTMS.*

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Real-Time BCI Control of a Virtual Third Arm

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Introduction: Motor augmentation is a transformative field in neuroscience and robotics, enabling humans to extend their physical capabilities beyond natural anatomical boundaries [1]. This study focuses on the development of a virtual reality (VR) paradigm designed to facilitate the learning processes for controlling a supernumerary effector (SE), a third arm, through an electroencephalography (EEG)-based brain-computer-interface (BCI).

Material, Methods and Results: A VR-based simulator was developed to integrate an EEG-driven BCI for controlling a virtual SE. Seven participants controlled a modified avatar featuring a third arm in a virtual reality environment, performing tasks requiring the use of the SE alongside natural arms (see Fig. 1). The SE's actions - grasping and releasing - were operated using motor imagery (MI), with sensory feedback delivered via a haptic vest to enhance embodiment [2]. EEG signals collected during a motor imagery task were processed using Common Spatial Patterns (CSP) and Linear Discriminant Analysis (LDA) to train a hand state classifier [3]. The classifier achieved an average accuracy of 73% (±4% std) for recognizing hand grasping, and 71% (±5% std) for releasing (Fig. 2). Neural activity patterns during motor imagery exhibited event-related desynchronization in the mu band. Additionally, participants reported high levels of ownership and control over the virtual SE.

Figure 1: *A user interacting with the virtual environment using the modified avatar equipped with a supernumerary effector (SE). The left panel shows an external view of the avatar, and the right panel shows the first-person perspective of the user.*

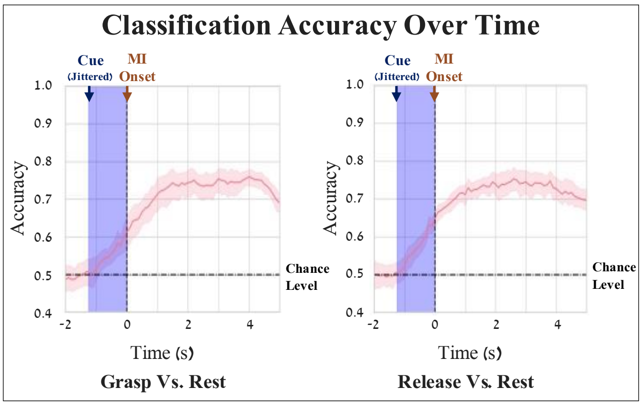

Figure 2: Accuracy of the supernumerary arm actions during the motor imagery task.

Conclusion: This preliminary study validates the feasibility of direct MI BCI-controlled motor augmentation within a VR setting. The findings lay the groundwork for future research into motor augmentation, with potential applications for assistive technologies and rehabilitation.

Acknowledgments and Disclosures: This study was supported by the European Research Council (ERC-2019-COG 866093).

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Bilateral frontotemporal neuronal dynamics during natural conversation: Single-neuron insights for BCI technologies

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Introduction: Recent neurotechnology advancements, particularly single-neuron recordings in humans, offer unprecedented insights into language processing at previously inaccessible spatiotemporal scales [1,2]. This study leverages bilateral single-neuron recordings from human frontotemporal cortices during natural dialogue to uncover cellular processes involved in language production and comprehension. By analyzing structural features of speech from word to sentence and dialogue levels, along with their temporal dynamics, we provide a unique perspective on language representation across cortical regions. These insights could help the development of advanced communication-restoring brain-computer interfaces (BCIs) and deepen our understanding of the neural basis of human communicative competence.

Material, Methods and Results: We conducted semi-chronic recordings from 251 neurons across both hemispheres in five participants implanted with Utah arrays in temporal (i.e., MTG, STG) and frontal (i.e., LPFC) regions. Participants engaged in natural conversations with familiar people (friends and family) and healthcare professionals (doctors, nurses, etc.) while we simultaneously recorded neural activity. Employing speech-tracking algorithms, we segmented dialogues into individual utterances and mapped them to specific linguistic constructs using natural language processing and word embedding techniques. We then identified neurons with selective responses to these constructs and modeled their ensemble activities. Our analysis revealed distinct neuronal populations in both hemispheres that selectively represented various aspects of language production and comprehension. The temporal lobe distinguished between speaking and listening, displaying greater activity during comprehension, while the frontal lobe exhibited comparable activity patterns in both comprehension and production (Fig.1). We observed dynamic transitions in neuronal activity patterns during turn-taking and identified neurons that encoded speaker identity. Notably, the activity patterns of these neurons demonstrated predictive capabilities for upcoming linguistic elements and conversational flow. Employing BERTopic to create dense topic clusters, we discovered that sentences within the same topic elicited highly similar neuronal responses, as measured by cosine similarity. In contrast, comparisons with no-topic sentences yielded lower similarity scores, indicating topic-specific neural representations together suggesting a rich representation of linguistic information at cellular scale.

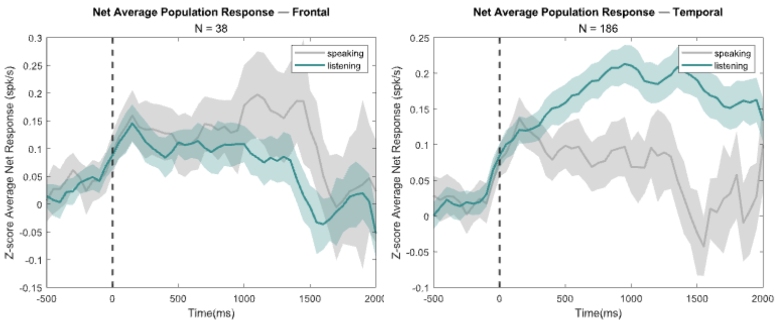

Figure 1: *Population response of frontotemporal neurons during speaking versus listening*

Conclusion: This research provides new insights into the bilateral dynamics of language processing at the cellular level, illuminating linguistic and pragmatic components of human communication. By revealing some of the basic cellular building blocks underlying natural language processing, we offer a neuron-based framework for understanding communication disorders and a prospective platform for developing BCIs capable of decoding and generating natural language.

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Recalibration of implantable brain-computer interface devices to enable long-term independent use: a systematic review

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Introduction: Implantable brain-computer interfaces (iBCIs) decode neural signals to generate command signals for effector devices which can restore a lost function, such as movement or speech. However, maintaining device performance over time requires recalibration of decoding algorithms due to inherent instability in neural signals. To this end, we systematically reviewed recalibration procedures in iBCIs for patients with motor impairments, focusing on the clinical implications of recalibration requirements and strategies to enable long-term, independent use.

Methods and Results: A systematic search was conducted across EMBASE, MEDLINE, and CINAHL databases to identify studies involving recalibration of iBCIs. After deduplication, 2767 studies remained which were then screened to yield 58 studies. Data on recalibration frequency, duration, staff requirements, and location were extracted and analysed, along with other outcomes like user pathology and signal stability. Penetrating arrays, i.e., microelectrode arrays (MEA) or microwires, were used in 67.2% of studies (n=39), while electrocorticography (ECoG) arrays, were used in 32.8% of studies (n=19). Recalibration practices varied widely amongst studies and were typically performed according to predetermined study protocols, rather than clinical need due to deteriorating device performance. Practices were divided into manual recalibration requiring a specialist research team (89.7% of studies; n=52), semi-automatic recalibration which could be performed by a non-specialist caregiver (3.4%; n=2), and automatic recalibration methods whereby patients did not require assistance (6.9%; n=4). In 63.8% (n=37) of the included studies, iBCIs were recalibrated before each testing session. In contrast, 36.2% (n=21) reported device use for periods >24 hours without recalibration, with an average duration of 13.8 ± 14.2 weeks (ranging from 32 hours to 61 weeks). Notably, 92.3% (n=36) of studies using intracortical (MEA-/microwire-based) iBCIs required daily or per-session recalibration. Studies employing ECoG iBCI devices generally reported less frequent recalibration, with intervals ranging from several weeks to over a year. Extended independent use was more frequently reported with ECoG-based iBCIs. Regarding the location of recalibration, 69% (n=40) took place in a lab (research) setting. Others were carried out at home (13.9%; n=8), both in the lab and at home (10.3%; n=6), not at all (1.7%; n=1), or it was unclear (5.2%; n=3). Across all studies, the most common conditions among iBCI users were spinal cord injury (42%; n=37), amyotrophic lateral sclerosis (ALS) (29.5%; n=26), and stroke (21.6%; n=19). In the subgroup with less frequent recalibration, ALS was relatively more prevalent than other conditions (48.4%; n=15), possibly reflecting the greater clinical need for reduced recalibration burden in individuals with advanced ALS.

Conclusions: Reducing recalibration frequency and/or complexity can improve patient autonomy, and optimizing recalibration strategies is crucial for enhancing the long-term independent use of iBCIs in home and clinical settings. ECoG iBCI studies typically have a low recalibration burden due to inherent signal stability. Whilst MEA iBCI studies usually involve a higher recalibration burden, recent studies have demonstrated reductions in recalibration burden, due to both latent space analysis methods, and continuously updating models during device use. Despite this progress, recalibration procedures are often not fully defined in iBCI studies, and where they are, they usually relate to the study protocol rather than the clinical meaningful requirement of recalibration due to worsening device performance. Future studies should continue to develop user-friendly recalibration procedures and outline the clinically relevant recalibration requirements where possible.

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EEG-based Motor Imagery Neurofeedback Enhance Mu Suppression during Motor Attempt in Stroke Patients

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Introduction: Neurofeedback using EEG-based event-related desynchronization (ERD) has shown potential in stroke rehabilitation [1]. However, its effects on ERD during actual motor attempts remain underexplored. This study investigates the impact of motor imagery-based neurofeedback on mu suppression in the sensorimotor cortex, aiming to inform its role in enhancing neuroplasticity and improving rehabilitation outcomes.

Material, Methods and Results: Fifteen patients with hemiplegia after subacute ischemic stroke participated in a randomized cross-over study. The study consisted of two experimental conditions: neurofeedback and sham. Each condition was divided into four sequential blocks: resting, grasp, resting, and intervention, followed by an additional block of resting and grasp. During resting sessions, participants fixated on a white cross on a black screen for 2 minutes without moving their upper limbs. In grasp sessions, they repeatedly opened and closed their affected hand at approximately 1 Hz for 3 minutes while maintaining fixation on the same cross. The neurofeedback intervention displayed a punching image of the impaired limb corresponding to imagined movement-induced mu suppression, while the sham condition used mu suppression data from other participants.

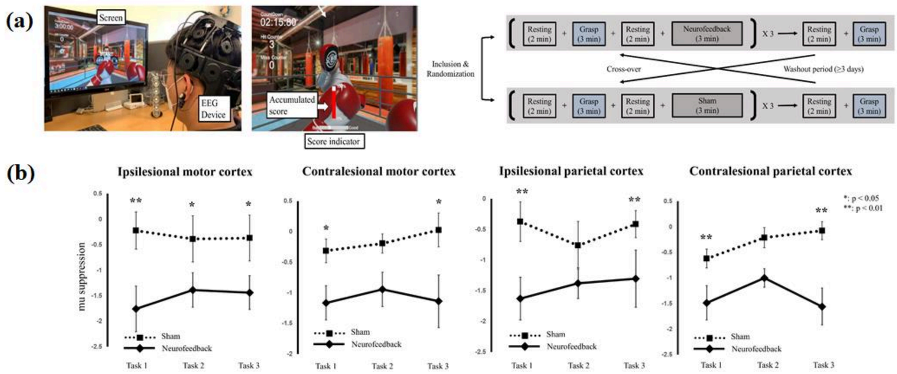

Figure 1: (a) Study design (b) *Mu suppression in the ipsilesional and contralesional cortex*

The neurofeedback intervention produced significant mu suppression in the bilateral motor and parietal cortices compared to the sham condition across repeated sessions ($p < 0.001$). During real grasping sessions following neurofeedback, progressive increases in mu suppression were observed in the ipsilesional motor cortex and bilateral parietal cortices compared to sessions after sham ($p < 0.05$). This effect was not present in the contralesional motor cortex.

Conclusion: Motor imagery-based neurofeedback effectively enhances mu suppression in the ipsilesional motor cortex and bilateral parietal cortices during motor execution in patients with subacute stroke. These results highlight the potential of motor imagery neurofeedback as an adjunctive therapeutic approach to improve motor-related cortical activity and support motor rehabilitation in stroke recovery.

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Collaborative Virtual Reality BCI Post-Stroke Neurorehabilitation Using Head-Mounted Displays

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Introduction: We are thrilled to present our newly developed collaborative Brain-Computer Interface (BCI) and Head-Mounted Display (HMD) system, designed to revolutionize post-stroke neurorehabilitation. In this system, both the post-stroke patient and a healthy therapist enter a shared virtual environment (VE) through their respective avatar representations. This immersive setup enables real-time interaction, allowing the therapist to guide and support the patient in performing rehabilitative tasks. By combining neural signal processing with virtual reality, our collaborative BCI-HMD system fosters motor recovery and cognitive engagement, offering a novel approach to accelerating rehabilitation outcomes and improving quality of life.

Material, Methods and Results: Our collaborative BCI-HMD system builds upon the theoretical framework outlined in [1] and the practical implementation described in [2]. The system combines a collaborative VE developed using the Unity game engine with a BCI that detects the patient's motor imagery intentions. Publicly available OpenViBE™ software for BCI integrates EEG signal acquisition, processing, and classification. A proprietary VE server application facilitates communication between the VEs of the patient and therapist and the OpenViBE™ engine. This setup allows the therapist to control, modify, and pace the neurorehabilitation training, while the patient, through motor imagery (MI) intentions, carries out the designed motor rehabilitation tasks (Fig. 1).

EEG-based control leverages the concept presented at the 17th BCI Meeting [3], with its core element being the tensor decomposition of EEG data. The tensor method extracts subject-specific, spatially, and spectrally constrained EEG oscillations associated with the MI process [4]. Additionally, the system is enhanced with functional electrical stimulation.

We conducted a series of experiments with healthy volunteers and post-stroke patients during the system's development stages, focusing on user acceptability. The results of these experiments will be reported.

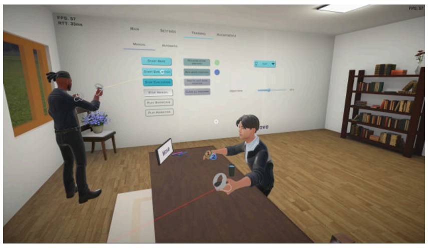

Figure 1: *A therapy room showing a standing therapist's avatar on the left and a sitting patient's avatar on the right. A control menu visible to the therapist is displayed on the back wall. The therapist selects, modifies, and paces the task, while the patient controls the avatar's hand movements in a closed BCI loop utilizing recorded EEG. Interaction between the therapist and patient takes place throughout the experiment.*

Conclusion: While we can currently support the validity of the proposed BCI neurorehabilitation system only with partial clinical results, we believe that the collaborative concept between therapist and patient within the BCI-VR environment has the potential to significantly influence wider clinical practice.

Acknowledgments: This research was funded by the EU NextGenerationEU through the Recovery and Resilience Plan for Slovakia under the project No. 09I03-03-VO4- 00443, and APVV-21-0105, TInVR, programs. N.E. received funding from the HORIZON-MSCA-2022-DN, 101118964-DONUT project.

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Self-Correcting Multi-Command Brain-Computer Interfaces based on Error-Related Potentials

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Introduction: Electroencephalogram (EEG)-based Brain-Computer Interfaces (BCIs) are often hindered by high error rates, limiting their effectiveness. In previous work we developed a self-correcting BCI, based on classification, rather than just detection, of error-related potentials (ErrPs), which are evoked when users observe erroneous BCI actions. The error classifier (EC) had three outputs: (1) correct movement, (2) failure to remain idle (i.e., performing a movement when none was intended), and (3) erroneous movement (i.e., performing one movement when another was intended). This approach was successfully demonstrated on a three-command BCI that adjusted the pose of the right hand, left hand, or neither hand, achieving an average accuracy improvement of 6.6±3.8% (n=11) [1]. However, scaling this methodology to BCIs with more commands introduces new challenges, as detecting an "erroneous movement" does not resolve which of the remaining movements should be executed.

Methods and Results: We present the development and evaluation of a novel self-correcting BCI designed to handle five commands. The system integrates a basic Movement Classifier (bMC) and an enhanced Movement Classifier (eMC), as illustrated in Figure 1. The eMC incorporates an EC followed by a novel combined classifier (CC) that determines the final command. Various CC configurations were evaluated, leveraging different features and scores derived from the convolutional neural networks (CNNs, [2]) used to implement the bMC and EC. All CC configurations demonstrated significant performance improvement, with the best configuration achieving an average accuracy improvement of 10.1±4.8%, resulting in average accuracy of 79.0±10.4% (n=18).

Conclusions: This study demonstrates that ErrPs encode valuable information about the type of error that elicit them and can be leveraged to enhance self-correcting BCIs capable of handling multiple commands. These findings represent a critical advancement in the development of more accurate, reliable, and user-adaptive non-invasive BCIs.

Acknowledgement and Disclosures: This work was supported by Dan and Betty Kahn Foundation, and the Technion's PMRI and ADRI grants. There is no conflict of interest.

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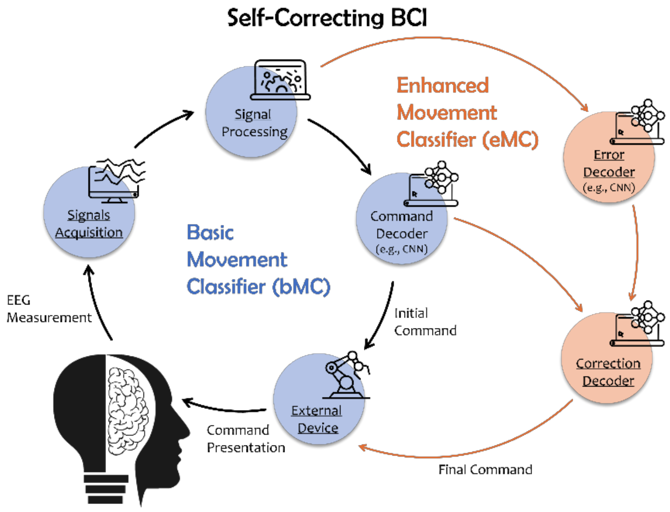

Figure 1: Architecture of self-correcting brain-computer interface.

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Exploring Early Predictability of Grasping Movements with non-invasive EEG

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Introduction: Grasping is a complex neural process integrating motor control and intention. In brain-computer interface (BCI) research, interpreting human intentions to control assistive devices is a key focus. Electroencephalography (EEG) serves as a critical tool for studying grasping, but traditional methods like movement-related cortical potentials and spectral power analysis often perform poorly [1]. Few studies have explored neural activity during the planning phase to predict grasp types early [2,3]. This study investigates the predictability of four grasp types—power, tripod, lateral, and cylindrical—during the planning phase.

Materials, Methods, and Results: We recorded EEG data (64 channels) from 10 healthy participants (3 males, 7 females, age 27.3 ± 3.7) during a reach-grasp-relocation task (Fig. 1A-C). Each participant performed 30 repetitions per grasp type across five directions. EEG preprocessing included bandpass filtering (0.1–45 Hz), artifact removal, re-referencing, and independent component analysis. We epoched from -2.3 to 0.9 seconds relative to movement onset, capturing peak motor planning activity [4]. Features were extracted using Common Spatial Patterns (CSP) [3], xDAWN spatial filter [3], and wavelet transform, paired with machine learning classifiers (LDA, LR, RF, SVM) and validated via 10-fold cross-validation. Data were tested for normality and 3-way ANOVA was used to assess performance with different parameter configurations.

We evaluated classifiers performance across two EEG configurations (64- vs 5-channel) and three feature sets. We found (Fig 1C) that xDAWN outperformed CSP and Wavelet, and CSP outperformed wavelet. RF and SVM outperformed LDA and LR. The 64-channel setup significantly improved performance over the 5-channel configuration, highlighting the benefits of broader spatial coverage. Statistical analysis revealed SVM using xDAWN and 64-channel setup as the best configuration.

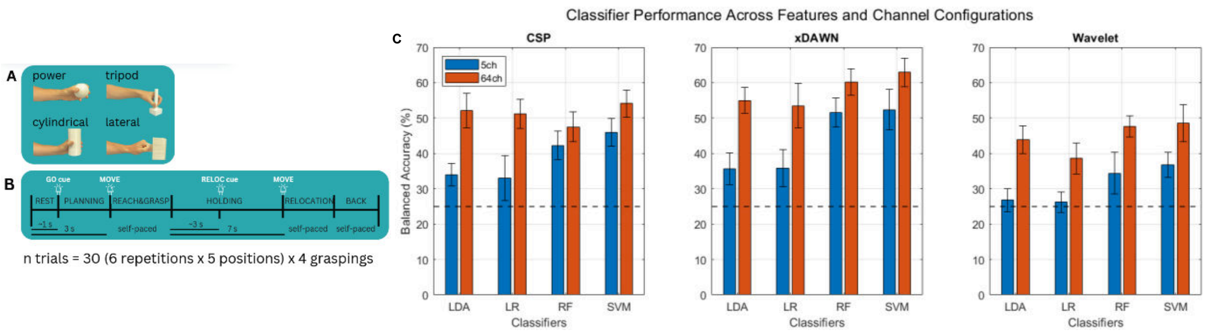

Figure 1: A) Experimental paradigm. B) Grasping types. C) Balanced accuracy for classifying four grasps using three feature extraction methods (CSP, xDAWN, Wavelet) across two electrode configurations (5-channel and 64-channel). Performance is shown for four classifiers: Linear Discriminant Analysis (LDA), Logistic Regression (LR), Random Forest (RF), and Support Vector Machine (SVM). A dashed line indicates the chance level (25%).

Conclusion: This study demonstrates EEG's ability to differentiate grasp types during the planning phase, offering valuable insights into motor control. These findings could inform methodologies for investigating grasp and for assistive technology development. Future research is needed to validate these results and optimize prediction strategies.

Acknowledgments and Disclosures: The authors thank N. Boccardo, M. Canepa, M. Mozzon, and A. Salvia for their support in experimental design and technical implementation. Authors have no conflicts of interest.

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Defining Out-of-Distribution detection for EEG-BCIs

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Introduction: Out-of-Distribution (OoD) detection methods are variations on Machine Learning (ML) models that can detect when a sample is different from the data the model is trained on [1]. OoD is minimally explored in BCI research [2], but it has the potential to make a BCI system that detects problems and delivers corrective action. OoD detection may detect: variabilities that cause decreases in performance, bugs in preprocessing that cause bad predictions, destructive artifacts that obfuscate the signal, and even off-task neural patterns. Traditional ML would give arbitrary guesses in these cases.
The broad definition of OoD makes the effectiveness of general OoD-detection hard to measure. In Computer Vision research this definition is worked out into established benchmarks covering a broad range of causes. For evaluating universal OoD detection in BCIs we should define BCI-specific causes that generate OoD data. This requires an employable definition for OoD specific to (EEG-based) BCIs. Our aim is to create a dataset of a broad range of artifacts, variabilities and other problems that can arise in BCIs that should be detectable by a good OoD detection system. At the 2025 BCI Meeting, we will establish with the community a shared definition of what OoD data in BCIs really is. We will then continue to develop a matching benchmark to evaluate various OoD detection methods.

Material, Methods and Results: As an example we consider a common OoD detection task called *leave-one-class-out*. Here, a model is trained on $C-1$ classes, and is tested on all C classes. It should report high uncertainty for the excluded class, which would represent off-task behaviour as OoD. We previously presented results on (non-BCI) datasets with various models, where the uncertainty is higher for the excluded class. This allowed us to detect them with AUROC scores between 0.65 and 0.98 [4]. However, in Fig. 1 we show that in a within-subject four-class Motor Imagery classification task [5] these methods fail with an AUROC score of ~ 0.5.

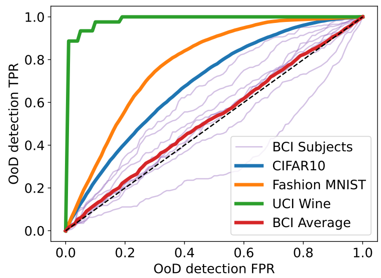

Figure 1: *Leave-one-class-out OoD detection works well on non-BCI datasets, but not for four-class Motor Imagery.*

Leave-one-class-out OoD detection is a moderately difficult OoD detection task. Some large artifacts or bugs in preprocessing may be more easily detected, whereas variabilities could be more difficult. A good and community-supported understanding of what OoD detection can mean for BCIs is needed to construct proper benchmarks

Conclusion: OoD detection identifies when traditional ML methods may fail. However, it has a very broad definition. To be able to work with OoD detection and advance the BCI field, our community needs to define an agreed set of examples that are to be worked out into benchmarks. We aim to implement such benchmarks in an open-source repository using public datasets. We already have plans for defining OoD data (including off-task behavior, movement artifacts, disconnected electrodes, hardware and preprocessing differences, and cross-subject BCIs), but by getting input from the community we can create a complete and appropriate benchmark. A definition of OoD will include a better understanding of variabilities [6], which is an established need in BCI research.

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A Continuously Learning Neural Decoder for Versatile and Transferable Motor Control

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Introduction: Brain-computer interfaces (BCIs) offer individuals with conditions such as paraplegia or ALS the ability to gain control of assistive devices. Most BCIs rely on fixed neural decoders that require a long initial calibration to achieve accurate functionality. The non-stationarity of brain signals however often causes performance degradation over time, making frequent recalibration necessary – a time consuming and frustrating process that limits BCI practicality. To address these limitations, we present a novel neural decoder that combines short calibration time, continuous learning, and versatile feature selection - making it robust to a wide range of neural oscillations and implant locations. This approach allows for dynamic adaptation to changing brain signals, fostering co-adaptation between the user and the decoder while reducing the need for frequent recalibration.

Methods: We recorded brain activity using intracranial electroencephalography (iEEG) from multiple epilepsy patients undergoing presurgical monitoring. All patients engaged in a short, supervised calibration to initially train a closed-loop decoder on executed and imagined movement. The decoder uses a novel feature selection strategy that combines distributed low-frequency and localized high-frequency signals to enhance performance. Prior to testing the closed-loop system, patients used Neurofeedback to learn to control the continuous decoder output. The decoder then enabled control of a racing game, integrating continuous learning via real-time finetuning using pseudo-labeled data.

Results and Discussion: The decoder accurately identified motor intention above chance in all participants. After just one minute of calibration, the algorithm achieved over 90% of each participant's personal maximum performance. Patients found that the neurofeedback prior to the closed-loop game helped make the BCI feel more intuitive, as they could directly manipulate and observe the movement probability in real-time. Throughout the closed-loop sessions, the decoder was updated every minute with the newly acquired data, enabling continuous adaptation to evolving brain signals.

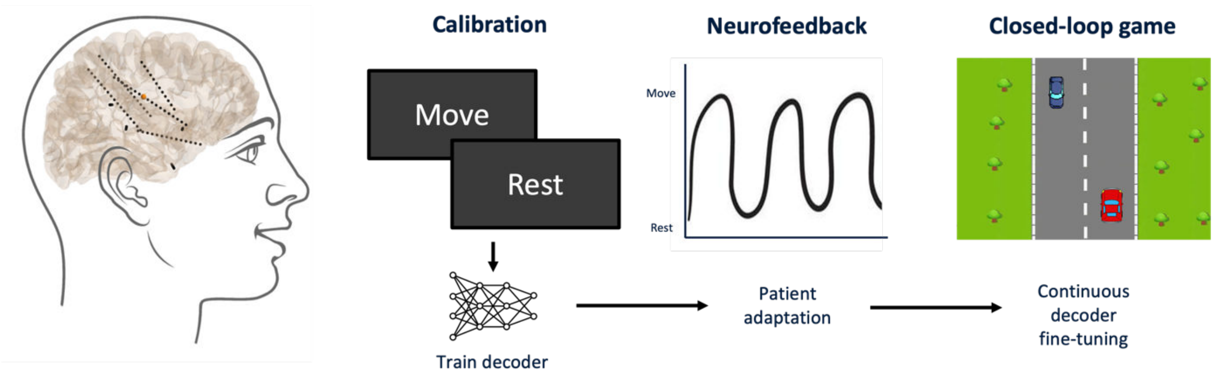

Figure 1. *Experimental setup for a continuously learning decoder, featuring an initial calibration, neurofeedback, and a closed-loop game to fine-tune the decoder and facilitate patient adaptation.*

Significance: This work contributes to improving the usability of brain-computer interfaces by reducing calibration time and the need for frequent re-calibration. With continuous adaptation and minimal manual setup, the system becomes more autonomous, empowering patients with greater control and making long-term use more practical.

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Optimizing Decoder Dynamics Strength for Closed-Loop Brain-Computer Interfaces

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Introduction: The use of artificial neural networks for decoding movement from neural signals has led to recent improvements in closed-loop brain-computer interface (BCI) control [1, 2]. Since neural signals typically have low signal-to-noise ratio (SNR) for task relevant information, the decoder must find the optimal balance between relying on noisy inputs versus prior knowledge of movement patterns. However, open-loop accuracy does not directly predict closed-loop performance [3, 4] making it challenging to design neural network decoders that optimize this balance. Here we investigated a novel decoder loss function, which allows for tuning the degree of decoder memorization, on closed-loop performance.

Materials, Methods and Results: We trained recurrent neural network (RNN) decoders to predict finger kinematics from spiking-band power features. RNNs were trained using a loss function that combined mean-squared error (MSE) with additional, tunable weight penalties that varied the decoder's reliance on learned task dynamics versus neural inputs. By tuning the penalties, we trained decoders with reduced reliance on neural inputs ("strong dynamics") or with increased reliance on inputs ("weak dynamics"). Additionally, we created a "dynamics strength" metric that quantifies the ratio of the current hidden state's sensitivity to its previous hidden state (derivative with respect to the prior hidden state) versus its sensitivity to neural inputs (derivative with respect to neural inputs), averaged over time. Using simulated data from an open-loop 3-target task with log-linear tuned channels, weak and strong dynamics decoders had similar kinematic decoding accuracies (correlations of 0.94 and 0.97, respectively) despite having largely different dynamics strengths (1.01 versus 5.75, respectively), suggesting different internal decoding mechanisms (Figure 1). We tested both decoders in closed-loop trials across three sessions with one rhesus macaque who was implanted with Utah arrays in motor cortex and trained to perform a 1-degree-of-freedom (DoF) continuous target-acquisition task. Both weak and strong dynamics decoders had 100% success rate, however, the smoothness of decoder movements increased as dynamics strength increased. When dynamics strength was increased further by training with a 100x instead of 10x weight penalty, the decoder failed to generalize to produce corrective movements resulting in a decreased success rate of 83%.

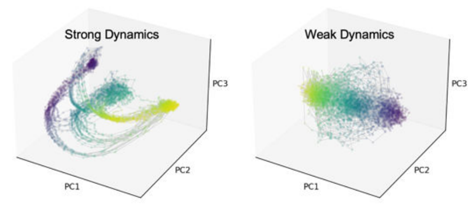

Figure 1: *PCA of the hidden state of GRU decoders trained with strong vs weak dynamics, on a 3-target task. Each dot is one time-point, and color represents the output position. Both decoders have similar accuracy but have visually different state trajectories.*

Conclusion: These results suggest that decoder generalization can be tuned using the loss function, which may be an important tool as BCIs expand to more complex tasks. Future work may investigate the optimal decoder dynamics strength for closed-loop control with varied SNR neural signals, and how this impacts the choice of decoder architecture.

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MultiPy – An open-source Python toolbox for multimodal real-time analysis

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Introduction: Real-time data processing is essential for interpreting neural signals in mobile brain-computer interfaces (BCI) and neurofeedback (NFB) [1]. Current systems often rely on unimodal approaches like electroencephalography (EEG) or functional near-infrared spectroscopy (fNIRS) [2]. EEG provides high temporal resolution for detecting fast electrical brain activity but is limited by noise, artifacts, and poor spatial information. Conversely, fNIRS measures hemodynamic responses such as blood flow and oxygenation with higher spatial specificity and lower artifact sensitivity but suffers from slower temporal resolution due to the nature of hemodynamic signals [3]. Combining EEG and fNIRS could offer complementary insights, improve accuracy, and address challenges like BCI illiteracy [3,4]. However, implementing real-time multimodal systems remains challenging due to a lack of software for simultaneous integration and analysis [4]. To address this, we present **MultiPy**, an **open-source Python toolbox** that integrates and analyzes **EEG and fNIRS** data in real time.

Material, Methods and Results: MultiPy is a graphical user interface (GUI) toolbox (cf. Fig. 1) designed to integrate real-time data streams from multiple modalities via the Lab Streaming Layer (LSL) protocol [5]. It includes three modules that can operate independently or together. The **fNIRS module** enables visualization, preprocessing, and key functions such as channel quality assessment, pruning, and converting light intensity to hemoglobin concentration using the modified Beer-Lambert law. It also offers motion artifact and (extracerebral) systemic activity correction, with or without short-distance channels. The **EEG module** provides real-time signal visualization and robust preprocessing tools, including artifact subspace reconstruction and temporal filtering. The **feature extraction and machine learning (ML) module** extracts time- and frequency-domain features from both modalities and integrates them using ML algorithms. Additionally, EEG and fNIRS data can be combined using a generalized linear model (GLM), allowing EEG features to inform fNIRS GLM analysis. Preliminary tests show MultiPy successfully integrates and synchronizes EEG and fNIRS data streams in real time, improves signal quality through preprocessing, and mitigates motion artifacts and noise using advanced algorithms.

Figure 1 GUI of MultiPy in the fNIRS module, showing channel selection, real-time data visualization and available preprocessing options.

Conclusion: The open-source MultiPy toolbox facilitates real-time integration and analysis of EEG and fNIRS data and is designed to support any device that enables real-time data streaming via the LSL protocol [5], thus aiming to increase the reach of NFB and BCI applications. This promotes accessibility and standardization in the field and allows researchers to easily develop and test multimodal approaches. Since MultiPy is open-source software, the community can participate in the development, provide feedback, and make MultiPy a versatile and comprehensive tool for advancing neurotechnology.

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Exploring fNIRS-guided neurofeedback to alleviate motor symptoms: A proof-of-concept study in Parkinson‘s disease and healthy older adults

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Introduction: Parkinson's disease (PD) is the second most common neurodegenerative disorder and affects up to 3% of people over 80 years, with its prevalence and societal costs expected to rise by 2030 [1]. Motor symptoms such as tremor, bradykinesia and rigidity are due to neuropathological causes, including degeneration of the substantia nigra and the supplementary motor area (SMA) [2]. Current therapies, including medications, exercise and deep brain stimulation, often face challenges such as side effects and varying effectiveness. Neurofeedback (NFB) in combination with motor imagery (MI) offers a promising complementary therapy [2]. Initial findings from fMRI show that NFB can increase SMA activation in PD [3]. After confirming with fMRI that fNIRS reliably measures SMA activity [4], here we test an NFB system with healthy older adults and PD patients to investigate its potential for motor neurorehabilitation [5]. This study is the first to use fNIRS to guide NFB based on changes in deoxygenated hemoglobin (Δ[HbR]) concentration during MI tasks in PD.

Material, Methods and Results: 19 early-stage PD patients (**PD-NFB** group, 63.95 ± 8.41 years, 7F/12M) and 38 healthy older adults participated in the study. Healthy adults were divided into an **NFB** group (63.63 ± 9.04 years) and a **noNFB** control group (63.68 ± 7.75 years), both age- and gender-matched to the PD-NFB group. The NFB groups performed MI of whole-body movements with real-time NFB based on SMA activity (Δ[HbR]), while the noNFB group performed MI without NFB. All participants completed 4 training sessions (S1–S4), with SMA activation assessed before and after training (PRE & POST) using MI without NFB. SMA activation was quantified with GLM-based analyses, incorporating nuisance regressors from short-distance channels and EMG of all limbs to account for voluntary movements.

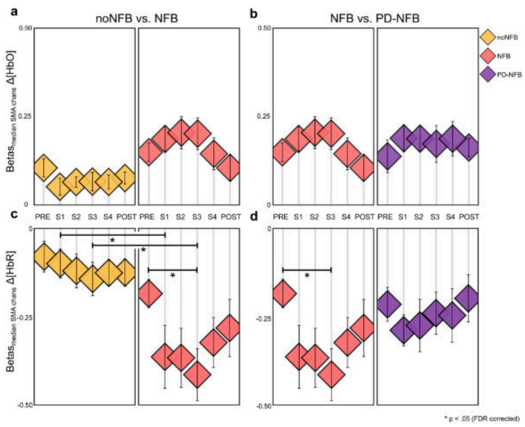

Figure 1 Mean beta values across all runs (PRE, S1–S4, POST) for Δ[HbO] (a, b) and Δ[HbR] (c, d). Panels (a) and (c) compare noNFB and NFB groups, while panels (b) and (d) compare PD-NFB and NFB.

As shown in Fig. 1, the NFB group had significantly higher SMA activation than the noNFB group during training sessions (S1–S4), especially for Δ[HbR]. SMA activation in the NFB group increased significantly from PRE to S1 ($p < 0.05$), while the noNFB group showed minimal changes. Between-group comparisons revealed significantly higher activation for the NFB group during S1 and S3 ($p < 0.05$). The PD-NFB group showed moderate but non-significant increases in SMA activation during training, remaining lower than the NFB group. Both NFB groups reported positive perceptions of NFB controllability.

Conclusion: This study demonstrated the feasibility of an fNIRS-guided NFB system targeting the SMA during MI in healthy older adults and PD patients. Results showed that combining MI with NFB significantly enhanced SMA activation in healthy adults, with good perceived controllability reported across sessions. The PD-NFB group exhibited lower and more variable SMA activation, reflecting potential challenges related to disease pathology and individual differences. These findings highlight the potential of fNIRS-based NFB for motor rehabilitation while emphasizing the need for protocol refinements, optimized channel selection, motor improvement assessments, and further testing with a PD-noNFB control group.

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Genetic Algorithm Implementation for Intersubject Motor Imagery Classification

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Introduction: The classification of EEG signals for motor imagery (MI) presents significant challenges, particularly in recognizing new subjects based on limited instances. For this reason, this project explores whether shared characteristics among subjects can allow the recognition of new individuals using a set of well-known methods to tackle this problem. After that, we assess whether the methods' performances could be improved using genetic algorithms (GA) to find a good set of models' parameters and features that allow for this purpose. These approaches allow us both to detect patterns from minimal instances of new subjects without extensive retraining of the models and to optimize the performances of the models, ultimately streamlining the classification process in BCI applications.

Material, Methods, and Results: This work analyzes a 62-channel EEG dataset comprising recordings from 20 participants during two motor imagery tasks (left and right hand). This dataset was chosen because it has few instances for each subject, 20 epochs per subject (10 epochs for each class). We followed a leave-one-subject-out scheme for the evaluation, i.e., using only one subject to test the model. To estimate the performance of non-optimized methods with their default parameters, the EEG signals were cleaned and filtered to remove artifacts and noise, ensuring high-quality data for analysis. Later on, several sets of features were extracted from the signals in different domains (time, frequency, and fractal dimension) [1]. Then several classifiers of different types such as Random Forest, SVM, Linear Discriminant Analysis (LDA), Convolutional Neural Network (CNN), and EEGNet were implemented to evaluate model performance [2]. On the other hand, to assess whether an optimization process could improve the performance (accuracy) of the aforementioned methods, a GA was implemented (See Figure 1 for consult its main parameters) to explore different combinations of preprocessing methods, feature extraction techniques, and classifiers. Before applying genetic algorithms, the initial accuracies were as follows: SVM at 48.5%, RF at 48.25%, LDA at 45%, and CNN at 70%. Whereas, using the GA for the optimization stage, CNN achieved 80% accuracy, Support Vector Machine (SVM) reached 57.75%, Random Forest (RF) 65.5%, and LDA 47%.

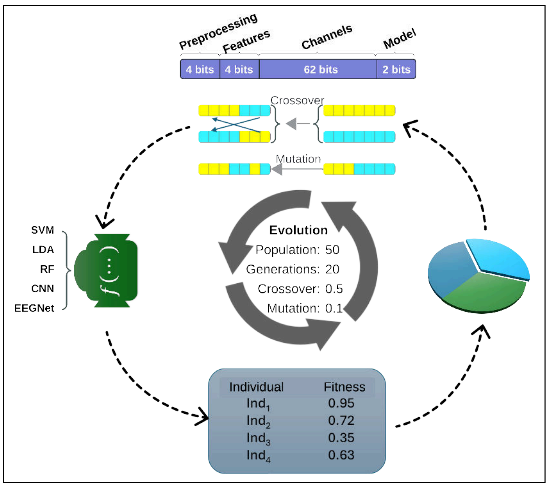

Figure 1: *Diagram of the configuration of the genetic algorithm with the probabilities in each evolution and the genes that will change.*

Conclusion: Our experiments suggest that the classification of EEG signals related to motor imagery of a new subject using fewer instances is feasible in an intersubject scheme. Two approaches were assessed, highlighting the approach based on GA to optimize the models. A better performance could be reached by applying fine-tuning to the model for a new subject using a few instances of this.

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Bayesian Reinforcement Learning for Optimizing the BCI-Utility of P300 Brain-Computer Interfaces

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Introduction: P300 brain-computer interfaces (BCIs) provide a means of communication for individuals with severe disabilities by analyzing EEG responses to a series of stimuli [1]. A key challenge in these systems is optimizing BCI-utility, a comprehensive metric that balances accuracy and speed while incorporating the cost of error correction [2]. Methods such as dynamic stopping, which determines when enough information has been collected, and dynamic stimulus selection, which determines the next stimulus based on prior EEG responses, can potentially significantly improve BCI-utility. Meanwhile, advances in reinforcement learning (RL) have demonstrated its potential to address complex decision-making tasks in diverse domains, making it a promising approach for optimizing real-time BCI systems.

Methods: We propose a Bayesian model-based reinforcement learning (RL) framework that systematically optimizes both a dynamic stopping policy and a dynamic stimulus selection policy to maximize BCI-utility. The BCI system is treated as an agent, with each stimulus representing a state. The state consists of confidence scores for characters, calculated from classifier scores of previous EEG responses. At each state, the agent decides whether to stop and predict the target character (dynamic stopping policy, π_1) or to continue by selecting the next stimulus to present (dynamic stimulus selection policy, π_2). The dynamic stopping policy is implemented using an actor-critic algorithm. For stimulus selection, a Gaussian process-based Bayesian model predicts changes in confidence scores resulting from the next stimulus, guiding the agent to select the next stimulus that maximizes the expected BCI-utility. Figure 1 illustrates the workflow of this framework. Furthermore, the framework can effectively address online implementation challenges, including the double-target issue and delayed EEG responses.

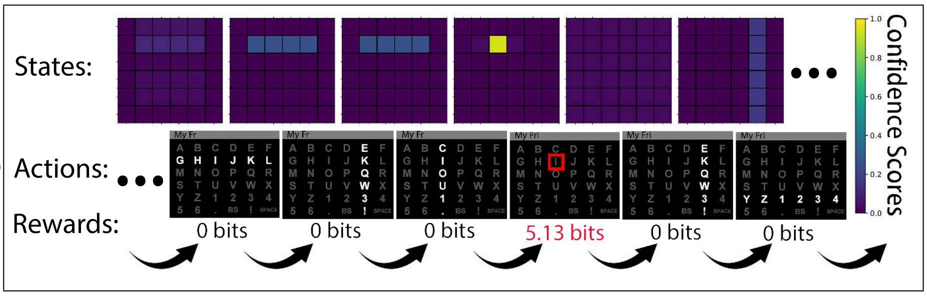

Figure 1: *Illustration of the reinforcement learning framework in P300 BCIs.*

Results: The proposed framework was evaluated on simulated datasets with varying signal-to-noise ratios (SNRs) and validated using recorded EEG data from a P300 speller study conducted by the University of Michigan Direct Brain Interface (UMDBI) laboratory [3]. Simulations demonstrated that our method significantly improved BCI-utility compared to benchmark methods across different SNR conditions. On real participant data, the framework achieved approximately a 20% improvement in BCI-utility while maintaining an accuracy of around 90% and reducing the time required per character. These results highlight the framework's ability to enhance BCI-utility by balancing speed and accuracy.

Conclusion: By integrating Bayesian model-based reinforcement learning, the proposed framework demonstrates significant improvements in BCI performance.

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Classification of upper extremity function in stroke using magnetic resonance imaging acquired during Brain-computer interface protocols for neurorehabilitation

J. Cantillo-Negrete[1], M.E. Rodriguez-García[2], P. Carrillo-Mora[1], N. Marín-Arriaga[1], R. Valdés-Cristerna[2], RI. Carino-Escobar[1*]

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Introduction: Upper extremity (UE) motor function is highly relevant for assessing the clinical and neuroplastic effects of brain-computer interfaces (BCI) aimed at stroke neurorehabilitation. However, trained personnel and specialized material are needed for performing clinical assessments of the UE. Magnetic resonance imaging (MRI) is already employed for stroke diagnosis and could also be used for UE motor function assessment within BCI protocols.

Material, Methods and Results: In this study, a dataset acquired during two BCI studies aimed at stroke neurorehabilitation with the ReHand-BCI system was used [1]. The dataset was comprised by 85 measurements of UE sensorimotor function measured with the Fugl-Meyer Assessment for Upper Extremity (FMA-UE) [2], functional performance measured with the Action Research Arm Test (ARAT) [2], as well as diffusion tensor imaging (DTI) obtained from MRI. The ratio of fractional anisotropy, a measure of interhemispheric white matter integrity was computed from the DTI sequences across 21 regions of interest. These features were used to classify if patients had UE motor function in their paralyzed hand using a hyperparameter-free machine learning algorithm [3]. For FMA-UE the model had a classification accuracy of 88% while for ARAT it was 81%. For assessing FMA-UE, the white matter interhemispheric integrity of the superior coronata radiata was the most important feature, while for ARAT, it was the posterior limb of internal capsule, as shown in Fig.1.

Conclusion: Interhemispheric white matter integrity can be used to detect if stroke patients present UE motor function in their paralyzed hand during BCI neurorehabilitation interventions.

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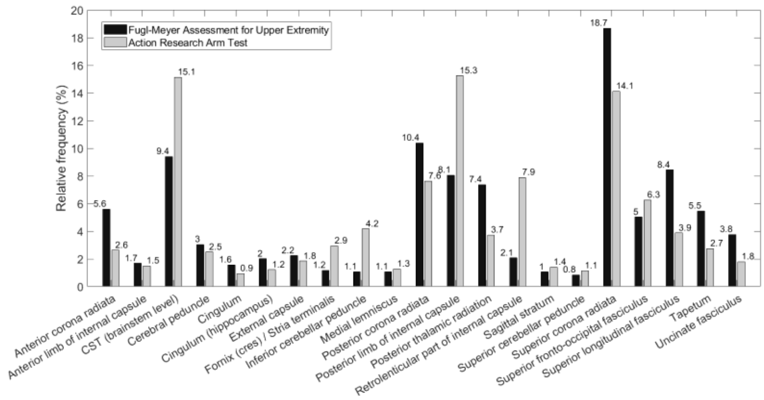

Figure 1: *Importance of regions of interest within the corticospinal tract (CST) for the classification of upper extremity motor function.*

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Building ethics into next-generation BCI: A model for embedded ethics in neurotechnology industry

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Introduction: Over the last decade, brain-computer interfaces (BCIs) and neurotechnology have become an impactful industry, innovating for various applications and enjoying optimistic market projections.[1] In this context, deep ethics integration is more important than ever. Embedded ethics, popularized via frameworks like responsible research and innovation (RRI),[2] has been applied in some academic neurotechnology research labs.[3] However, despite industry members' interest in ethics,[4,5] this model is largely absent from neurotechnology industry.[6] Prior work in our lab identified some potential reasons for this. For instance, traditional embedding emphasizes idea generation through embedded observation, which can be impractical in industry. Moreover, the distinction between embedding and consulting can become blurred in the industry context. Here we present a partial embedding approach that addresses these challenges to support research that both draws from and contributes to neurotechnology industry.

Materials, Methods and Results: We implemented our model in partnership with Motif Neurotech, a company developing novel therapeutic neurotechnology to measure and regulate mental and cognitive states. Our process (Fig. 1) begins with pre-embedding discussions between neuroethicists and company leadership to identify valuable research directions. Background research based on this early brainstorming informs both the project proposal and the identification of relevant teams for embedding. In this project, we established relationships with product, science, clinical, and lived experience teams that ranged from participation in team meetings to one-on-one meetings with team members to develop research questions, methods, applications of potential findings, and more. Through this process, we co-developed a research project examining how factors such as neurotechnology device characteristics, implantation procedures, and therapeutic regime impact patients' risk perceptions and willingness to undergo a neurotechnology intervention. As study activities are completed in the spring, we will collaborate with Motif team members to incorporate findings into future decision-making related to device development and commercialization activities. Critically, the project is designed to generate insights into patient perspectives that will inform not only the specific partner company, but also priorities for future implanted BCI and neurotechnology research across the field.

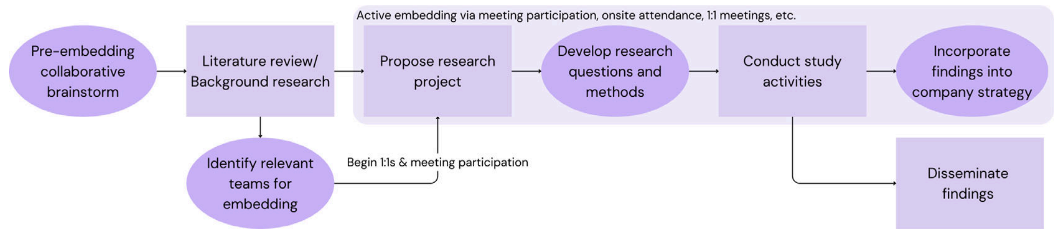

Figure 1: Process for conducting embedded ethics research with neurotechnology industry partners. Ovals represent steps taken in active collaboration with team members at the partner company.

Discussion and Significance: This project presents a new model for ethics engagement in the neurotechnology industry. Beyond collaboration or consulting, the embedded model fosters deeper integration of the ethicist with the company and prioritizes research with broad implications for the field while remaining grounded with practical industry needs. Moreover, the embedded model can generate ethics recommendations that are mindful of the constraints and realities of neurotechnology companies.

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From Physical to Virtual: Expanding Boccia Accessibility through Patient Partner Engagement

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Introduction: Participation in sports provides significant development, social, and quality of life benefits. Paralympic sports, such as Boccia, provide an avenue for individuals with complex needs to participate in sports. Boccia is a precision Paralympic sport that consists of propelling a ball as close as possible to a target (i.e., a jack ball). Athletes who cannot propel the ball by themselves can use a ramp operated by an assistant. However, those with complex motor needs and limited communication cannot currently play and are deprived of their right to participate. To allow these individuals to play Boccia, we developed a brain computer interface (BCI)-enabled Boccia system that consists of a hardware ramp prototype, and P300-based software to control the rotation of the ramp or the height of the ball [1]. The hardware prototype was functional but lacked ease of transportation and operation. Additionally, the software required multiple P300 selections to reach the desired position. The purpose of this work was to improve the design using a patient partner engagement approach.

Material, Methods, and Results: To improve the ease of use and the user experience we engaged six patient partners. This included three families with BCI experience, two professional Boccia athletes, and one recreational Boccia athlete. Patient partner input for the hardware prototype focused on the importance of ramp stability, rigidity, and ease of transportation (Fig. 1A). We adapted the rolling floor stand from Ideas for Independent Living, Inc (Scarborough, Canada). Patient partner input for the software prototype focused on requiring fewer P300 selections to position the ramp. We developed the new software using the Unity 3D game engine with the BCI-essentials Unity package [2]. The new ramp control interface consists of two fan-shaped selectors that allow more intuitive positioning of the ramp while requiring fewer P300 selections (Fig. 1B). Additionally, patient partners highlighted the importance of being able to use the system at home. Thus, we implemented a software simulation mode. In this mode, the user can control a simulated virtual ramp to practice with the BCI system.

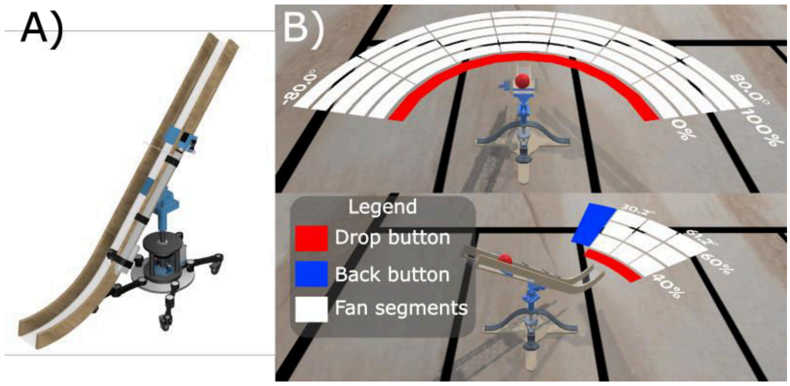

Fig. 1. A). Render of the modified hardware prototype. B) Screenshots of the new software interface. Top: coarse fan for absolute position. Bottom: fine-tunning fan for smaller, relative position adjustments. The player can adjust the number of segments of the fans, and ranges of motion to suit their needs.

Conclusion: Patient partner engagement resulted in improvements of the hardware prototype and software of the BCI-enabled Boccia system. This new design promises to improve user experience thanks to more stable hardware that is easier to operate and transport, and software that is more intuitive to use. Further validation of the system with the target population will focus on measuring ease of use.

Acknowledgments and Disclosures: We would like to thank the patient partners that contributed to the co-design of the new software and hardware. The authors have no conflicts of interest to disclose.

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The first BCI clinical trial for stroke neurorehabilitation in Latin America: The ReHand-BCI trial

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Introduction: More than 20 million people are estimated to live with stroke sequalae in Latin America, with limited access to rehabilitation, particularly for upper extremity (UE) neurorehabilitation [1]. Brain-Computer Interfaces (BCI) could increase neurorehabilitation access for the region. However, more clinical trials are needed for assessing their clinical and physiological effects. For these reasons, an electroencephalography-based BCI for stroke UE neurorehabilitation, the ReHand-BCI, was developed and assessed in the National Institute of Rehabilitation at Mexico City in the first clinical trial of its type in Latin America (NCT04724824).

Material, Methods and Results: The study was a triple-blinded randomized controlled clinical trial, that aimed to assess the clinical and neuroplastic effects of 30 sessions of therapy with the ReHand-BCI (depicted in Fig. 1) [2]. In the experimental group (EG), patients attempted to control the movement of a 3D-printed robotic orthosis that provided passive finger movement by decoding hand movement intention from electroencephalography (EEG). The control group (CG) was comprised by a sham-BCI intervention. Nineteen patients completed the trial. There were no significant between-group differences. However, only the EG had significant improvements in both clinical measures after the intervention and at follow-up, and a tendency of higher ipsilesional corticospinal integrity measured with the ratio of fractional anisotropy computed from magnetic resonance imaging, as shown in Fig. 2.

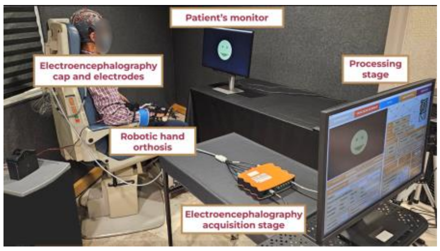

Figure 1: *The ReHand-BCI system.*

Conclusion: Stroke patients can improve their upper extremity function with both a BCI and sham-BCI intervention, but functional performance of the upper extremity and ipsilesional enhancement of corticospinal tract integrity seems to be promoted in a greater degree if kinesthetic feedback is provided according to hand motor intention.

Acknowledgments and Disclosures: The authors declare no conflicts of interest and acknowledge Consejo Nacional de Humanidades, Ciencias y Tecnologías for supporting this study through grant SALUD-2018-02-B-S-45803 and DGPIS for the grant FPIS2024-INR-6865.

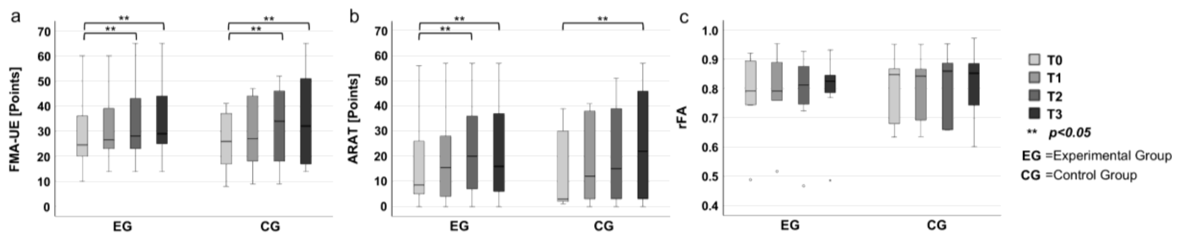

Figure 2: a) *Outcomes of the Fugl-Meyer of the Upper Extremity (FMA-UE), b) Action Research Arm Test (ARAT) c) Ratio of fractional anisotropy (rFA) for pre (T0), intermediate (T1), post (T2), and 6-month follow-up (T3) intervention measurements.*

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Wavelet Scattering-based EEG Channel Reduction for Motor Imagery Classification

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Introduction: EEG-based motor imagery (MI) classification has been widely used for movement brain-computer interfaces (BCIs) to enable intuitive control of external devices. A key challenge in MI-BCIs is reducing the number of EEG channels to minimize computational burden and improve user comfort, while maintaining robust classification performance [1]. Wavelet scattering, a method that captures hierarchical time-frequency features, has shown promise for robust feature extraction from EEG signals [2]. Here, we investigate wavelet scattering-based channel selection for MI classification and evaluate its performance.

Methods and Results: This study utilized the publicly available Shu EEG dataset [3], consisting of motor imagery (MI) data from 25 subjects across five sessions, recorded during left- and right-hand MI tasks using 32 EEG channels. Wavelet scattering was used to process the raw EEG signals, which involves wavelet filter convolution, modulus transformation, and low-pass filter averaging. Scattering coefficients for each channel were ranked by their mutual information with MI class labels, and the top 15, 9, 7, 5, and 3 channels were selected. A simple convolutional neural network (CNN) consisting of three convolutional layers was used for 10-fold cross validation classification. The classification accuracy was 79.24% when all channels were used, and showed the highest of 79.81% with 9 selected channels. A performance of 77.44% was reported when only 3 channels were used. Statistical analysis using the Friedman test followed by the Wilcoxon signed-rank test with Bonferroni correction showed no significant differences in accuracy across all channel counts. We also examined the differences in selected channels between a high and low performer. The high performer showed a consistent selection of channels on the motor and prefrontal cortex, while the low performer displayed a more dispersed selection pattern.

Conclusion: This study demonstrates the effectiveness of wavelet scattering as a robust feature extraction method for EEG-based motor imagery classification. We achieved comparable classification performance with significantly reduced channel sets, underlining the potential for efficient BCIs without compromising performance.

Acknowledgments: This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT)(RS-2024-00417959).

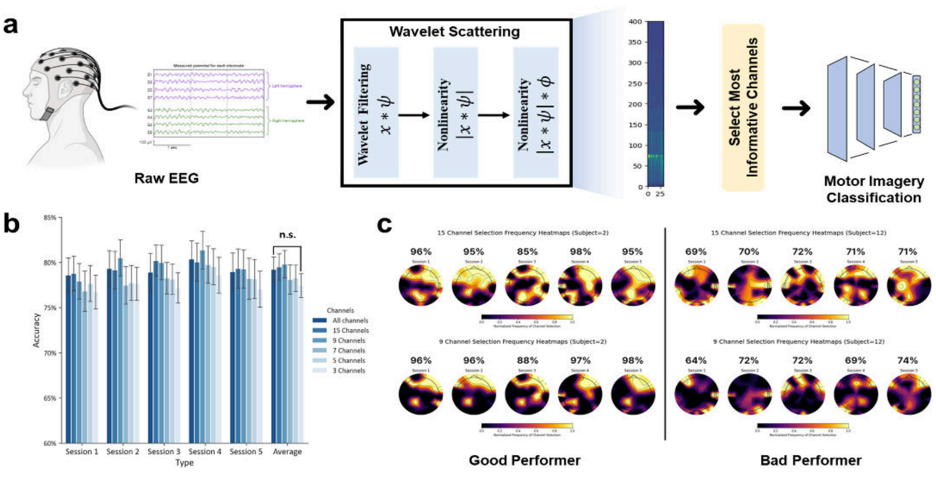

Figure 1. ***a*** *Schematic of wavelet scattering-based channel selection using mutual information.* ***b*** *Classification accuracies across all sessions according to the number of selected channels showed no significant differences.* ***c*** *Heatmap of selected channels. The good performer consistently selected motor and prefrontal cortex electrodes unlike the bad performer (top: 15 channels, bottom: 9 channels).*

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Transformative and Generative Data Augmentation for EEG-based BCIs

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Introduction: The effectiveness of machine learning models used in brain-computer interfaces (BCIs) is often limited by the availability of training data [1]. In this study, we explore data augmentation methods to enhance machine learning classifier performance on imbalanced datasets, specifically in BCIs based on the Rapid Serial Visual Presentation (RSVP) paradigm [2].

Materials, Methods and Results: We considered two types of data augmentation techniques. First, *transformative* methods that generate new samples by manipulating existing datasets, including frequency shift (FS) , Fourier transform surrogate (FTS), smooth time mask (STM), and time shift (TS) [3]. The second type uses *generative* artificial intelligence approaches to produce synthetic data, including class-conditioned Wasserstein GANs (CCWGAN) [4] and a conditioned denoising diffusion probabilistic model (CDDPM) [5]. The impact of these methods for augmenting data in two RSVP public datasets [1, 6] was assessed using four different classifiers: LDA, RSVM [7], MDM [8], and EEGNet [9].

Among the *transformative* methods, STM provided the most consistent performance improvement, with gains of up to 8.36%, followed by TS with improvements of up to 5.29%.

Regarding the *generative methods*, the EEG-optimized CCWGAN excelled in generating signals with high temporal similarity and validity (c.f., Figure 1). Meanwhile, the CDDPM, adapted from computer vision, demonstrated improved training stability. However, both generative methods showed a consistent decrease in classification performance when synthetic data was used to train an MDM classifier. In turn, the EEGNet decoder maintained comparable average performance across subjects regardless of the amount of augmented data used, while some subjects exhibited improved performance.

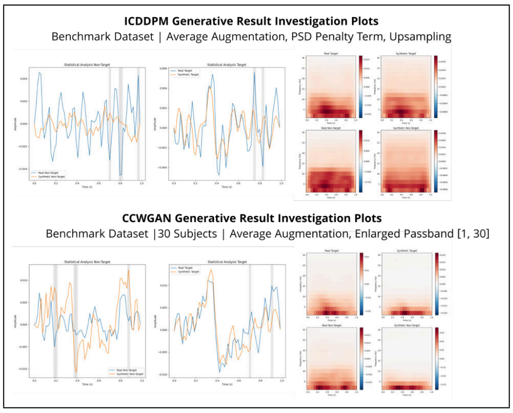

Figure 1: *Qualitative Comparison between generative Results of ICDDPM and CCWGAN.*

Conclusion: We found that *transformative* data augmentation event yield more consistent performance improvement in RSVP paradigms characterized by high class imbalance. Synthetic data created with *generative* approaches yielded signals with similar temporal an spectral characteristics. However, our results suggest that data augmentation using *generative* methods is more subject-dependent than for *transformative* methods. *Acknowledgments and Disclosures:* N/A.

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Too busy to feel? Studying the impact of workload on visuo-tactile perception through EEG

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Introduction: Perception lies at the heart of our interaction with the environment. Users in virtual reality (VR) can develop a sense of ownership over their virtual body [2]. This sense of embodiment leads users to interact with and protect their virtual body as if it were their own. However, it remains unclear how brain activity reflects the perception of virtual interactions. Furthermore, workload is known to influence attention processes and perception [3], with these effects varying depending on the sensory modalities that are overtaxed [1]. Thus, the goal of our study was to assess neurophysiological modifications occurring during visual and visuo-tactile stimulation in VR under different workload conditions.

Material, Methods and Results: A total of 32 participants were embodied in a virtual avatar, that resembled them (e.g., in terms of gender), using an HTC Vive Cosmos and a Leap Motion. A 6-axis robotic arm (Universal Robot UR5) with a soft foam ball as end effector, delivered tactile stimulation to the participant's hand, while a replication of the virtual robot delivered visual stimulation to the avatar's hand following the movement of the real robot. Using this system, visuo-tactile touch (using real and virtual robot) or visual-only touch (using virtual robot) was delivered while the brain activity was recorded using EEG (48 active electrodes; g.USBAmp from g.tec). To assess the impact of workload, we employed a N-back task in which participants had to compare a number displayed on their hand after each stimulation, determining whether it matched the number from one stimulus ago (1-back, low workload) or three stimuli ago (3-back, high workload).
Signal was filtered using a notch filter at 50 Hz and a band-pass filter between 0.1 and 30 Hz. We applied an independant component analysis to mitigate artifacts. Epochs were realigned so that the onset of the stimulation is at time 0. We studied the impact of workload on the perception of touch by observing event-related potentials (ERP) over the sensorimotor band relative to the left hand (CP4) (Figure 1a). We found significantly lower ERP amplitudes ($F(1, 26) = 13.17$, $p = 0.001$, $\eta^2 = 0.071$) (Figure 1b) in response to the visuo-tactile touch when the workload was high (mean = $5.01(\pm 2.23)\mu V$) compared to low (mean = $3.96(\pm 1.58)\mu V$), suggesting that workload led to a reduction in ERP amplitudes in response to visuo-tactile touch. However, we didn't find any significant difference in the visual-only condition.

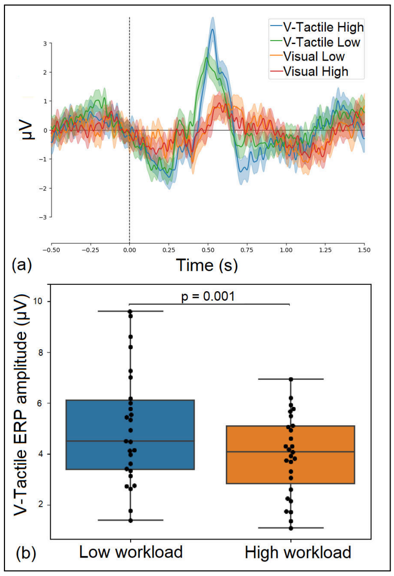

Figure 1: *(a) Grand-average event-related potential in reaction to the stimulation. (b) Amplitude of the positive potential measured between 400 ms and 700 ms after stimulus onset for the visuo-tactile touch.*

Conclusion: In this experiment, we show a direct evidence of the impact of workload on the tactile perception, consistent with findings in the literature [4], but not on the visual stimulation. Subsequent analyses will investigate the underlying reasons for the differences in the effect of workload between visual and visuo-tactile touch, as well as the potential role of embodiment in shaping these differences.

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Addressing the Non-stationary Learning Problem with Graph Attention Networks in Motor Imagery

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Introduction: ALS progression causes non-stationary EEG signals, challenging methods like Common Spatial Patterns (CSP). While adaptive BCI research addresses non-stationarity and cross-session adaptation, they often rely on few sessions from healthy subjects [1] thereby neglecting to truly tackle the issue. Representing EEG signals as graphs provides a dynamic framework for decoding neuronal interactions with reduced computational cost, improving motor imagery classification in the face of non-stationarity. We propose using Graph Attention Networks to enhance classification accuracy over sessions, advancing longitudinal, robust BCIs for real-world applications [2].

Material, Methods and Results: We use two multi-session datasets: 25 healthy subjects (SHU dataset: 5 sessions, 500 trials/class) and 8 ALS patients (4 sessions over 2 months, approx. 160 trials/class), both performing Left and Right Motor Imagery. A novel 3 Layer GAT model (GAT Layer, ReLu, GraphNorm per layer) (≈7000 Parameters) with Phase Locking Value input is trained on the first session of each dataset, with subsequent sessions used for testing. The performance is compared against Band Power of each electrode with LDA, CSP with SVM, EEGNet (≈ 3000 Parameters), and DeepConvNet (≈ 180000 Parameters).

Conclusion: BCI subjects from diverse cohorts and varying performance levels consistently achieve better outcomes with PLVGAT compared to alternative state-of-the-art methods as demonstrated in Fig. 1, which are often computationally intensive. This underscores PLVGAT's effectiveness in capturing dynamic brain connectivity, providing a more accurate and adaptable solution for longitudinal motor imagery classification across larger cohorts. Notably, the model excels with participants who struggle with traditional techniques, thereby addressing BCI Inefficiency and improving usability.

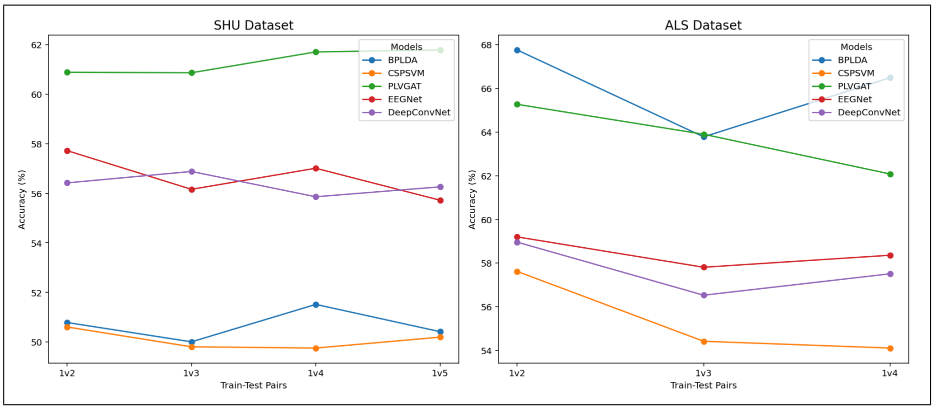

Figure 1: *Cross session accuracies over SHU and ALS datasets with five models including PLVGAT*

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Dynamic Class Balancing for Real-time Decoder Learning

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Introduction: Real-time BCI decoders training enables taking into account the sensitive responses in the brain neural signals. However, during the training sessions, class imbalance can occur, significantly decreasing the decoder's performance. Class balancing during online streaming model learning is a challenging task as the full training dataset is not available. Moreover, during a session, the experimenter can add new classes/tasks, disrupting class balance. This paper introduces an algorithm for dynamic class balancing during real-time BCI decoder learning, and addressing key BCI requirements: multiclass support, online training, low computational requirements for high-dimensional data.

Material, Methods and Results: This paper proposes the Recursive Sample Weighted – N-way Partial Least Squares (RSW-NPLS) algorithm integrated into a HMM, for dynamic online class balancing during decoder training. The algorithm dynamically tracks the size of classes to compute weights assigned to the training samples at each decoder update. A constraint is applied to avoid large weights. The proposed algorithm is compared in pseudo-online configurations to the generic Recursive Exponentially Weighted – N way Partial Least Squares (REW-NPLS) algorithm using 3 databases from 2 patients. BCI – Exo5, and BCI – Exo8 databases were recorded with a tetraplegic patient (P1) [1] (clinical trial "BCI and Tetraplegia", NCT02550522). BSI – Gait database was recorded in a paraplegic patient (P2) [2] (clinical trial "STIMO-BSI", NCT04632290). Both patients were implanted with two WIMAGINE ECoG recording implants [3] placed in the skull, facing the sensory motor cortex. The patient P2 was also implanted with a spinal cord stimulator to activate his leg muscle groups and restore gait. We consider a 5 states classification problem (right and left hands translation, wrists rotation, idle states) with the database BCI – Exo5. BCI – Exo8 introduces 3 additional classes (right and left grasps, and a walking state). 3 states (left and right hips flexion, idle states) were decoded for the database BSI – Gait. The features were extracted using complex continuous wavelet transform (Morlet) from ECoG recording of 64 channels. The proposed *RSW*-NPLS based HMM outperforms the generic *REW*-NPLS based HMM in term of classification performance (56%, 209%, 18% of improvement for BCI – Exo5. BCI – Exo8, BSI – Gait databases respectively) (Fig.1). The proposed algorithm effectively compensates class imbalance in real-time and maintains high performance, even in case of significant training data imbalance.

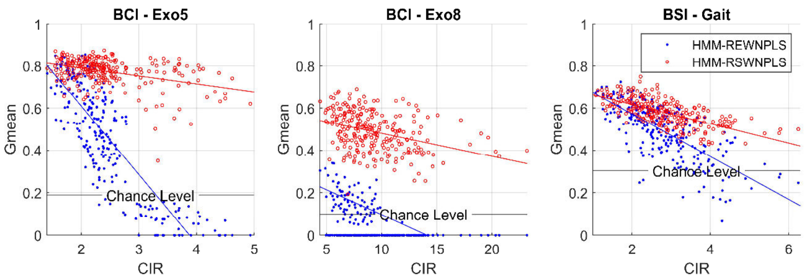

Figure 1: *Gmean performance criterion depending on Class Imbalance Ratio (CIR), the ratio of the majority and the minority class sizes, for 3 databases for the generic REW-NPLS based HMM and the proposed RSW-NPLS based HMM algorithms.*

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An intuitive, bimanual, high-throughput QWERTY keyboard touch typing neuroprosthesis

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Introduction: Keyboard touch typing represents a high information rate communication paradigm that most people are familiar with. In this work we introduce an intracortical brain computer interface (iBCI) typing neuroprosthesis that mimics a bimanually controlled QWERTY keyboard layout with corresponding able-bodied typing imagery. Typing with our keyboard involves minimal attempted finger movements which, as we show, can be decoded accurately and robustly, and may be less effortful for the user compared to other augmentative and alternative communication methods. Decoding is performed at the sentence level, allowing typing speed to be regulated by the user.

Material, Methods and Results: Previous iBCI handwriting [1] decoding has the potential to be limited in accuracy for users with overlapping neural trajectories pertaining to similarly shaped characters. Our typing paradigm provides versatility, by offering an alternative iBCI communication method for users who may have superior finger decoding. Our typing neuroprosthesis performs sequence decoding of key presses using a Recurrent Neural Network (RNN) decoder trained using a Connectionist Temporal Classification (CTC) loss function, similarly to [2, 3, 4]. When paired with a probabilistic 5-gram language model, decoding is much improved via integration of RNN decoder output and English language statistics, where the deliberate QWERTY keyboard layout reduces sentence inference confusion, in an out sized way compared to other communication based sequence decoding paradigms [1, 2, 3, 4]. The results from two iBCI clinical trial participants (T17 and T18) communicating using this decoding paradigm indicates that our neuroprosthesis is user and pathology robust. We report communication speeds reaching 84 characters per minute, approaching the state-of-the-art in hand-motor based iBCI communication rate [1], resulting in 16 words per minute with a character error rate of 1% at this high speed.

Conclusion: In this work we introduce a touch typing neuroprosthesis which we show to be among the fastest iBCI communication methods based on decoding of hand motor cortex neuron populations, while maintaining high precision. Our typing neuroprosthesis represents an intuitive, familiar, and easy-to-learn communication device for individuals with quadriplegia caused by ALS, spinal cord injury, and related conditions.

Acknowledgments and Support: We thank T17, T18, their families and carepartners for the time and effort they contributed to the BG2 trial. This work was supported by Office of Research and Development, Rehabilitation R&D Service, Department of Veterans Affairs (N2864C,A4820R, A2295R); NIH NIDCD (U01DC017844, R01DC014034, U01DC019430, K23DC021297,1DP2DC021055); NIH NINDS (U01NS123101, R25NS065743), AHA (23SCEFIA1156586); CDMRP (HT94252310153), A.P. Giannini Postdoctoral Fellowship to N. Card. Disclosures: IDE Caution Statement: CAUTION: Investigational Device. Limited by Federal Law to Investigational Use. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health, or the Department of Veterans Affairs, or the United States Government. The MGH Translational Research Center has a clinical research support agreement (CRSA) with Axoft, Neuralink, Neurobionics, Precision Neuro, Synchron, and Reach Neuro, for which LRH provides consultative input. LRH is a co-investigator on an NIH SBIR grant with Paradromics, and is a non-compensated member of the Board of Directors of a nonprofit assistive communication device technology foundation (Speak Your Mind Foundation). Mass General Brigham (MGB) is convening the Implantable Brain-Computer Interface Collaborative Community (iBCI-CC); charitable gift agreements to MGB, including those received to date from Paradromics, Synchron, Precision Neuro, Neuralink, and Blackrock Neurotech, support the iBCI-CC, for which LRH provides effort. Stavisky is an inventor on intellectual property owned by Stanford University that has been licensed to Blackrock Neurotech and Neuralink Corp. Wairagkar, Stavisky, and Brandman have patent applications related to speech BCI owned by the Regents of the University of California. Stavisky was an advisor to wispr.ai and received equity. Brandman is a surgical consultant to Paradromics Inc.

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Virtual Reality-Based Investigation of Error-Related Potentials in ADHD for BCI applications

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Introduction: Error-related potentials (ErrPs) represent specific brain activity patterns elicited when individuals recognise errors during task performance, measurable via electroencephalography (EEG), and have been linked to executive functions and self-monitoring processes. In individuals with Attention Deficit Hyperactivity Disorder (ADHD), atypical cognitive and brain functions include reduced amplitudes of error-related negativity (ERN), (McLoughlin et al., 2022) and affected self-monitoring. To better understand potential biomarkers and treatment targets, we developed and tested a virtual reality (VR) environment of an adapted Wisconsin Card Sorting test to study ERN in ADHD and neurotypical populations (Figure 1) in a more ecologically valid way, using machine learning to classify the ErrPs.

Material and Methods: Participants (N=20) were divided into ADHD and neurotypical groups based on Conners' Adult ADHD Rating Scales. A VR-based task inspired by the Wisconsin Card Sorting Test (Berg, 1948) required sorting study-related objects by colour or shape, with feedback indicating correct or incorrect actions. Two error types were simulated: feedback errors (intentional incorrect feedback) and tracking errors (object manipulation failures). EEG data was recorded and processed to identify ErrPs. Machine learning classifiers were trained to distinguish between error types and participant groups.

Results: Behavioural and EEG data analysis revealed a trend towards a reduced ERN amplitude in the ADHD group compared to controls, aligning with prior meta-analytic findings (e.g., Bellato et al., 2021). However, this reduction was not statistically significant. Machine learning classifiers successfully distinguished error types and participant groups, with all tested models outperforming a dummy classifier, emphasizing the potential use of ErrPs in Brain-Computer Interface applications.

Conclusion: This study demonstrates the feasibility of using VR to investigate ErrPs in ADHD and control groups. While the reduction in ERN amplitude in ADHD was not significant, the medium effect size suggests the potential for further exploration with larger samples. Machine learning-based classification supports the future development of various BCI applications, such as adaptive self-corrective systems leveraging real-time brain data.

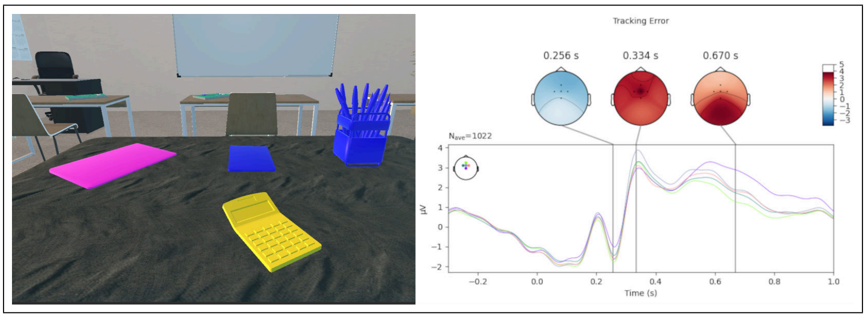

Figure 1: *Left: VR-based task environment. Right: Grand average ErrP and topoplot in the "Tracking Error" condition in the area of interest.*

Acknowledgments: We thank Alexandros Christopoulos for his support in data collection and analysis.

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Decoding Hand Gestures from Gyral and Sulcal Regions of the Sensorimotor Cortex Using High-Resolution fMRI

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Introduction: Implantable brain-computer interfaces (iBCIs) aim to restore communication for individuals with severe motor impairments by establishing a pathway between signals measured from the surface of the brain and a computer. The recording electrodes are commonly placed in or on the sensorimotor gyri, covering parts of the precentral and/or postcentral gyrus. However, much of the human primary motor cortex (M1) is located within the central sulcus [1] and is thereby not easily accessible for electrodes [2]. To establish the potential contribution of sulcal information for decoding, this study compares the classification performance of hand movements in the sulcal and gyral part of the sensorimotor cortex using 7-Tesla functional magnetic resonance imaging (fMRI).

Material, Methods and Results: Ten able-bodied volunteers (age: *mean* = 25.5 years, *range* = 21–42 years, 6 females) participated in the 7-Tesla fMRI study. They performed 20 different gestures with the right hand during fMRI acquisition (*voxel size* = 1.5 mm^3). Results showed that all 20 gestures were classified above chance level (5%) in the primary motor cortex (M1; *mean* = 26%, *SD* = 5%, $p < 0.001$) and the somatosensory cortex (S1; *mean* = 42%, *SD* = 7.4%, $p < 0.001$). The most informative voxels for gesture classification within the combined sensorimotor cortex were located in the hand knob region, covering both the sulcal and gyral areas (Fig. 1B). In M1, classification performance did not significantly differ between the sulcus and the gyrus ($t(9) = -0.5$, $p = 0.6$, $CI = [-5.5, 3.3]$; Fig.1A), while in S1, the classification performance was significantly higher in the gyrus than in the sulcus ($t(9) = 5.3$, $p < 0.001$, $CI = [7.2, 17.7]$)).

Conclusion: These findings suggest that choosing intrasulcal recordings for decoding from M1 and S1 may not benefit performance compared to gyral recordings for BCIs. It should be noted that S1 activity during the task might be driven by proprioceptive and tactile feedback of the executed movements. Thus, the observed higher classification performance in the S1 gyrus compared to the sulcus might be absent in paralyzed individuals.

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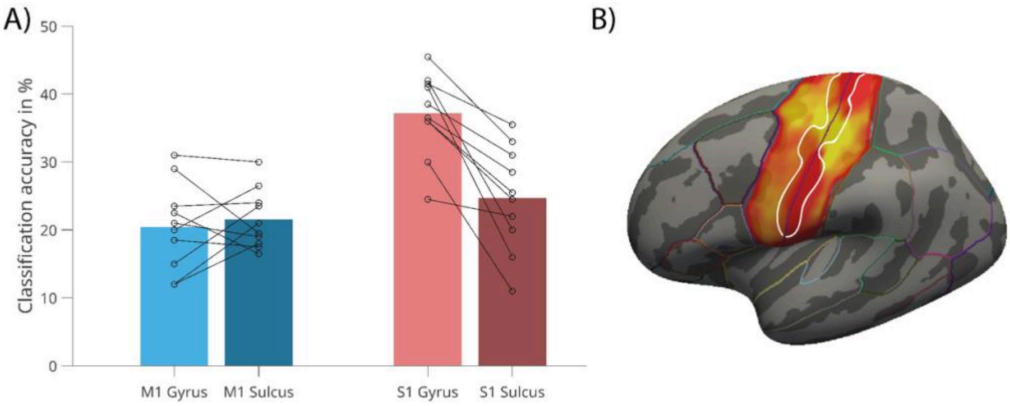

Figure 1: A) *Mean gyral (light) and sulcal (dark) classification accuracy of 20 gestures for M1 (blue) and S1 (red). The circles and connecting black lines show single-subject performance.* B) *Group-averaged SVM-weights show the contribution of sulcal and gyral parts of the sensorimotor cortex to the gesture classification; yellow color indicates higher contribution.*

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Identifying Brain Activity Biomarkers For Cognitive Skills In Children Aged 7 To 12 Years Using The EPOC X Mobile EEG

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Introduction: Neurodevelopment disorders (NDDs) are one of the most frequent disabilities among children. However, strong overlap exists across NDDs symptoms that are challenging for diagnosis and therapeutic intervention [1]. Among emerging techs, mobile electroencephalography (mEEG) is a good candidate for identifying brain activity biomarkers of NDD children and for understanding the underlying neural mechanisms of these conditions, such as cognitive, linguistic and emotional dysfunctioning [2]. The present study intends to identify brain activity biomarkers for specific cognitive skills in children aged 7 to 12 years.

Material, Methods and Results: Participants were retrieved from the EPIDIA4Kids study (CPP Sud-Est II, 2022-A00766-37) database as of December 22nd 2024. Quantitative EEG (qEEG) signals were recorded from 12 French-speaking children without brain injuries or epilepsy (mean age = 11.0 years) during gamified psychometric task sessions. These children also underwent neuropsychological assessments (WISC-V) and self-report questionnaires (children and parents). EEG data were preprocessed using Emotiv Pro. Correlations were identified between neuropsychological performance scores and EEG power bands in two fronto-central regions (FC5 and FC6). Relationships of relative alpha band power (8–13 Hz) were examined with linguistic performance through mixed models and principal component analyses (MATLAB and SAS Version 9.4).
During gamified psychometric task sessions, alpha power in FC5 and FC6 was found associated with performances on the "Similarities" ($F=5.91$, $p=0.03$) and "Vocabulary" subtests ($F=6.99$, $p=0.02$), both involved in lexical information processing and altered in NDD while no association was found on "Matrix reasoning".

Conclusion: These findings strongly suggest alpha power in the fronto-central regions as a good candidate for linguistic processes biomarker. Future analyses will extend to beta power and the theta/beta ratio (TBR) to further explore their associations with cognitive performance, providing additional insights into NDD diagnostic markers.

Acknowledgments and Disclosures: We would like to express our sincere gratitude to the entire O-Kidia team and the Bioelectronics Department at Ecole des Mines Saint-Etienne for their invaluable support and collaboration throughout this study. We are especially thankful to the children and their parents who participated in the research, as their contributions were essential to the success of this work.

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Should BCIs shape experiences of communication of people with LIS, and if so, how?

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Introduction: Locked-In Syndrome (LIS) is defined by (near) complete paralysis and intact cognition [1]. This condition profoundly shapes a person's experiences of communication [2]. Not much is known about the lived experiences of communication of people with LIS [3], which is related to the nature of LIS, where one loses almost all abilities to communicate and is reliant on augmentative and assistive communication (AAC) devices such as letter boards and eye-trackers to communicate. A promise of implantable communication-BCIs (cBCIs) is to 'restore' the communication abilities of people with LIS [4]. Considering the call for user-centered approaches to cBCI design [5], this raises the ethical question: should cBCIs shape the experience of communication of people with LIS, and if so, how?

Material, Methods and Results: We interviewed 8 people with LIS (4 female), 8 caregivers (5 female), and 10 medical professionals (8 female). The interviews with people with LIS were conducted with typing text, the others face to face. The goal of the interview was to explore typical experiences of communication, personhood, and wellbeing of people with LIS and familiar interlocutors. All interviews followed a phenomenological approach, where the goal of the interview was an in-depth, open exploration of the lived experience of the interviewee [6]. Interviews were transcribed ad verbatim and coded thematically following a grounded theory approach, making sense of the data in an iterative back and forth between the transcripts and the emerging themes. The following intertwined themes emerged to describe typical experiences of embodied communication: 1) intimate technological mediation of embodied interaction with the world (AACs shaping experiences of the voice, emotional expression, reliability, tempo and access to the world), 2) altering of familiar embodied expressions of aliveness (dehumanization, cyborgization, new communicational affordances in relation to skilled interlocutors, embodied diversity) 3) temporal delay in communication leading to a breakdown of flow (alienation from social life, failure of conversational flow).

Conclusion: For research and design of cBCIs, these results mean that user adoption stands to benefit from a focus on (tone of) voice, emotional expression, speed and reliability of communication, aesthetics of the device, designs that can adapt to the social setting and physical environment that a user is situated in, and subtle forms of embodied communication required for flow (nods, hmhm's, etc.). Moreover, these results imply a much-required shift from seeing a cBCI 'user' not as an individual but as a network that includes their close interlocutors.

Acknowledgments and Disclosures: We want to thank all the interviewees that participated in our study for sharing their experiences with us. Support by the Ethics of Socially Disruptive Technologies research program, funded by the Netherlands Organization for Scientific Research [#024.004.031]. We have no conflicts of interest to disclose.

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Imagined Phoneme Decoding and Protocol Optimization for Non-invasive EEG-based Speech BCIs

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Introduction: Speech impairments can seriously hinder quality of life. Brain-computer Interfaces (BCIs) provide a potential solution to convert thoughts into text or audio for communication restoration. Non-invasive neuroimaging techniques such as electroencephalography (EEG) offer a safe rehabilitation method [1]. However, abstract neural activities from speech and noise from scalp challenge the imagined speech decoding. Compared with motor imagery, a mature BCI paradigm with standard tasks of 'left/right' hand movement imagery [2], it is also crucial to find a robust paradigm for intuitive speech imagery (SI) BCIs with a distinct word set.

Material, Methods and Results: 10 subjects with English proficiency were asked to imagine silently speaking 6 phonemes (/b/, /p/, /s/, /e/, /i:/, /u:/). 32-channel EEG covering the temporal and primary motor cortex was recorded [3]. Then, a paired two-tailed t-test within the same subjects was done on EEG power and evoked potential to find the difference between imagined phonemes. We used a non-parametric cluster-based permutation test to reduce type I error for multiple comparisons problems [4]. Finally, binary classification tasks were performed for all 15 phoneme pairs. For each subject, we trained a CSP-SVM model and evaluated it with 5-fold cross-validation.

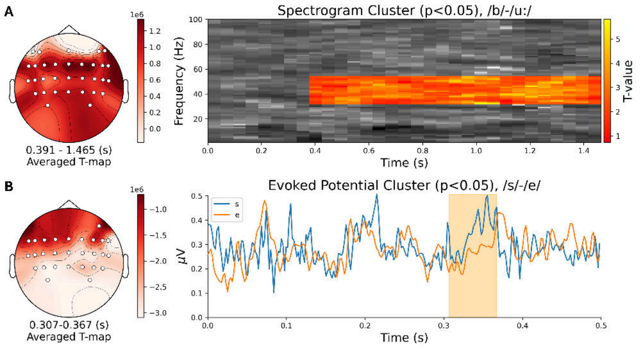

Figure 1: *(A) EEG spectrogram contrast for imagined phoneme /b/ and /u:/. showing significant time-frequency cluster (brightened) with T-values maximized over the significant channels cluster (white circles). (B) EEG evoked potential contrast for imagined phoneme /s/ and /e/ showing significant time window clusters (brightened) with evoked potentials averaged over the significant channel clusters (white circles).*

A significant time-frequency cluster was found for class power contrast between /b/ and /u:/ within the frequency band from 31 to 53 Hz (p=0.026) (Fig. 1(A)), indicating the importance of the gamma band to distinguish between bilabial plosive and rounded vowel phonemes. A significant temporal cluster was also found for evoked potential contrast between /s/ and /e/ around 300ms after the event (p=0.02) (Fig. 1(B)), showing the potential response differing between the fricative consonant and mid-front unrounded vowel. The subject with the best decoding accuracy reached an average accuracy of 67.14% on /b/ and /e/ comparison. The spectral and temporal contrast might indicate that the imagined articulation between consonants and vowels is more distinct and ideal for classification commands [5].

Conclusion: This research studied the EEG pattern of phoneme imagery and provided considerations for command selection for universal speech imagery paradigm optimization. We found significant temporal-spectral differences between some consonant-vowel pairs and the great potential of selecting the distinct phoneme set for reliable SI decoding performance. This ongoing work represents an important step towards real-time decoding with a relatively low-density EEG setup.

Acknowledgments and Disclosures: All authors declare no conflicts of interest.

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Predicting V1 spike dynamics using scalp EEG in macaques

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Introduction: Despite decades of electroencephalography (EEG) research, the relationship between EEG and underlying spiking dynamics remains unclear. This gap in knowledge limits our ability to infer intracranial signals from EEG, a critical step to bridge electrophysiological findings across species and to develop non-invasive brain-computer interfaces (BCIs).

Methods and Results: We recorded both spiking activity from a 32-channel floating microarray permanently implanted in parafoveal V1 and scalp-EEG in a male macaque monkey. While the animal fixated, the screen flickered at different temporal frequencies (0, 5, 10, 20, and 40 Hz) to induce steady-state visual evoked potentials (SSVEP). We analyzed the relationship between the V1 multi-unit spiking activity envelope (MUAe) and EEG frequency bands to predict MUAe at each time point from EEG. We found that the phase and amplitude of EEG frequency bands are differentially related to V1 MUAe, and this relationship is further dependent on stimulus frequencies. Additionally, phase-amplitude coupling exists between EEG bands. Using multivariate linear regression to predict MUAe from EEG frequency bands, we found that flickering SSVEP stimuli help predict MUAe from EEG better than non-flickering stimuli at both the trial-averaged and single-trial levels. Subsequent analyses revealed that the amplitude, phase, and coupling of EEG bands each contribute to model predictions, with MUAe signals in shallow cortical layers predicted better than deep layer MUAe. Interestingly, the phase of stimulus frequency also improved EEG-to-MUAe prediction.

Conclusion: Our study shows that non-invasive EEG can predict V1 spiking activity under SSVEP stimulus conditions by utilizing the phase and amplitude of EEG frequency bands. By bridging the gap between invasive cortical signals and non-invasive EEG signals, these results help identify candidate scalp EEG signals that could benefit brain-computer interfaces.

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BCI Training-Induced Neuroplasticity: Evidence from Long-Term Neural Activity Analysis

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Introduction: Brain-Computer Interfaces (BCIs) offer innovative potential for motor substitution and rehabilitation by facilitating direct communication between the brain and external devices. Beyond their practical applications, BCI protocols can also induce neural plasticity, driven by prolonged training. Despite its importance, the dynamics of BCI-induced plasticity remain poorly explored. Yet, it could highlight that BCI is supported by a mutual learning process between brain and the algorithmic decoder, often referred as co-adaptation [1].

Material, Methods and Results: This study investigates the potential of BCI-induced neural plasticity in a patient implanted with WIMAGINE® electrocorticographic (ECoG) recording device [2]. We analyzed brain activity of a patient engaged in an extended BCI training over several months with a fixed decoder (without any recalibration) [3]. Using the ECoG recordings of BCI sessions, we evaluated both sensorimotor activity patterns and functional connectivity at regular intervals. Connectivity is a key marker of neuroplasticity, reflecting changes in the interaction between neural networks. Results revealed progressive changes in brain activation patterns overs sessions. Connectivity analysis demonstrated increased interregional cortical synchronization, suggesting an adaptive remodeling of functional networks. These findings provide compelling evidence of sustained changes in motor brain function induced by BCI training, even in the absence of decoder updates.

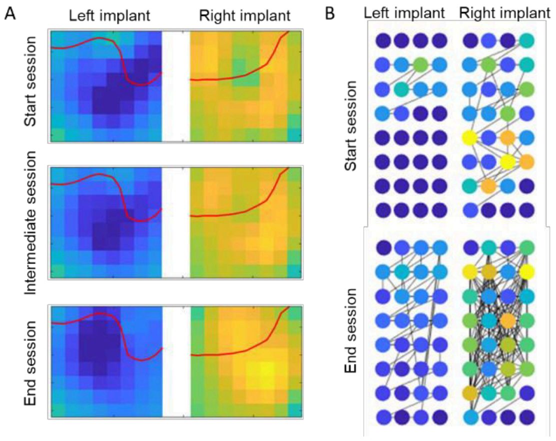

Figure 1: Evolution of brain patterns over sessions. (A) Regression of activation over the sessions in gamma band (100Hz – left minus right motor imagery). (B) Degree of activation between electrodes in the first and last session of training.

Conclusion: Our findings demonstrates that the user's brain undergoes significant changes in intensive BCI training, highlighting patient's learning and adaptation, even under fixed decoder. This potential of BCIs to drive neuroplasticity underlines the dual role of BCIs as tools for both motor compensation and rehabilitation, offering new avenues for neurorehabilitation and optimized therapeutic protocols.

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Impact of Surrounding Audio-Visual Complexity on Symptomatology of Laryngeal Dystonia: A Virtual Reality Study

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Introduction: Laryngeal dystonia (LD) is an isolated focal dystonia characterized by involuntary spasms in laryngeal muscles selectively impairing speech production. Anecdotal observations reported the worsening of LD symptoms in stressful or vocally demanding situations [1, 2]. We examine the impact of surrounding audio-visual on Laryngeal Dystonia (LD) symptomatology to better understand its phenomenology.

Material, Methods, and Results: We developed well-controlled virtual reality (VR) environments of real-life interpersonal communications to investigate how different levels of audio-visual complexity may impact LD symptoms. The VR experiments were conducted over five consecutive days, during which each patient experienced 10 hours of 4,100 experimental trials in VR with gradually increasing audio-visual complexity. Daily reports were collected about patients' voice changes, as well as their comfort, engagement, concentration, and drowsiness from using VR.

After a weekly exposure, 82% of patients reported differences in their voice symptoms related to changes in audio-visual complexity. Significant differences in voice symptoms were found between the first two levels of the audio-visual VR challenge, independent of study sessions or scenes. Self-reported changes in voice symptoms were significantly positively correlated with scene level.

Conclusion: This study demonstrated that LD symptoms are impacted by audio-visual background across various virtual realistic settings. These findings should be taken into consideration when planning behavioral experiments and evaluating the outcomes of clinical trials in these patients. Moreover, VR presents a reliable and useful tool for providing real-life assessments of the impact of various experimental settings, such as during the testing of novel therapeutic interventions in these patients.

Acknowledgments and Disclosures: This study was funded by the grant R01DC019353 from the National Institute on Deafness and Other Communication Disorders, National Institutes of Health, to KS. No conflict of interest for any author relevant to this study.

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Patient-Specific Visual Neglect Severity Estimation for Stroke Patients using an AR and EEG based BCI

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Introduction: Visual spatial neglect is a condition that causes inattention to contralesional stimuli after a stroke. It disrupts basic and instrumental activities of daily living (such as dressing and driving) and increases the risk of falling and hospitalization. The current standards for neglect detection are successful in identifying neglect but do not provide any information on the extent/severity of neglect, i.e., the neglected field of view (FOV), which can be useful to inform personalized neglect rehabilitation. Previously, we built a BCI system called Augmented Reality-based EEG-guided Neglect Detection, Assessment, and Rehabilitation System (AREEN). We have already shown that the AREEN BCI system, using EEG can detect neglect with high accuracy and can classify among neglected and non-neglected visual targets [1]. In this work we aim to expand upon the previous findings, and develop and evaluate a machine learning method for the estimation of neglected FOV.

Material, Methods and Results: For FOV estimation, we propose EEG-based Spatio-Temporal Network (ESTNet) that captures essential EEG frequency band/time information associated with visual neglect. Through a Bayesian fusion, ESTNet combines EEG evidence with probabilistic prior information on potentially neglected visual field, which we denote as FOV correction module. ESTNet also generates an average saliency map to improve the explainability of the network model and identifies EEG time ranges (i.e., potential event related potentials – ERPs) and frequency bands most informative on neglected FOV estimation. Using our proprietary AREEN dataset (a total of 20 stroke patients including 11 with visual neglect and 9 without neglect), the performance of ESTNet is compared to benchmark machine learning models in a leave-one-subject-out (LOSO) manner. ESTNet outperformed the benchmark machine learning methods for FOV estimation, achieving 79.62% accuracy, 76.71% sensitivity, and 86.36% specificity. Average saliency map (Fig. 1) demonstrates the frequency/time ranges for each EEG channel identified to be most informative for FOV estimation: (i) ERPs in the 100-150 ms and 300-400 ms range associated with visual attention tasks [2, 3]; (ii) alpha and beta bands which are biomarkers associated with visual attention [4] and visual task correction [5].

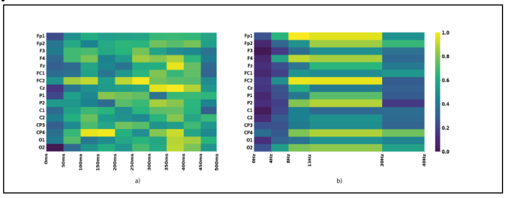

Figure 1: *Average saliency maps for a) time domain and over 50ms long windows and b) frequency domain data over EEG bands delta (0-4Hz), theta (0-8Hz), alpha (8-13Hz), beta (13-30Hz) and gamma (30-40Hz). Note that both domains are normalized within themselves for better visibility and model/data explainability.*

Conclusion: The AREEN BCI system with high accuracy can estimate neglected FOV. This severity assessment does not require any input from stroke patients, could potentially supplement other clinical neglect related disability measures, and in the future could inform personalized neglect rehabilitation.

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Adaptive Closed-Loop Neurofeedback Brain-Computer Interface for Treatment of Laryngeal Dystonia

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Introduction: Laryngeal dystonia (LD) is a task-specific focal dystonia characterized by involuntary spasms of laryngeal muscles that selectively impair the production of speech but not whispering, crying, or laughing. A recent EEG study [1] showed apparent differences in brain activity between speaking and whispering in LD patients compared to healthy individuals. In a double-blind, sham-controlled study, we aimed to build on the selectivity of speech impairment in LD for the development of a non-invasive adaptive closed-loop neurofeedback-based brain-computer interface (NF-BCI) for the treatment of this disorder.

Material, Methods, and Results: Eighteen LD patients participated in the study, divided into two groups: nine in the active condition and nine in the sham condition. The personalized EEG-based NF was displayed using the head-mounted virtual reality (VR) goggles and included real-life scenarios with various auditory and visual complexity and high vocal demand to elicit LD symptoms. Over five consecutive days, each patient participated in two one-hour NF-BCI sessions daily, during which they were trained to modulate abnormally increased EEG activity associated with impaired speaking to the levels associated with normal whispering. All patients assessed changes in their symptom severity after each session using a Likert-item questionnaire, ranging from -5, Worsened to +5, Improved. In addition, patients assessed their level of comfort, engagement, concentration, controllability, and responsiveness during NF-BCI sessions. Repeated-measures Friedman ANOVA corrected for ties was used to examine the differences in symptom severity and the overall performance during NF-BCI between the active and sham LD groups.

We found that patients who received active NF-BCI had a statistically significant improvement of their voice symptoms compared to patients who had sham NF-BCI ($\text{Chi}^2 = 9.99$, $p = 0.002$). Patients with active NF-BCI had significantly greater controllability of NF-BCI than patients with sham condition ($\text{Chi}^2 = 10.05$, $p = 0.002$) but had no difference in their comfort, engagement, concentration, or responsiveness during the training (all $\text{Chi}^2 \leq 2.6$, $p \geq 0.10$).

Conclusion: By integrating personalized EEG modeling, neurofeedback, and VR, this first study of adaptive closed-loop BCI intervention in LD patients demonstrated the feasibility of the treatment of this disorder, opening new opportunities for patients with LD and other focal task-specific dystonias.

Acknowledgments and Disclosures: This study was funded by the grant R01DC019353 from the National Institute on Deafness and Other Communication Disorders, National Institutes of Health, to KS. No conflict of interest for any author relevant to this study.

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Hardware Friendly Corticomorphic Hybrid CNN-SNN Architecture for EEG-Based Auditory Attention Detection

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Introduction: For a healthy listener, the ability to selectively attend to a particular speaker in a multiple-speaker, or ”cocktail party” [1], scenario is a trivial task. Those who suffer from hearing loss or are hearing impaired have difficulty with selective auditory attention [2]. Cognition and selective auditory attention of an individual play an important role in listening and communication [2], but unfortunately, these are currently not fully utilized during hearing aid design [3].
Studies into the auditory attention network of the brain have shown that it is possible to decode auditory attention through the neural responses of a listener, suggesting that assisted selective auditory attention is possible, which led to developments in auditory attention decoding (AAD) using EEG-based BCIs. The current AAD methods are impractical for hearing aids due to large model architectures, requiring many operations, that when ported to hardware call for a sizable memory footprint, more compute resources, and higher power consumption than realistic.

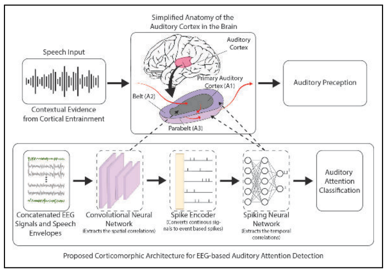

Figure 1: *The proposed corticomorphic hybrid architecture, inspired by the anatomy of the auditory cortex. Speech input and contextual evidence from other regions in the brain are passed into the primary auditory cortex (A1). The processed signals are then transmitted to the belt (A2), and finally the parabelt (A3). We hypothesize that the convolution layer will mimic the primary auditory cortex (A1) while the spiking neural network layer will emulate the belt (A2) and parabelt (A3).*

Material, Methods and Results: Our work demonstrates a pioneering approach to developing a hardware-friendly corticomorphic neural network modeled to mimic the layered cortical structure of the brain. Our proposed hybrid network is biologically inspired by the organization of the auditory cortex, Fig. 1. The proposed hybrid convolutional and spiking neural network (CNN-SNN) is evaluated on our own EEG-based BCI dataset [4] (10 participants) and, additionally, compared to the current state-of-the-art AAD methods on a publicly available dataset, DTU [5] (18 participants). The CNN-SNN achieved an accuracy of 98.8% on our dataset with int8 precision, while utilizing 50% fewer EEG channels with an $\sim 5\%$ decrease in operations. Similarly, the model was able to outperform all state-of-the-art models on the DTU dataset by $\sim 10\%$ for the 0.5, and 1 second decision windows, while using 87.5% fewer EEG channels and int8 precision. Hence, the overall benefits of using fewer channels, reducing the memory footprint with a lower bit precision, and a shorter decision window.

Conclusion: The proposed model architecture has surpassed current state-of-the-art results for AAD. The CNN-SNN architecture performs within a more desirable decision window (0.5 or 1 sec), uses fewer EEG channels, and increases the accuracy compared to state-of-the-art models. These results indicate that with the proposed model, it is possible to accurately decode auditory attention with high accuracy and less power consumption and smaller memory footprints compared to a conventional ANN.

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Zero-shot Deep Learning for Calibration-free Motor Imagery BCIs

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Introduction: Despite the potential of motor imagery (MI) BCIs, their usability outside of laboratory settings is limited due to the need for frequent system calibration and user training. A promising direction to create more user-friendly, plug-and-play BCIs is **zero-shot learning** [1]. This approach enables models trained on data from a set of subjects or tasks to generalize and perform classification on unseen subjects/tasks. While this approach has been previously attempted on task-to-task learning [2,3], very few studies have applied it to cross-subject learning for calibration-free MI-BCIs, and those that have suffer from limitations such as relying on small datasets and hand-crafted machine learning models [4]. Contrary to past research, this study aimed to leverage end-to-end deep learning (DL) to evaluate the robustness of zero-shot learning on a large dataset, which included MI EEG signals from **142 participants**. Our RQ was: Is calibration-free MI BCI feasible if zero-shot learning is applied to a large group of users?

Methods and Results: To obtain a large dataset, we aggregated two existing datasets; Leeuwis et al. (55 subjects, 2021) [5] and Dreyer et al. (87 subjects, 2023) [6], both employing the same EEG device and right- vs. left-hand MI protocol. The signals were resampled and overlapping electrodes relevant to MI task were selected (C3, C4, Cz, CP1, CP2). For each subject, the available trials (min 120, max 320) were included. From each trial, 4 seconds of MI was selected for model training. Five models were selected for zero-shot learning; an SVM trained with ERD/ERS patterns (used as the baseline) and 4 DL models namely, EEGSimpleConv [7], EEGNet, Deep and Shallow ConvNets [8] trained with raw EEG data. The training pipeline consisted of leave-one-subject-out cross-validation (LOSO-CV), where models were trained on all subjects except one, and then tested on the left-out subject. The obtained accuracies per model are presented in Figure 1.

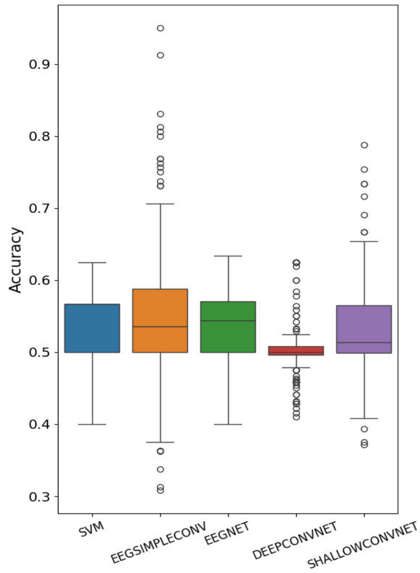

Figure 1: Comparison of model accuracies.

Conclusion: While for some subjects, EEGSimpleConv and Shallow CovNet models achieved noticeably better performance compared to the baseline, the overall results show that calibration-free MI BCIs remain a challenging task due to the high inter-subject variability of MI patterns. Future research could explore the benefits of one-shot or few-shot learning, allowing pre-trained models to adapt to new users with minimal data.

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Closed-loop error damping in human BCI using endogenous modifications in motor cortex activity

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Introduction: The motor cortex is known to encode motor intents, carrying rich information about movement kinematics. Interestingly, motor cortex activity also includes an *error signal*, i.e. a neural correlate of erroneous motor control that does not align with the movement goal. This error signal could potentially be leveraged during real-time BCI control, to detect a discrepancy between the decoded movement and the user's intent and to perform on-the-fly error correction. Previous studies have been able to identify a neural correlate of such periods of erroneous motor control to perform on-the-fly detection of BCI control in monkeys [1]. However, whether this signal is sufficiently robust to be used in human applications, and can generalize across realistic tasks, is still unknown. Here, we train a classifier to detect periods of erroneous motor control based on intracortical recordings from motor cortex, and use it to perform real-time error detection and control signal modulation in different BCI tasks with human participants.

Material, Methods and Results: We obtained intracortical data from 3 human participants (C2, P2, and P4) who were asked to perform a BCI 2D cursor control center-out task. Participants provided informed consent prior to enrolling in a clinical trial of an intracortical sensorimotor BCI that was approved under an FDA Investigational Device Exemption (NCT01894802). We trained a classifier to detect periods of erroneous control using data collected while the participants performed the center-out task, where "error" was defined as an increasing distance between the cursor and the target. Crucially, neural features immediately preceding the onset of an error (and which represent endogenous activity rather than responses to visual feedback) are also included in the training set, allowing earlier error detection. Then, in subsequent testing blocks, whenever the detected error probability reached a defined threshold, the system performed error modulation by reducing the decoded velocity, hence preventing the cursor from moving further away from its target (Fig.1**A**). Error modulation significantly improved BCI performance on a variety of performance metrics (Fig.1**B**). In individual participants, we demonstrated improved performance when applying error modulation to a more realistic and multidimensional click and drag task (Fig.1**C**) and to the precision task from the recent Cybathlon BCI competition (Fig.1**D**), where stability is especially critical to performance.

Conclusion: Results show that motor cortex activity is significantly modified during erroneous control, and that this neural signature can be leveraged to minimize errors, hence improving BCI performance.

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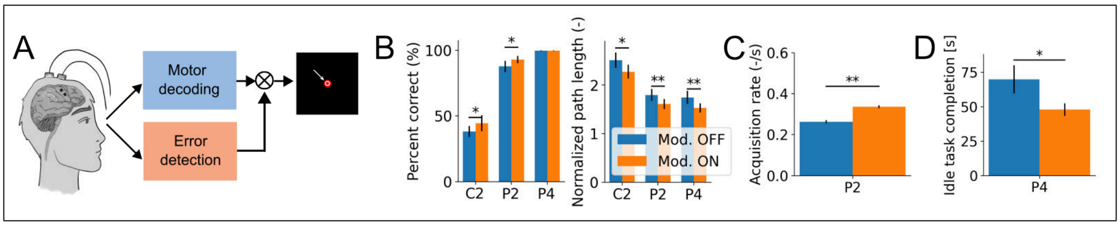

Figure 1: ***(A)*** *A BCI system is used to decode the motor intent and to move a cursor towards a target in a 2D control task. In parallel, a classifier detects the error signal and modulates the decoded velocity accordingly.* ***(B)*** *Trajectory accuracy metrics without (blue) and with (orange) error modulation.* ***(C)*** *Target acquisition rate without and with error modulation during a click-and-grasp task.* ***(D)*** *Completion time improvements with error modulation during the precision task from the BCI Cybathlon competition.*

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MindVoice: A Multimodal Framework for EEG-Based Speech Decoding

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Introduction: Speech impairments pose challenges for automatic speech recognition (ASR) systems, which struggle with slurred pronunciation, unpredictable pauses, and variability in speech patterns [1]. We propose a contrastive learning framework combining speech and EEG, designed to decode speech from neural signals using minimal EEG channels, enabling scalable solutions for speech impairments.

Material, Methods and Results: We developed a robust data collection protocol to record EEG and speech data from 13 participants, which consisted of 20 English words carefully selected to maximize phonemic diversity and three paragraphs commonly used in speaking tests. The stimuli were designed to ensure a broad representation of English phonemes, enabling the model to learn the phonetic patterns of the language. Stimuli presentation was fully automated using PsychoPy [2] and time-synchronized using the Lab Streaming Layer (LSL). A multimodal model was trained to encode EEG and speech data into a shared latent space, employing cross-attention to enrich EEG embeddings with temporally aligned speech audio and a contrastive loss to align these embeddings effectively. Trained on 1,366 samples (1,093 training, 273 validation), the model achieved an impressive top-1 validation accuracy of 98.94%, highlighting its capacity to capture complex EEG-speech relationships. A channel ablation study confirmed robustness, showing minimal accuracy decline to 97.90% even when using a single EEG channel (F4) selected from the cortical region involved in speech production. This minimal performance drop underscores the model's suitability and potential for deployment in practical, low-channel wearable devices. The overall workflow is illustrated in Figure 1.

Conclusion: This study demonstrates a generalizable contrastive learning framework for decoding speech from EEG signals, extending our previous work [3]. Our proposed model provides robust shared embeddings between EEG and speech, facilitating downstream decoding tasks such as zero-shot classification and EEG-to-text applications. Its effectiveness with fewer EEG channels further highlights its potential for scalable deployment in low-channel wearable devices, extending the reach of brain-computer interface (BCI) applications beyond assistive communication.

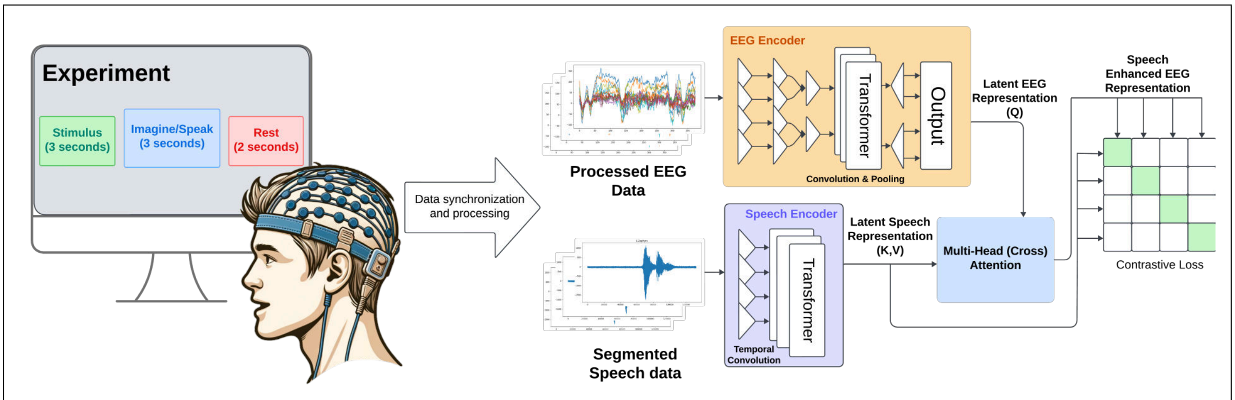

Figure 1: *Overview of experimental setup and pipeline for EEG and audio data collection, synchronization, encoding, and multimodal alignment for speech decoding.*

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Toward Commercialization of a High-Efficiency AAC System with BCI Access for Individuals with Minimal Movement

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Introduction: Augmentative and alternative communication (AAC) systems are widely used for efficient communication, but require movement, preventing use by people with the most severe impairments. Wearable P300 brain-computer interfaces (BCIs) offer an alternative AAC access method.

Material, Methods and Results: AAC manufacturer and university research resources supported a mixed-methods approach for late-stage development to commercialize an AAC-BCI system (now at translational level T2). We have started a small clinical trial of in-home product use to optimize the design, evaluate training resources, plan future, larger clinical trials, and prioritize regulatory and reimbursement pathways.

Figure 1: *The PRC AAC-BCI includes the Accent speech generating device and a VR300 dry electrode headset.*

The PRC BCI system (Fig. 1) is designed as an add-on access method for the PRC Accent speech generating device. The AAC-BCI consists of a Wearable Sensing VR300 dry electrode headset and the PRC BCI application program controlling all the BCI features and functionality. The BCI application is a stand-alone Windows program that has been granted permission to run in an overlay window on top of the Empower AAC program (design schematic in Fig. 2). The BCI app uses the Accent device's computational and display resources while Empower is waiting for the user to make a vocabulary selection. BCI prediction begins with the BCI app sending a Microsoft User Interface Automation (MUIA) command to Empower requesting a list of all the GUI elements on the AAC display. The BCI app creates a transparent layer of stimuli with the same size and location as the AAC display elements to produce the P300 evoked response from the user. The BCI application analyzes the resulting EEG, sends a MUIA command to activate the selected AAC key, and the Accent device produces the speech associated with that key.

Evaluation of dosage and delivery modality for AAC-BCI trainings and resources relied on published feedback results [1]. Competency-based assessment compared training types and lengths. A 3-day in-person, hands-on workshop resulted in PRC service delivery consultants achieving competence at the train-the-trainer level with a high degree of trainee satisfaction.

Conclusion: A small T2 clinical trial was initiated successfully to evaluate in-home use of a commercial AAC-BCI across the US. Paperwork is in development to ensure that the AAC-BCI qualifies for medical device reimbursement and other US and international regulations.

Acknowledgments and Disclosures: SM, JZ, & SB work for PRC-Saltillo. Funded by National Institute of Deafness and other Communication Disorders (NIDCD) in the National Institutes of Health (#SB1DC015142).

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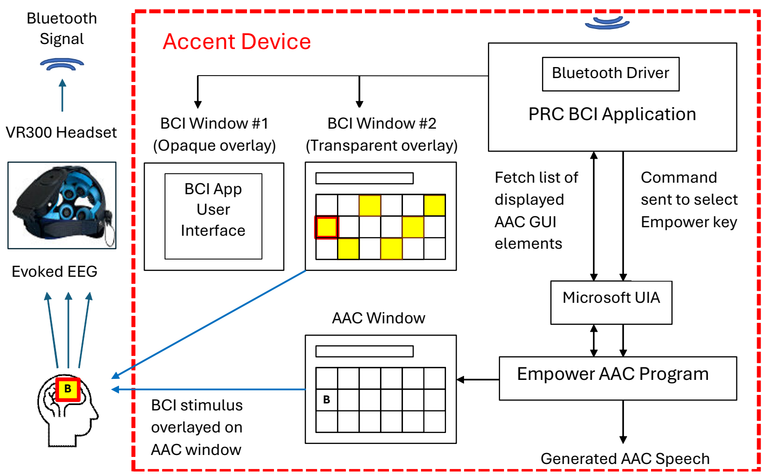

Figure 2: *Schematic of AAC-BCI system.*

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Neuroethical considerations on Brain Computer Interface research in Latin America

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Introduction: Neuroscientific research in Latin America (LA) focuses on biology, psychology, and neurology, often guided by a clinical perspective. The countries with the most significant contributions in international neuroscientific literature are Argentina, Brazil, Chile, Colombia, and Mexico [1]. Research on brain-computer interfaces (BCI) has become increasingly significant over the past 20 years. EEG presents advantages compared such as being a non-invasive, relatively low-cost, easy-to-use technique, that does not require special facilities to function. Furthermore, open-access datasets facilitate complex computational processing methods, spearing the purchase of the acquisition device. However, experts from LA highlight the lack of legal means to protect brain data and its integrity [2]. In this sense, our aim is to highlight the main ethical considerations related to BCI research in LA, according to the acquisition method, signal processing, application, and training paradigm.

Material, Methods and Results: Previous scientometric research collected 1458 publications on BCI from Pubmed, Science Direct, IEEE, Scopus, and Redalyc databases authored by scientists affiliated in LA and the Caribbean (unpublished data). Results for *number of publications* for these countries showed Brazil (515), Mexico (292), Colombia (197), Argentina (128), and Chile. Five subcategories were considered for scientometric purposes: *Acquisition* (EEG, fMRI, MRI/MEG, ECoG, and fNIRS), *Signal processing* (feature extraction, classification models, and filtering), *Application* (rehabilitation, robotics, neuroscience, robotics, and human-computer interface), and *Paradigm* (P300, MI, SSVEP, and other). In this study, EEG represented the acquisition method in 85% of the publications, while MI was used in 62% of them. The most common *Application* found was *neuroscience* (41.38 %), followed by *rehabilitation (25.61%). EEG Acquisition* must consider privacy, agency, and data protection. Privacy guarantees anonymity, by protecting the identity of the participants. Agency refers to the right of individuals to preserve their personality. The *Paradigm o*f MI has raised questions on how much control/intention/responsibility is attributable to the user and to the coding/decoding algorithm [3]. Nowadays, no country in LA, except for Chile, explicitly mentions the protection of neural data on a fundamental legal document. On *Signal processing* and *Application*: Informed consent must clearly explain the use and purpose of brain information. It should also state the clinical benefit of the application and/or how it contributes to humanity. About brain open datasets, we found poor dissemination of the FAIR requirements (Findable, Accessible, Interoperable, and Reusable), that promote data integrity, identity protection, and liability.

Conclusion: BCI research in LA has grown significantly, primarily utilizing EEG and employing motor imagery (MI) with fundamental neuroscience applications. Ethical considerations regarding these aspects of BCI must be incorporated during protocol planning and explicitly stated in publications. Privacy, agency, data protection, and informed consent should adhere to international guidelines while accommodating regional disparities. To address these challenges, it is crucial to promote ethical frameworks, equitable research funding, and regional collaboration to ensure that BCI research in LA progresses responsibly and inclusively.

Acknowledgments and Disclosures: The authors thank LASCON IX for enabling this collaborative research. The authors express no conflict of interest.

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An Innovative Method for Detecting P300 Signals in Patients with Disorders of Consciousness

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Introduction: Distinguishing between patients in a vegetative state (VS) and those in a minimally conscious state (MCS) is challenging due to the complexity of clinical manifestations and the limitations of current diagnostic tools. Behavioral differences between VS and MCS can be subtle and are often easily mistaken for reflexive or random activities. Passive acoustic P300 has emerged as a valuable tool for detecting cognitive functions, even in individuals unable to actively engage or respond. The primary challenge lies in reliably detecting the P300 component, as its latency, amplitude, spatial distribution, and polarity can vary significantly across patients [1].

Material, Methods and Results: A dedicated software was developed to generate a P300 sequence of acoustic stimuli, consisting of 50 target and 250 standard stimuli. Twenty-seven non-responsive subjects were tested (10-20 EEG System) before they were diagnosed, with the stimuli being the patient's name and a masked version of the same name to preserve the same envelope. The NPXLab suite was used for signal preprocessing (including ICA, filtering, etc.). A custom software implementation was used to compare responses to target and standard stimuli with the following methodology with no assumptions regarding P300 latency, amplitude, spatial distribution, and polarity:

1) For 1000 iterations, 50 standard stimuli were randomly selected to compute the standard responses for each channel before (-1750ms to -250ms) and after (250ms to 1750ms) the stimuli.
2) After each iteration, a t-test on each of the 14592 samples (768 per 19 channels), was conducted between the standard and target responses for all channels.
3) Samples with a statistical difference (t-test) less than 0.01 were counted
4) Histograms (pre, post, standard, target) were constructed from all iterations, with the number of samples identified in step 3, and compared. (Fig. 1).

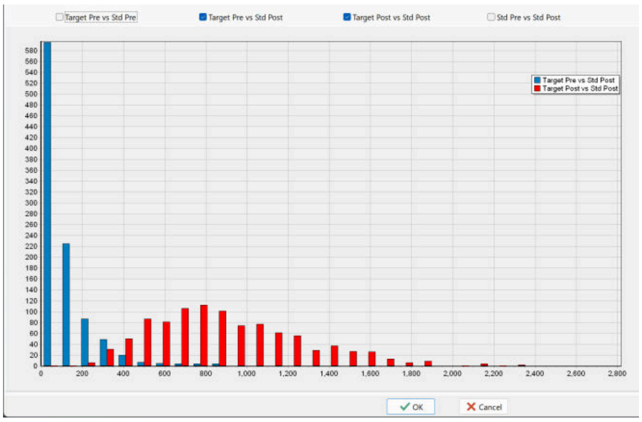

Figure 1: *Histograms relative to the number of statistically different samples computed by comparing Target Pre vs Standard Post epochs (blue) and Target Post vs Standard Post epochs (red) of one subject. It can be deduced that Standard Post activity is similar to Target Pre stimuli (values are close to the 0 bar), while Standard Post and Target Post stimuli activities belong to a different distribution (KS test p<0.001).*

All 17 subjects who exhibited a significant difference between standard and target responses (K-S test) were later diagnosed as MCS, with no false positives observed. Five false negatives were detected.

Conclusion: Accurately differentiating between VS and MCS is crucial for determining appropriate treatment, guiding rehabilitation efforts, and making end-of-life decisions. Here, a method that is shaped for each subject is shown.

Acknowledgments and Disclosures: The authors declare that there is no conflict of interest regarding the publication of this article.

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Measuring motor intent for BCI control – a comparative analysis of the Stentrode and scalp EEG

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Introduction: The Stentrode is a novel endovascular brain-computer interface (BCI) that is implanted within the superior sagittal sinus to record bilaterally from the motor cortices. The device has enabled people with severe paralysis to gain computer control and digital communication. The Stentrode is currently undergoing an early feasibility clinical trial in the United States (NCT 05035823).

For any BCI to be viable long-term, the signals need to be high quality and remain stable over time to enable high-accuracy decoding of user intent. Multiple factors contribute to the signal-to-noise ratio (SNR) including distance to neural source, task attention, electrical contact and spacing, referencing scheme, physiological noise (such as ocular, muscular, cardiac, etc), feedback, and environmental noise. While the Stentrode sits closer to the cortex, in the absence of interceding bone, than scalp electroencephalography (EEG) electrodes and would presumably have higher signal quality, there has been no reported comparison of intravascular to scalp-based signal quality in humans.

Material, Methods and Results: Here, we explore the quality of vascular ECoG and scalp EEG signals during volitional motor attempts in one participant with paralysis due to ALS, who retains some residual movement. During two training sessions, the participant underwent simultaneous recording with the Stentrode and a scalp EEG with a standard, commercially available 64-channel gel cap. During the sessions, they were visually cued to attempt various motor tasks, such as repeated flexion and extension of the wrists and ankles. Signal quality was assessed by analyzing motor event related synchronization/desynchronization during cued movement tasks. SNR was defined as 10*log((Attempted movement band power)/(Resting band power)). The correlation between task conditions (move vs. rest) and specific frequency bands was examined via the correlation coefficients.

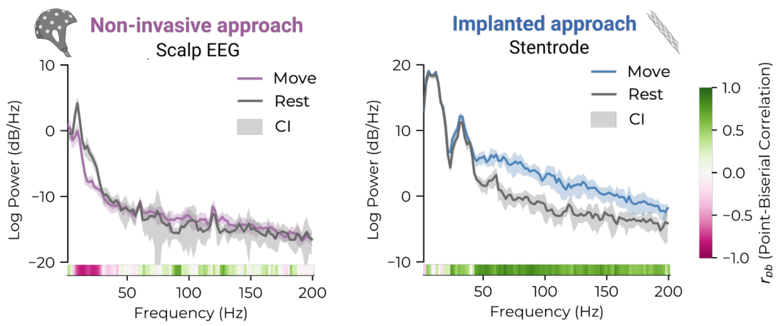

Figure 1: *Example power spectral density showing both ankle movement compared to rest for both scalp EEG (Ch Cz) and Stentrode recordings (Ch 12).*

During attempted flexion of both ankles, the most modulated channel on the EEG cap, Cz, had a mean SNR in the beta band (13-30 Hz) of -1.69 (strong de-synchronization), while the most modulated channel on the Stentrode had an SNR of -0.43. Of particular interest is the high-gamma band (70-200 Hz), which offers rich, focal information with high utility in BCIs. In this band, the scalp EEG and Stentrode had SNRs of 0.57 and 1.95 respectively. The high SNR in the high-gamma band for the Stentrode, which doesn't face the attenuating effects of the skull, is promising for successful, reliable decoding of user intention. Data will be presented for a variety of channels, frequency bands, and referencing schemes while the participant attempts different types of movements.

Conclusion: Overall, the scalp EEG shows alpha and beta desynchronization during movement and post-movement beta rebound, while the Stentrode shows strong gamma synchronization. The ongoing study will continue to evaluate the signal quality and stability in multiple participants across modalities.

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Ear-EEG Auditory Error-Related Potentials

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Introduction: Ear-EEG provides a comfortable, user-friendly alternative to traditional scalp-EEG, supporting the use of daily, wearable recording of EEG. By integrating custom 3D-printed earpieces with AIRTrode-sponge electrodes [1, 2], this study advances ear-EEG technology, enabling the recognition of error-related potentials (ErrPs) in real-time. ErrPs are neural correlates of error awareness [3].

Material, Methods and Results: Custom right-oriented earpieces were fabricated using flexible resin and embedded with AIRTrode-sponge electrodes for enhanced biocompatibility, contact quality, and long-term recording. The earpieces contained 4 electrodes. For all experiments, both ear-EEG and scalp-EEG were acquired. Characterization included recording impedance, changes in alpha rhythms, and auditory steady-state responses. Auditory ErrPs were elicited by subjects perceiving incorrect answers to questions delivered via audio. The brain-computer interface (BCI) relied on the AIRTrode-sponge electrodes and on a Riemannian geometry-based classification framework to decode auditory ErrP [4]. BCI output feedback was delivered via audio, indicating whether or not the classifier successfully decoded the subjects' EEG as either ErrP or correct depending on the trial. Ten healthy subjects participated in the experiments. Results showed that all 4 electrodes captured the ErrPs, albeit with different dynamics, thus, demonstrating the high spatial resolution of our AIRTrode-sponge electrodes. Furthermore, the BCI achieved a statistically significant online performance in the recognition of the presence or absence of auditory ErrPs, outperforming pseudo-online performance of a BCI that used scalp-EEG. Figure 1 displays the online performance of the ear-EEG ErrP BCI for each subject, as measured by Cohen's Kappa, indicating reliable accuracy for 9 out of 10 subjects.

Conclusion: The AIRTrode-sponge ear-EEG device successfully captured EEG signal including ErrPs, demonstrating its potential for BCI applications. To address reduced spatial coverage limitations and improve performance, future work will incorporate dual-ear devices and extend training sessions to multiple consecutive days. This study establishes a strong foundation for practical, long-term neural monitoring and BCI development using ear EEG recorded with AIRTrode-sponge electrodes.

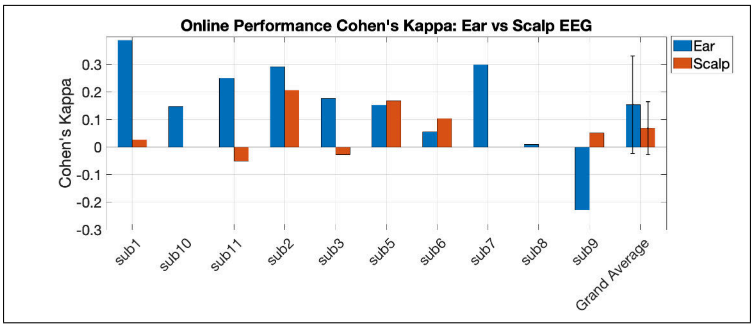

Figure 1: *Online and pseudo-online performance evaluation metric Cohen's Kappa of the auditory ErrP BCI using ear-EEG and scalp-EEG, respectively. The Cohen's Kappa value for each subject represents the grand average of all their corresponding runs in the online session. Scalp-EEG for subjects 7,8, and 10 were discarded due to poor quality.*

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A biomimetic iBCI decoder for restoring hand function in people with spinal cord injury

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Introduction: Intracortical brain-computer interfaces (iBCIs) offer paralyzed individuals the ability to generate movement. While effective for guiding a computer cursor [1] or a robotic arm [2], [3], current systems lack the ability to control applied forces and adjust limb compliance—critical limitations for grasping and interacting with objects. To address this, we propose developing an iBCI that decodes intended muscle activity (EMG) from primary motor cortex (M1) recordings. This system would then control joint kinematics and impedance, as well as contact forces via a forward musculoskeletal model of the hand [4], more closely mimicking the natural function of M1 than do existing iBCI decoders. We hypothesize that this biomimetic iBCI will be easier to learn and outperform existing decoders for hand function tasks.

Material, Methods and Results: Data to train kinematic iBCIs is obtained as users observe and attempt to replicate a certain movement trajectory; the decoders are built by correlating the recorded neural activity with the observed kinematics. To create a muscle-based equivalent, we first needed to determine the muscle activity patterns that a paralyzed individual might use when observing and attempting to mimic hand actions. For this, we collected data from an able-bodied individual performing a series of multi-degree-of-freedom hand posture-matching movements. We recorded intrinsic hand muscle activity using high-density surface electrode grids (LISiN, Torino, Italy) placed on the dorsal and palmar side of the hand, along with intramuscular leads also targeting the dorsal interossei. We recorded extrinsic hand muscles using standard surface bipolar electrodes (Delsys Inc., Boston, USA) on the forearm. We were able to accurately classify hand postures using only data from the surface recordings. Intramuscular leads offered only minor improvements in accuracy. This suggests that high-density grids alone provide sufficient information about intrinsic muscle activity, potentially eliminating the need for intramuscular leads in the hand. We next used these EMG signals as decoding templates together with M1 data recorded from a spinal cord-injured participant, implanted with two microelectrode arrays (Blackrock Microsystems, Salt Lake City, UT) in the arm and hand representations of M1, who attempted the same posture-matching task. To ensure consistency between the able-bodied participant's actual movements and the paralyzed participant's attempted movements, we recreated the actual hand kinematics in virtual reality through an avatar hand, which the participant observed. They were prompted to attempt to replicate the motion using their own hand. Posture classification accuracy using the M1 signals was well above significance, but below that achieved in the able-bodied participant using EMG signals. We also used the M1 signals in combination with the EMG templates to compute EMG decoders. The predicted EMG activity from left-out M1 data had R^2 values (computed with respect to the separately recorded EMG templates) ranging from 0.2 to 0.4.

Conclusion: Our findings demonstrate that hand muscle activation can be effectively decoded from the M1 signals of a paralyzed participant attempting to imitate various hand postures. Although our experiments were limited to posture-matching movements, we intend to extend them to object manipulation and force generation. Our results represent a critical step towards using decoded EMGs to drive a musculoskeletal model of the hand for improved performance compared to standard kinematic decoders.

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The AppleCatcher Game: A Novel Motor Imagery BCI for Hand Rehabilitation

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Introduction: The AppleCatcher game is a novel motor imagery brain-computer interface (BCI) designed with the idea to facilitate hand rehabilitation for individuals with motor impairments. It was developed to address the limitations of traditional methods by providing a more engaging and user-centered approach to rehabilitation. The system utilizes electroencephalography (EEG) to detect and interpret brain activity associated with motor imagery, allowing users to control a virtual apple-catching game. AppleCatcher leverages the brain's neural plasticity by tapping into the overlapping neural pathways of motor imagery and motor execution. Through mental rehearsal, it can enable users to practice and enhance their motor skills, fostering motor recovery and rehabilitation. Unlike conventional motor imagery-based BCIs that rely on EEG data processing in the sensor space, the AppleCatcher game employs EEG source imaging (ESI) to enhance classification performance. This method has proven effective in improving the accuracy of motor imagery detection. [1, 2].

Material, Methods and Results: The player's objective is to use motor imagery to catch an apple falling on the screen, as shown in Fig. 1. The two vertical lines on the green progress bar serve as markers for when the player is supposed to perform the motor imagery, and data is collected between these two markers using a 32-channel Mentalab Explore EEG cap. Features are extracted from the data by isolating the μ frequency band and then computing the average power of source estimates obtained with sLORETA. These features are classified using Linear Discriminant Analysis, and the output is used to control the virtual hands. For initial testing and validation of the classification pipeline, data from [3] was used. The results of live gameplay tests are promising, with subjects achieving an average accuracy of 75.5%. The accuracy increased by an average of 11.5% between the first and second test session, demonstrating the potential for improving motor imagery skills by playing AppleCatcher. In subsequent offline testing with improved parameters the accuracy rose to 85.0%, equal to the initial test results obtained from the ten best subjects in [3].

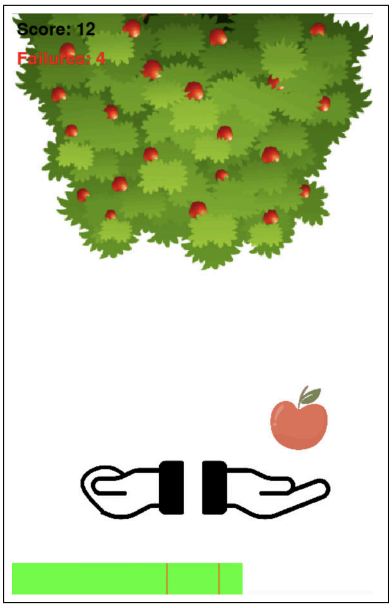

Figure 1: *AppleCatcher game interface.*

Conclusion: The initial results reported here suggest that the AppleCatcher game serves as a promising proof of concept for a motor imagery-based gaming concept. Further refinement and broader testing with a larger, more diverse participant group are needed to evaluate its effectiveness in hand movement rehabilitation.

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Investigating inter-participant performance variability in mental imagery EEG-BCIs: Descriptive methods to analyze inter- and intra-trial signal variation

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Introduction: Vast literature has reported high inter- and intra-individual variation in electroencephalography (EEG) signals [1]. However, few methods exist to assess and describe EEG signal variability. Here, we present methods to assess EEG variability for mental imagery BCIs. The methods yield insight into different aspects of signal variation, specifically (i) inter-individual, (ii) inter-task, (iii) inter-trial, and (iv) intra-trial variation. These methods are part of broader work developing descriptive user-performance assessments to improve user training and personalization of BCI design.

Material, Methods and Results: A novel representation of the time evolution of EEG signals was developed. Task trials were segmented into shorter 2 second temporal windows and represented in a feature space derived from unsupervised K-means clustering of trial covariance matrices [2]. Using this representation, temporal signal trajectories through the feature space were constructed as shown in Fig. 1A. Two metrics were defined to assess user performance based on these trajectories: (1) *InterTaskDiff*, based on time-varying distances between the mean trajectories of different tasks, and (2) *InterTrialVar*, which measured the inter-trial variation along the different feature dimensions of the observed temporal trajectories. Analysis of three-class BCI data from 14 adolescents revealed both metrics correlated significantly with classification results (Fig. 1B). Further analysis of intra-trial trajectories suggested the existence characteristic task- and user-specific temporal dynamics.

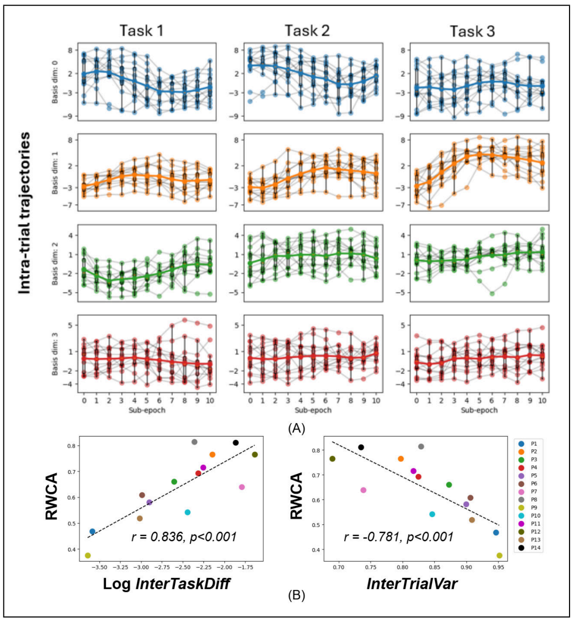

Figure 1: *(A) Example of intra-trial temporal trajectories for a single user. Rows and columns represent different feature space dimensions and tasks, respectively. Horizontal axes represent temporal segment windows and vertical axes represent positions along feature space dimensions. Bold lines indicate the mean trajectories; points connected by thin lines are individual trial observations. (B) Classifier-based discernibility metric (RWCA: run-wise classification accuracy [3]) vs. InterTaskDiff (left) and InterTrialVar (right). Dashed lines indicate lines of best fit; r values are pearson correlation coefficients.*

Conclusion: Our analysis demonstrated significant associations between the proposed metrics and the machine discernibility of EEG-BCI data. Moreover, the methods provide opportunity for more nuanced descriptions of intra- and inter-trial EEG data variation for mental imagery BCIs. Further work will investigate whether participant-specific characteristics revealed by this analysis could be used to improve user training feedback or select user-optimal classification algorithms and hyperparameters.

Acknowledgments and Disclosures: This work has been supported by NSERC CGS-D, Ontario Graduate, and a Kimel Family Pediatric Rehabilitation Scholarships.

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Autonomic Activation, Mental Effort, and Fatigue While Using Non-Implantable RSVP and Matrix cBCIs

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Introduction: Non-implantable communication BCI (cBCI) systems may offer substantial benefits to individuals with communication impairments. However, prior research has suggested that sustained use of these systems may be impeded by factors such as fatigue, sleepiness, and boredom [1]. Relatedly, there is little extant data to directly compare differences in mental effort or autonomic activation between two common P300-based cBCI paradigms: Rapid Serial Visual Presentation (RSVP) and Matrix. The present study compared measurements of autonomic activation during both RSVP and Matrix tasks, as well as self-reported mental effort, fatigue, sleepiness, and boredom. We predicted elevated autonomic and self-report levels during RSVP as compared to Matrix, and also increases in these measures over time.

Material, Methods and Results: Twenty-four healthy adult participants (age range 22-49 years) provided physiologic and self-report data during a single experimental visit to OHSU. Participants completed P300-based RSVP and single-character Matrix spelling tasks in BciPy [2], both of which were delivered in random counterbalanced order across individual sessions. Each paradigm included calibration (50 inquiries with 1 target and 9 non-target letters, with an additional 5 inquiries with 10 non-targets), resulting classifier calculation, and three copy-spelling sessions to complete 5-letter words. EEG was recorded with a dry-sensor DSI VR-300 (Wearable Sensing); autonomic measures were collected with a VitalStream CT5 (Caretaker Medical) and included systolic and diastolic blood pressure, mean arterial pressure, heart rate (HR), and respiration rate. Self-reported state sleepiness [3], mental fatigue [4], and boredom [5] were collected before/after each calibration and copy-spelling phase. Mental effort was measured using a single item from the Multidimensional Fatigue Inventory, "It took a lot of effort to concentrate on things." The entire visit with a total of two calibrations and six copy spelling tasks lasted approximately 105 minutes.

Calibration AUC estimates during RSVP (M=0.85; SD=0.10) were slightly lower on average than Matrix (M=0.88; SD=0.10), though this difference was not significant (p=0.08). The number of target letters correctly copied during copy-spelling was significantly higher in Matrix (M=13.54; SD=3.14) than in RSVP (M=12.08; SD=3.90; p=0.012). Results indicated a main effect of time on all self-report measures, such that all self-reported fatigue and effort measures increased significantly over the course of the visit (all p values < 0.001). The changes in self-report measures from the beginning to the end of RSVP and Matrix were not different. There were significantly greater increases in all self-report levels from the beginning to the end of calibration, as compared to the beginning to the end of copy-spelling (all p values ≤ 0.006).

With regard to the autonomic measures, we observed a main effect of paradigm (RSVP vs. Matrix) for mean HR (p=0.005), which increased during RSVP (M=72.15; SD=9.42) as compared to Matrix (M=70.60; SD=8.51). There was a main effect of task phase as well, such that all autonomic measures were higher during calibration relative to copy-spelling (all p values ≤ 0.035).

Conclusion: Participants demonstrated significant increases in self-reported mental effort, fatigue, sleepiness, and boredom across completion of two cBCI paradigms and following calibration relative to copy-spelling. Autonomic measures increased during calibration relative to copy-spelling, suggesting calibration is more effortful and fatiguing than copy phrase. Elevated HR during RSVP likewise suggests increased effort.

Acknowledgments and Disclosures: The authors report no conflicts of interest. This work was supported in part by NIH National Institute on Deafness and Other Communication Disorders (R01DC009834). We thank Andy Fish for additional administrative support.

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Comparative Evaluation of Compact and Research-Grade EEG in BCI: P300-Based Visual/Auditory Oddball Tasks

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Introduction: One of the main challenges in the practical adoption of brain-computer interfaces (BCI) is the cumbersome nature of traditional electroencephalography (EEG) systems, requiring extensive setup and wet electrodes. Recently, compact and cost-effective portable EEG devices with dry electrodes have emerged as promising solutions to address these barriers. Devices such as Muse have shown potential in BCI applications, with studies demonstrating their ability to detect ERP components like N200 and P300 [1]. However, systematic evaluations of the signal quality and feature consistency between portable and research-grade EEG systems remain limited [2, 3]. This gap raises critical questions about the reliability of portable devices in extracting and reproducing features comparable to those of high-fidelity systems.

Material, Methods and Results: This study employed LiveAmp system (32 chs, wet type) and Muse (4 ch, dry type). Data were collected from 6 healthy adults (mean age: 24 ± 2.1 years) during P300-based visual and auditory oddball tasks. EEG signals were preprocessed with band-pass filtering (1–40 Hz), segmentation, and artifact removal. P300 response time and peak amplitude were compared for each condition. Additionally, BCI performance was assessed using classification accuracy. LiveAmp signals displayed lower amplitude, faster P300 response times, and cleaner waveforms, while Muse exhibited higher noise levels (Fig. 1). LiveAmp achieved higher averaged accuracy in both visual (0.8554) and auditory (0.8210) tasks compared to Muse (0.6848 and 0.5790, respectively), with differences more pronounced in auditory conditions.

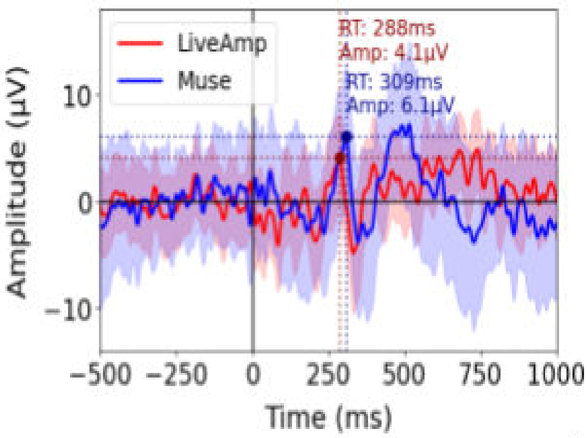

Fig. 1. Example ERP waveform comparison of target signals between LiveAmp and Muse in auditory oddball task (S04).

Conclusion: Muse offers a user-friendly and cost-effective option for basic P300-based BCI tasks but demonstrates lower accuracy, reduced signal amplitude, and delayed response time compared to LiveAmp. While promising for portable applications, improvements in dry-electrode technology are necessary for precision-demanding tasks.

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Daily independent conversational speech decoding from the intracortical neural activity of a man with ALS

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Introduction: Communication is a priority for the millions of people living with dysarthria due to brain injuries or neurological disorders such as stroke and amyotrophic lateral sclerosis (ALS). BCIs can enable rapid, intuitive communication for people with paralysis by transforming the cortical activity associated with attempted speech into text. Recent advancements in speech BCIs have demonstrated that attempted speech can be accurately decoded during prompted speech tasks [1, 2, 3]. However, work remains to achieve accurate speech decoding in a conversational setting that enables the user to communicate their own thoughts and needs with those around them. Here, we report a speech BCI that was accurate enough to enable the user to have extensive conversations with family, friends, and colleagues independently and on a daily basis.

Material, Methods, and Results: A 45-year-old man (‘T15’) with ALS and severe dysarthria was enrolled into the BrainGate2 clinical trial. Four microelectrode arrays were placed in his left precentral gyrus to record neural activity from 256 intracortical electrodes. We trained a recurrent neural network to decode sequences of phonemes (i.e., the building blocks of words) from T15’s neural signals as he attempted to speak. The recurrent neural network was continuously finetuned with new data to enable stable decoding over weeks of use. Predicted phoneme sequences were assembled into the most likely words being spoken by a language model with a potential output vocabulary size of 125,000 words and displayed on a screen in real time. At the end of a sentence, the decoded words could be played aloud using a text-to-speech tool that was programmed to sound like T15’s pre-ALS voice, or entered as text on his personal computer. We developed a “conversation mode” user interface that detects when T15 attempts to speak, decodes accordingly, and allows him to make simple corrections to decoded sentences. T15’s care partners were trained to connect T15 to the neural recording system whenever he wanted to use it, and the BCI computer system was streamlined so it could be turned on with just a few button presses.

Throughout 550 days since T15’s implant surgery, he has independently used the speech BCI as his primary form of communication on more than 300 individual days. He has used the BCI system for >2,500 hours to utter >150,000 sentences (>1,400,000 words) at an average rate of 64.6 words per minute. At the end of each sentence he uses an eye tracker to rate the correctness of the decoded sentence, yielding a distribution of 65.8% of all sentences being “completely correct”, 26.1% being “mostly correct”, and the remainder being “incorrect”. In recent months, sentence-level accuracy has increased to up to 85% of sentences being “completely correct”. Furthermore, we have conducted periodic decoding accuracy benchmarks where T15 attempts to say prompted sentences, resulting in an average word error rate of 2.5% maintained throughout 550 days post-implant.

Conclusion: We demonstrate a speech BCI that has enabled a severely dysarthric man with ALS to engage in conversations with his friends, family, and colleagues. The BCI now serves as his preferred method of communication.

Disclosures: M. Wairagkar: Inventor on IP owned by UC Davis; L.R. Hochberg: Consultant to Neuralink, Synchron, Axoft, Precision Neuro, Reach Neuro; D.M. Brandman: Inventor on IP owned by UC Davis; surgical consultant to Paradromics; S.D. Stavisky: Inventor on IP owned by Stanford University (licensed to Blackrock Neurotech and Neuralink) and UC Davis; advisor to Sonera.

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A Pilot Study for SSVEP-based Person Recognition

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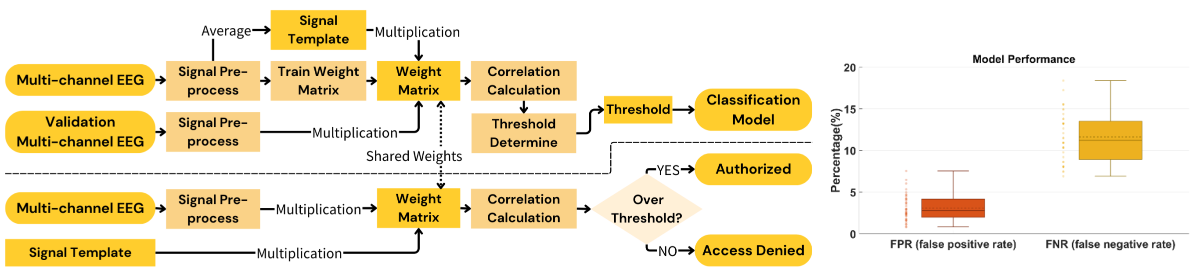
Introduction: Steady-state visual evoked potential (SSVEP) is widely used in brain-computer interfaces (BCI) due to its high signal-to-noise ratio (SNR). Although many studies focus on optimizing decoding algorithms to maximize the information transfer rate (ITR) in target classification tasks [1], there is still no universal decoding model due to inter-subject differences. In other words, using individual decoding models as classifiers for person recognition seems to be a feasible research direction. In this proof-of-concept study, we use state-of-the-art decoding algorithms to evaluate the false positive positives (the model mistakenly recognizes others as me) and the false negatives rate (model mistakenly identifies me as someone else) on a public dataset. The preliminary result highlight the potential of utilizing personalized decoding models for person recognition, taking a step toward in addressing the challenges of biometric recognition based on brain activity.

Material, Methods and Results: Thirty-five healthy participants volunteered for a 40-stimuli SSVEP study [1]. EEG data were recorded from 8 channels around the Oz region, with a 50 Hz notch filter and a 1-50 Hz band-pass filter applied for data preprocessing. Only the 0.5 to 4.5 second segment of the EEG data was retained for further analysis. Task-Related Component Analysis [2] and Canonical Correlation Analysis were combined (referred to as TRCCA) into a unified data processing pipeline to extract features in both the spatial and temporal domains. Specifically, TRCCA computes a weight matrix to extract the most relevant features from the multichannel EEG data, compares the feature templates with the testing features using the same weight matrix, and generates a correlation score for classification. The data processing pipeline is illustrated in Fig. 1a. Fig. 1b presents the decoding accuracy of the proposed model. The mean accuracy achieved 96.59%, with a mean false positive rate of 3.1% and a mean false negative rate of 11.6% among the 35 participants.

Conclusion: SSVEP is widely recognized for its high SNR and relatively short training time. However, numerous studies indicate that there is no universal decoding model for the general population. This proof-of-concept study proposes that an individualized SSVEP decoding model could serve as a classifier for person recognition. Our results (FPR of 3.1% and FNR of 11.6%) are close to a fingerprint-based recognition system, which typically exhibits an FPR ranging from 0.1% to 3% and an FNR between 1% and 10%, depending on image quality [4]. Future work will focus on optimizing the decoding pipeline to achieve the performance comparable to other biometric-based mechanisms.



(a) *Block diagrams of training process (top) and testing process (bottom).*

(b) *False positive rate and false negative rate among 35 participants. Each dot represents one participant.*

Figure 1: *The proposed data pipeline and the decoding accuracy of person recognition using a public dataset [1].*

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Improving P300 BCI Performance with OSCAR

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Introduction: Real-time artifact removal is essential for reliable EEG-based brain-computer interfaces (BCIs), as artifacts from eye blinks, muscle activity, and environmental noise degrade system performance [1]. Numerous algorithms have been developed to mitigate EEG artifacts, each with its own advantages and limitations [2]. We present an evaluation of the Online Signal Conditioning and Artifact Removal (OSCAR) module on P300 BCI performance. In particular, we assessed OSCAR LIVE, which is the real-time implementation with ≈250 ms delay and part of g.HIsys high-speed online processing for Simulink (g.tec medical engineering GmbH, Austria).

Material, Methods and Results: Dataset 1 (DS1) comprises 10 clean recordings from five subjects in auditory and visual oddball paradigms, which we randomly contaminated with template artifacts to produce 300 pseudo-recordings. Dataset 2 (DS2) consists of 120 recordings with real artifacts, obtained from five subjects and the same paradigms.

We processed all recordings using a standard P300 classification pipeline: bandpass filtering (0.5–10 Hz), epoching (–0.1 to 0.7 s, relative to stimulus onset), decimation, and 500 repetitions of a randomized hold-out validation (20 training trials, 4 test trial averages) with a linear discriminant analysis (LDA) classifier. The pipeline was applied to raw EEG and OSCAR LIVE-preprocessed EEG.

Figure 1 shows that OSCAR LIVE improved BCI accuracy in most recordings. Using a ±5% margin to define "similar performance," OSCAR LIVE improved 76.7% of recordings and worsened 6.0% in DS1. In DS2, improvement was observed in 39.4%, with deterioration in 12.5%. Overall, OSCAR LIVE achieved similar or better performance in 94.0% of DS1 and 87.5% of DS2 recordings. Grand average performance improvement was +17.0% (DS1) and +7.1% (DS2).

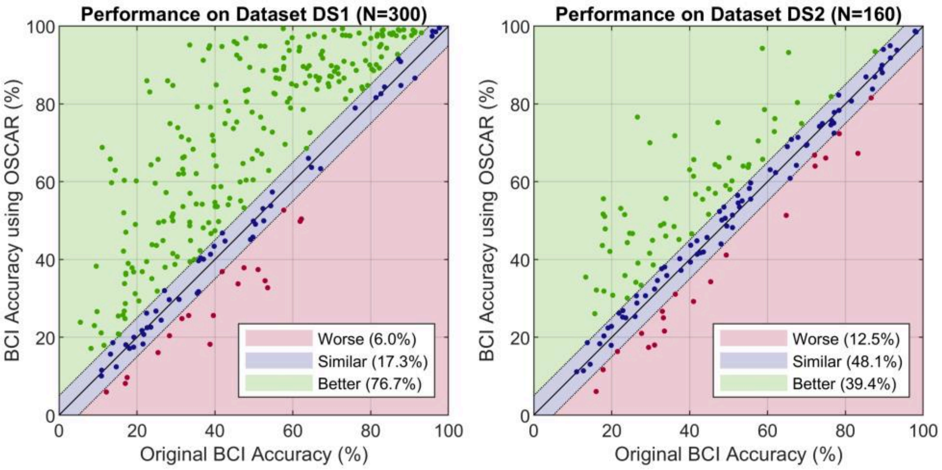

Figure 1: *Scatter plots showing P300 BCI accuracy with OSCAR versus original BCI accuracy for DS1 (left) and DS2 (right). Each dot represents the result of one recording. The red, blue, and green areas relate to worse, similar, and better performance, respectively.*

Conclusion: Our findings demonstrate that OSCAR LIVE effectively enhances P300 BCI performance for artifact-contaminated EEG recordings.

Acknowledgments and Disclosures: J.G. and S.S. are employees and C.G. is the CEO of g.tec medical engineering GmbH, which may pose a conflict of interest.

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Towards a decision-making BCI for dynamic detection of uninformed decisions

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Introduction: Making fast and accurate decisions utilizing the available information is essential for animal survival and human success. However, especially in the time of enhanced communication and information systems, additional information seeking behavior can enhance decision making quality in a time-efficient way. Previous studies have identified a decision variable signal decodable from animal single cell recordings and human electroencephalographic recordings that reflects a variety of decision parameters and cognitive processes. Passive BCIs are proposed to decode these decision parameters in real time. A BCI automatically differentiating between more or less informed decisions could assist a user by detecting uninformed decision-making and recommending the initiation of additional information search. This could be especially relevant in situations where important decisions need to be made under factors that have been reported to affect decision quality such as time pressure or stress. Additionally, patients suffering from disorders associated with decision making impairments could benefit from such an application.

Methods: Cortical and subcortical electrophysiological signals are acquired using stereoelectroencephalography (sEEG) implanted in 6 epilepsy patients for localization of the epileptogenic zone. The participants perform a computerized decision-making task where they are asked to decide which group each stimulus belongs to. While this decision is random in the first iteration, the participants are expected to learn from their previous decisions and to make an informed decision in the second and third iteration of seeing the same stimulus.

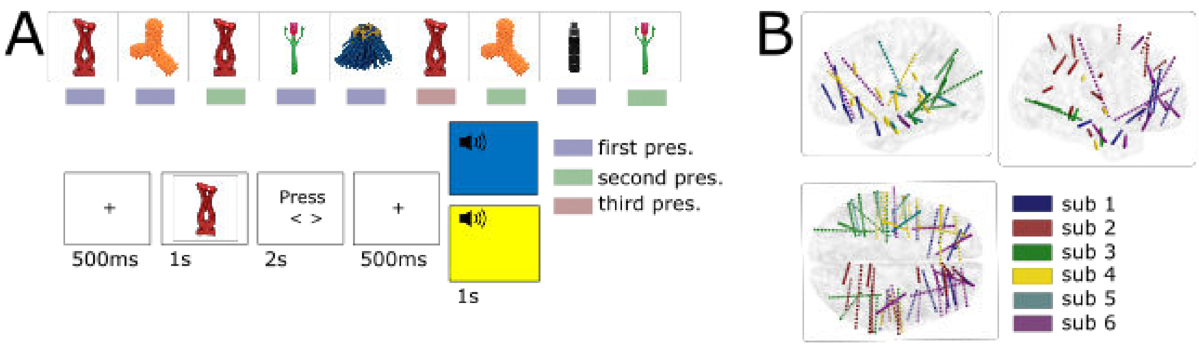

Figure 1. *(A)Task setup: 60 different stimuli are presented 3 times in random order (first, second and third presentation). For each stimulus participants are prompted to respond with a button press. Feedback is provided using a colored screen and an audio signal. (B) Electrode locations of the 6 participants included in this study are depicted in the left hemisphere, right hemisphere and in a top-down view in both hemispheres.*

Results and Discussion: From the electrophysiological signal we extract time-domain and oscillatory features during different time-intervals time-locked to stimulus presentation and response. We evaluate these features for their predictability for differentiating between random and informed decision-making using machine learning. We show the general feasibility of a passive BCI for detecting random versus informed decision-making above chance level.

Significance: This work contributes to gaining insights into the neural dynamics of decision-making and the differences between informed and uninformed decision-making. Additionally, it highlights relevant time-windows, electrode locations and neurophysiological features for decoding in invasive and non-invasive BCIs that aim to improve decision-making quality.

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Investigation on the material-tissue-interface of flexible epicortical electrode arrays in a ferret animal model

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Introduction: Engineering and material sciences have driven developments of miniaturized neural probes as tools to decipher function of the brain in neuroscientific investigations. Translation of implantable brain-computer-interfaces into clinical applications, however, is quite slow [1]. Development of active implantable devices has to comply with medical device regulations to meet safety standards. Amongst the most important topics should always be the investigation of the stability of implants for a predetermined time and their effect on the brain tissue. This work is about such a study.

Material, Methods and Results: µECoG arrays have been developed of polyimide with thin-film metal (platinum, iridium oxide) as electrode and interconnect material for chronic neuroscientific investigations in ferrets (Mustela putorius) [2] obtaining LFP and spike-like activity. Studies have been conducted up to one year with high quality of the recordings over the whole time. After termination of the experiments, methods for probe and brain dissection were developed (Fig.1). Initially, µECoGs and brain tissue were jointly investigated before being separated for detailed characterization. Even though probe thickness of 10 µm should not lead to any mechanical interaction with the brain [3], cortical depression was still observed. Electrodes showed signs of stress cracking, embrittlement and progressive adhesion loss [4].

Conclusion: Flexible µECoG allow stable recordings over months. Despite excellent functionality, deterioration of thin-films and tissue alterations around the array indicate limits in longevity and knowledge of the comprehensive processes in foreign body reactions for translation of implantable brain-computer-interfaces for life-long human applications.

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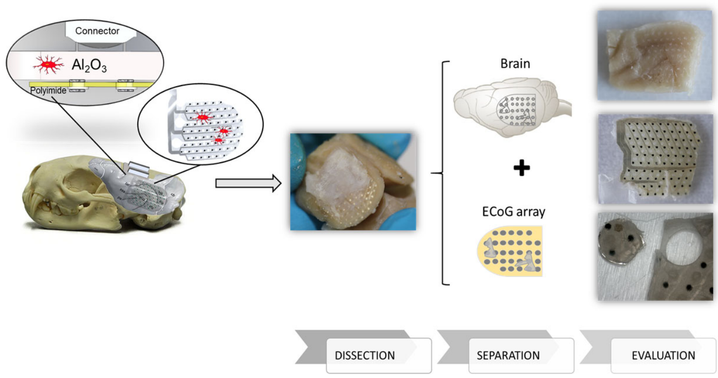

Figure 1: Investigation of ECoG arrays after chronic implantation in ferrets. Fixed brains with probes were dissected, separated and evaluated with respect to morphological changes of the brain and material alterations and adhesion loss of the ECoG array.

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EEG-Based Brain-Computer Interface for a Tetraplegic Individual Using Motor Imagery for Cybathlon 2024

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Introduction: Brain-computer interfaces (BCIs) have shown significant promise over the past decades but often fail to meet the requirements for robustness, portability, and usability in real-world scenarios [1]. Motivated by the Cybathlon 2024 competition, we worked towards addressing these challenges by developing a modular, online EEG-based BCI system to increase accessibility for individuals with severe mobility impairments, such as tetraplegia.

Material, Methods, and Results: Our system uses three mental and motor imagery (MI) tasks for up to five control signals. The data is collected using a 24-channel mobile EEG with a custom electrode layout. The pipeline consists of four modules: data acquisition, preprocessing, classification, and the transfer function to map classification output to control dimensions. These modules run in parallel to optimize the online delay. The preprocessing includes FIR bandpass filtering between 4 and 40 Hz, artifact removal (ASR and auto-rejection), and epoching with a sliding time window of 1.5 seconds. The feature extraction was done with Morlet and Common Spatial Pattern. As our deep learning classifier we use three S4D-layers [2] trained on augmented offline data achieving an accuracy of up to 82% for three classes.

We developed a data collection tool in the form of a T-Rex Dinosaur game, where the mental tasks control the game during quick-time events. This resulted in a better user experience, improving the collected data quality and quantity. We also implemented a mobile feedback application that can be used by any device with an internet connection. The components were designed with a human-centered approach in collaboration with the tetraplegic user to ensure optimal usability.

Our pilot completed one task during the Cybathlon competition but faced performance challenges under high-stress conditions in the arena, reducing accuracy. These observations suggest that stress negatively impacts MI performance, affecting BCI reliability. Despite these setbacks, our low budget set up (ca. 3000 € all costs included) and the pipeline demonstrated feasibility for real-world applications and laid the groundwork for further optimization.

Conclusion: We provide insights into developing a framework for portable BCIs, bridging the gap between the laboratory and daily life. Specifically, our framework integrates modular design, real-time data processing, user-centered feedback, and low-cost hardware to deliver an accessible and adaptable BCI solution, addressing critical gaps in current BCI applications. Future work will focus on increasing the robustness of our system by for example quantifying the effects of stress on MI and BCI performance, and improving system adaptability with increased data reusability through meta-learning.

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A P300 Brain-Computer Interface as a Diagnostic Tool for Measuring the Efficacy of Psychotherapeutic Intervention

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Introduction: Systemic therapy is a psychotherapeutic treatment that focuses on the patient's social and family relationships. It uses the Family Constellation Method (FCM), in which patients externalize a representation of their experienced family constellation by arranging people representing family members in a room. Non-verbal aspects, including distance between people, direction of gaze, and facial expression, are interpreted to facilitate the patient's insight into their family constellation. This process can lead to new insights or the revival of emotions from past experiences and is expected to have a positive impact on the patient's social interactions and well-being in the present. For example, if a person discovers through FCM that there was an unspoken rule in his or her family of origin to avoid conflict and maintain harmony, that person may be able to reconsider the pattern of avoiding conflict in current relationships. The efficacy of the FCM has been demonstrated [1], however, mainly questionnaires and subjective reports were used to evaluate therapeutic success. We argue that the efficacy of the FCM should have a neural correlate that might be measurable using a P300-based brain computer interface (BCI). According to Johnson's Triarchic Model, the P300 amplitude is influenced by the meaning of a stimulus [2]. We hypothesized that the P300 amplitude would increase for spelling words representing improved social interactions after undergoing the FCM as due to an increased meaning to the participant. We predicted that this P300 increase would exceed the P300 increase observed for control words.

Material, Methods and Results: For this pilot study we recruited 3 female participants, 31 (A), 34 (B), and 39 (C) years old from the Würzburg Systemic Institute and all of them participated in a family constellation seminar as part of their training to become counsellors. We assessed their subjective experience in social systems using the EXIS.pers questionnaire [3] which comprises 12 items assessing the subscales Belonging, Autonomy, Accord, and Confidence before and after undergoing the FCM. Higher values in the subscales represent more satisfying social experiences. For the BCI spelling task, we chose 12 words, two representing one category (e.g. autonomous and self-determined for Autonomy) and four control words. Participants spelled these words before and after participation in the FCM. We measured Fz, FCz, C3, Cz, C4, CPz, P3, Pz, P4, PO7, Oz and PO8, used two electrodes at the outer canthi for horizontal EOG and two electrodes for the vertical EOG. We used a 16-channel g.Tec amplifier (g.Tec, Austria) with a sampling rate of 256 Hz, a high pass filter of 0.1 Hz, a low pass filter of 30 Hz, and a notch filter of 48–52 Hz. The spelling was controlled by the BCI 2000 Software [4]. In all three participants the questionnaire scores increased in some subscales, but the P300 amplitudes of the corresponding target words showed a decrease. In Participant B, the two subscales Accord and Autonomy did not change, but an increase in P300 amplitudes was found for the target words. For participant C, a decrease in the Confidence subscale resulted in increased P300 amplitudes for the corresponding target words. P300 amplitudes decreased for control words for participants A and B, but remained constant for participant C.

Conclusion: Contrary to our hypothesis, P300 amplitudes decreased with improved subjective experience of social systems. This result may indicate that higher satisfaction with a component of social interaction, such as autonomy, leads to subjectively lower meaning of corresponding target words, compared to our hypothesis of higher meaning. Before we can interpret these results further, they need to be confirmed in a larger sample.

Acknowledgments: We would like to thank the Würzburg Institute for Systemic Thinking and Acting (WISH, Würzburg, Germany) for their support in participant recruitment.

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Detailed Somatotopy of Speech Articulators in the Somatosensory Cortex to Define Electrocortical Stimulation Location

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Introduction: Communication through speech is an important aspect in our daily life. People with severe motor impairment, caused by neurological disorders such as brainstem stroke or amyotrophic lateral sclerosis, are unable to speak or communicate effectively. Brain computer interfaces (BCIs) may offer a solution to this problem by using voluntarily induced signal changes in the sensorimotor brain areas, produced by attempts to move a body part (e.g., hand or speech articulators), to control a communication device. Achieving reliable BCI control can be a difficult and time-consuming process, likely related to the absence of relevant somatosensory feedback on the movement attempts. Indeed, somatosensory feedback through electrocortical stimulation improved robotic arm control in a person with tetraplegia [1], which suggests that also communication BCIs may benefit from this strategy. To determine where to apply electrical stimulation to the somatosensory cortex for relevant feedback, it is necessary to understand the underlying brain processes of tactile perception. Previous research consistently found an ordered representation of the hand and fingers in the somatosensory cortex [2], but the somatotopic organization of the speech articulators in this brain region remains unclear. We aimed to investigate the detailed representation of the speech articulators in the somatosensory cortex and assess how this representation relates to the location of sensations induced by electrocortical stimulation.

Material, Methods and Results: We recorded 7 Tesla functional magnetic resonance imaging (fMRI) data of ten healthy participants (mean age 26.8±6.7 years, 7 female) during pneumatic stimulation of the speech articulators (inner mouth, upper/lower lip, left/right cheek, chin, and neck) with an in-house developed air puff device. We mapped fMRI activity patterns per participant to a common surface space and calculated the mean activity map per articulator. In addition, we performed electrocortical stimulation on a high-density 32-channel electrocorticography (ECoG) grid implanted over the left ventral sensorimotor cortex of an individual with epilepsy (age 46 years, female). The epilepsy participant was asked to inform the researcher when she felt a sensation, and to indicate its location. The left hemisphere fMRI data revealed a ventral to dorsal arrangement of the speech articulators: the inner mouth (including tongue) covered a relatively large area of the somatosensory cortex, followed by the lips, and subsequently by overlapping areas of the chin and left and right cheek. The ECoG grid of the epilepsy participant only covered the inner mouth and lip regions of the fMRI activity maps. Stimulation of several electrodes in the ECoG grid induced sensation in the palate, teeth, jaw, tongue, right lower lip, and right cheek.

Conclusion: The speech articulators were found to be orderly represented in the somatosensory cortex, and results between fMRI and a preliminary electrocortical stimulation experiment seemed to align. These findings indicate that non-invasive methods, such as fMRI, may predict the optimal electrode locations for providing relevant somatosensory feedback and are therefore important for the correct placement of ECoG grids for communication BCIs. However, the results need to be confirmed with inclusion of more participants.

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Do Complex Vision Models Improve Feature Alignment with fMRI for Neural Decoding of Visual Stimuli?

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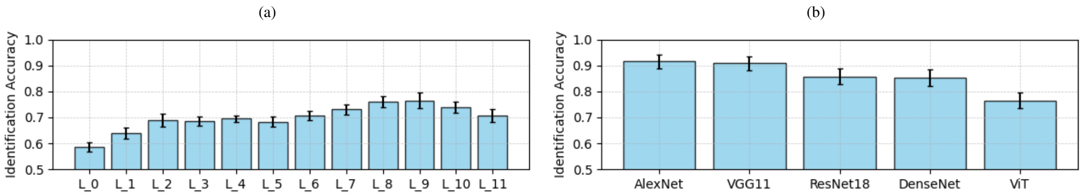

Figure 1: **(A)** Performance of ViT self-attention layers in aligning with fMRI data, highlighting the impact of layer depth on model identification accuracy. **(B)** A schematic comparison showing that more complex networks, such as ViT, are outperformed by simpler CNN architectures.

Introduction: Recent advancements in computer vision, particularly with Vision Transformers (ViTs) and foundation models, have led to significant improvements across various tasks by utilizing self-attention mechanisms to capture intricate patterns and global relationships in visual data. This study explores whether these advanced models, compared to traditional convolutional neural networks (CNNs), offer better alignment with neural data, particularly fMRI responses. We specifically investigate the impact of model complexity on interpreting brain activity by evaluating the alignment between fMRI data and features from several neural network architectures, including ViT, ResNet18, DenseNet [1, 2, 4], and simpler models like VGG11, and AlexNet [5, 7].

Materials, Methods, and Results: We used the fMRI dataset in [3], which links visual stimuli from ImageNet categories to corresponding fMRI data. The training set consisted of 1200 samples from 150 image classes (8 images per class), while the test set included 1750 recordings from 50 image classes, each observed 35 times. Preprocessed data through motion correction, voxel normalization, and ROI selection, was used for training AlexNet, VGG11, ResNet18, DenseNet, and ViT.

Performance in terms of identification accuracy [3] across features extracted from different layers, shows that simpler models, like VGG11 and AlexNet, outperform more complex architectures such as ResNet, DenseNet, and ViT. Notably, ViT exhibited the lowest performance, highlighting its reduced compatibility with fMRI signals.

With ViT models increasingly explored for decoding brain activity due to their representational power [6], we also investigated their alignment with fMRI data across all layers. As shown in Fig.1a, ViT exhibits a distinct trend compared to CNNs, where performance typically improves in early layers, peaks at intermediate layers, and declines in deeper layers[3]. In ViT, alignment gradually improves from early to deeper layers, with a performance drop in the final layer. This discrepancy may arise from fundamental differences in processing: CNNs hierarchically encode perceptual features in early layers and abstract semantics in deeper ones, while ViTs use self-attention to refine token relationships, emphasizing global context and abstraction throughout the network, especially in the last layer. Thus, the lower performance by ViT likely suggests that its highly abstract and complex representations are less compatible with the predominantly low- and mid-level features captured by fMRI signals.

Conclusion: This work indicates that higher architectural complexity does not always translate to improved compatibility with biological signals, underscoring the importance of considering model complexity and representation characteristics when applying machine learning to decode brain activity.

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The neural representation of fine hand movements in an individual approaching locked-in syndrome

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Introduction: For individuals who are paralyzed due to amyotrophic lateral sclerosis (ALS), brain-computer interfaces (BCIs) based on electrocorticography (ECoG) may restore communication [1, 2]. BCI control is driven by attempted movements of for example the hand, and next to the primary motor cortex (M1), the somatosensory cortex (S1) may contribute to decoding movements [1, 2]. Yet, in these BCI studies most participants were incompletely paralyzed, meaning they could still move parts of their body. To our knowledge, BCI users with locked-in syndrome (i.e., complete paralysis; LIS) due to ALS controlled the BCI using a simple attempted hand movement [2]. It remains unclear how the degeneration of neurons in M1 due to late-stage ALS and the absence of movement-related sensory feedback affect the neural representation of attempted movements in individuals who are locked-in as a result of ALS. In the current study, we explored the representation of attempted fine hand movements of an individual who was approaching LIS due to ALS.

Material, Methods and Results: We implanted four 32-channel subdural high-density ECoG grids with 3 or 4 mm pitch in an individual (41 years old, female) who was quadriplegic and anarthric due to ALS. Grid placement was based on pre-surgical functional MRI activation in response to attempted hand and mouth movements. For ECoG data collection, the participant performed a task where active trials were interleaved with rest trials. Prior to the task, the participant was instructed to attempt one out of six predefined movement types (classes) at the onset of each active trial, being index, thumb or little finger flexion/extension, or grasp, pinch or American sign language 'Y' movement (18 active trials during each of 3 sessions). After standard preprocessing, we calculated high-frequency band power (HFB, 60-120 Hz) per trial, for each electrode. HFB power was compared to a regressor, with the correlation coefficient calculated per class, averaged across the three sessions. Each class resulted in a different pattern of activation, with the strongest response generally over the central sulcus or postcentral electrodes (Fig. 1).

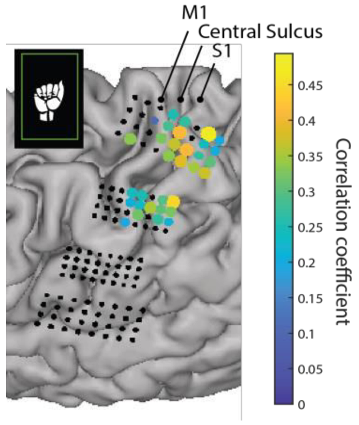

***Figure 1**. Electrode locations on the brain of the BCI participant. For the upper two grids, the correlation coefficients are shown for electrodes where the HFB showed a positive correlation to attempted movement in at least one of the three sessions. The electrode radius increases with the magnitude of the correlation coefficient.*

Conclusion: The pronounced post-central response, even in the absence of movement-related sensory feedback, warrants further investigation to better understand the neural representation of attempted movements in LIS, and its implications for BCI control.

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Redwood: A User Friendly Extension to the BCPy2000 System for Developing Advanced BCI Applications

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Introduction: BCI2000 [1] is a widely used software platform in BCI research. It has been integrated with a large range of brain signal acquisition modalities and hardware systems and has been used in many BCI research paradigms. The growing trend towards using advanced machine learning tools for online brain signal analysis has also led to the integration of Python, which provides cutting edge machine learning tools, into BCPy2000 [2]. While this allows for both Python-based signal processing (SP) and application (App) development it runs the Python code within the traditional C++-based BCI2000 framework. A fundamental feature of this framework is the process block cycle that ties the speed at which BCI Apps can update the feedback screen to the computational time needed to acquire, process and save new brain data. While BCI2000 has proven itself in the BCI research arena, we present Redwood as an extension to the BCPy2000 framework that aids in advanced BCI App development.

Materials and Methods: **BCI2000** is a modular system with 3 modules for: signal acquisition, signal processing (SP), and BCI application logic (App). These 3 modules are governed by an Operator module that calls each module in sequence each process cycle. The Operator process cycle is determined by the 'block size', which is the number of data samples acquired, processed and responded to by the App. Communication between the modules is achieved via 'state' variables that can be defined, read, and written by each module and are saved to a 'dat' file with the block of raw data samples each process cycle. **BCPy2000** supports Python use in the SP and App modules. The **Redwood** system builds on the BCPy2000 framework by adding a thread (Screen) that runs a PyQt based application parallel to App and accesses state variables via the BCI2000Remote class. In this way the BCPy2000 App logic that updates state values and responds to SP output is split from logic updating the visual feedback to the user. Redwood also opens a RedwoodOperator window to provide direct interaction with App.

Results: Building on BCPy2000, Redwood inherits its advantages while adding features that ease Python application development. By decoupling the Screen logic from that of App the update rate of the user feedback screen is no longer tied to the BCI2000 process cycle. This allows for two advantages; Firstly, complex logic defining the visual response to BCI events (e.g. computing AI agent behaviour or using language models for word completion) can be spread across multiple App cycle blocks. Secondly, the refresh rate of the Screen can be faster than the App cycle block. Given that with a BCI system of 100+ data channels and advanced SP a BCI2000 cycle time below 100ms is challenging, when a user initiates a screen action it will be made at 10fps if the screen is updated by App. However, Screen can easily meet the lower bound of 30 fps often needed for acceptable gaming interaction. Additionally, the RedwoodOperator allows the App to be started after the Screen window has been resized and positioned for the user, to be paused without stopping the .dat file recording, and to give real-time feedback about states. Finally, Screen can also create a log of screen events that happen in response to App state changes at the screen fps time scale.

Conclusion: Redwood expands capabilities for App development with Python while preserving all the benefits the BCI2000 platform offers.

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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%.

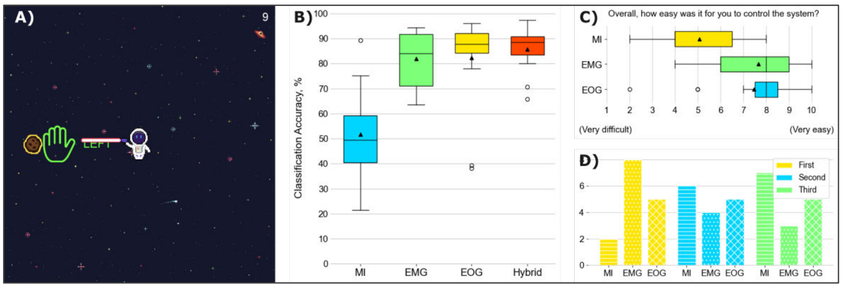

Figure 1: A) User interface of the computer game task; B) Cross-validated classification accuracy scores for each modality; C) Overall ease-of-use rankings for each modality; D) Preference rankings of each modality.

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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Identifying Motor-Specific Biomarkers in Parkinson's Disease: A Focus on Neural Activity in the Primary Motor Cortex

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Introduction: Current research on Parkinson's disease (PD) leverages beta-band oscillations from the subthalamic nucleus (STN) as a biomarker for optimizing deep brain stimulation (DBS) therapy. However, the beta dynamics in STN are not motor-specific [1], which constrains the effectiveness of adaptive DBS. A key challenge lies in the need to identify a more specific feedback control biomarker. In this context, we propose to expand the search for potential biomarkers to the primary motor cortex [2]. Our goal is to extract neural activity correlated with PD symptoms from M1 and investigate whether this biomarker is consistent across different stages of the disease.

Material, Methods and Results: The data acquisition and training process is shown in Fig. 1. We use Male C57BL/6 mice to build a PD model with 1-methyl-4-phenyl-1,2,3,6-tetrahydropyridine (MPTP). Before that, we implanted the 2*8 microelectrode array into the primary motor cortex, collecting both the spike activity and local field potentials. The mice were trained to perform the open-field test across early, middle, and late stages of Parkinson's progression. Meanwhile, signals from the motor cortex were recorded to assess whether the identified biomarker remains consistent throughout these stages. The PD-related features are learned via a Feature Extraction network [3], and then fed into classification models, including Support Vector Machines (SVM) and Long Short-Term Memory networks (LSTM), to validate its effectiveness. By comparing results across different disease stages, we assess whether the biomarker maintains consistent performance throughout all stages of PD.

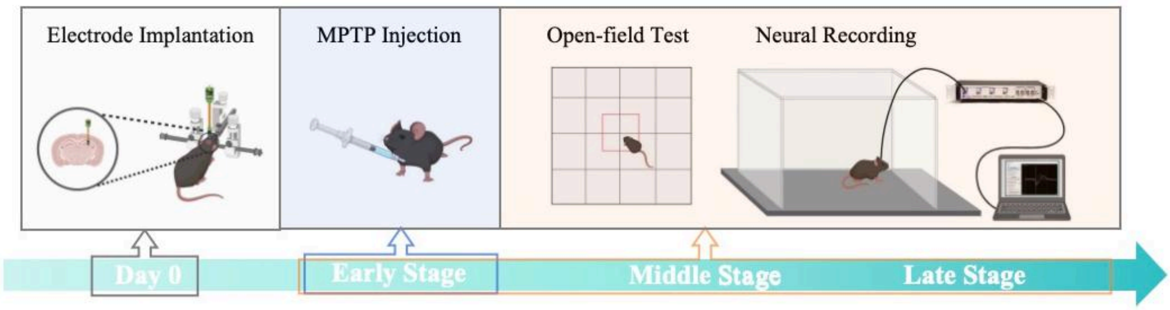

Figure 1. *The experimental setup of this work.*

Discussion and Significance: This work identifies a novel biomarker from M1 for Parkinson's disease and evaluates its performance across three stages of disease progression. The findings will provide a deeper insight into the underlying pathophysiology of PD. Future work will involve integrating this biomarker with an adaptive deep brain stimulation (DBS) device to create a closed-loop system, which could enable real-time monitoring and more personalized treatment strategies for patients.

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BCI-sift: An Automated Feature Selection Toolbox for Brain-Computer Interface Applications

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Introduction: Advancements in Brain-Computer Interfaces (BCIs) for clinical applications rely on precise and reliable signal interpretation. However, the high-dimensional and noisy nature of data captured from both implanted and non-implanted BCIs presents significant challenges, necessitating the use of sophisticated filtering techniques, such as feature selection algorithms. We introduce the Python-based BCI-sift (BCI Systematic and Interpretable Feature Tuning) Toolbox, a comprehensive tool designed to streamline the application of diverse machine-learning algorithms to BCI datasets for identifying the most relevant features in classification tasks. By enhancing classification accuracy, inference speed, and interpretability, BCI-sift addresses key challenges in developing efficient and transparent BCI systems.

Material, Methods and Results: Our scikit-learn-compatible toolbox (github.com/UMCU-RIBS/BCI-sift) simplifies feature selection in classification tasks by integrating advanced machine learning methods, including stochastic hill climbing, simulated annealing, evolutionary algorithms, recursive feature elimination, and particle swarm optimization. These techniques optimize classification performance on cross-validated training sets, with reported accuracies reflecting the application of identified optimal features to held-out test data.

We validated the toolbox using a dataset of eight able-bodied participants with 64 to 128 implanted high-density electrocorticography (ECoG) electrodes (1-mm exposed diameter, 3- or 4-mm inter-electrode distance). The electrodes were placed on the sensorimotor cortex (SMC), and participants repeatedly spoke 12 different words. BCI-sift effectively identified informative neural features across time points, channels, and frequency bands.

In the channel dimension, BCI-sift identified an optimal number and location of channels associated with highest classification accuracy. These selections were consistent across participants and aligned with the functional and anatomical organization of motor activity in the SMC. In the time dimension, the most relevant time points were clustered around word pronunciation on- and offsets. In the frequency dimension, when selecting from delta [0,5 – 3 Hz], theta [4 – 7 Hz], alpha [8 – 12 Hz], beta [13 – 30 Hz], and the high frequency band (HFB) [70 – 170 Hz], BCI-sift identified HFB as most informative for classification, consistent with prior research.

Beyond providing interpretability, BCI-sift significantly improved classification accuracy compared to using no feature selection. For instance, the classification accuracy of 12 different spoken words across eight participants increased from 26±10% to 75±22% ($p = 0.008$, Wilcoxon signed-rank test) with the best-performing optimization algorithm (recursive feature elimination) on the frequency band dimension, driven by the removal of noisy features. BCI-sift selects optimally performing classification features automatically from multi-dimensional input brain data. It outputs informative plots and tables for interpreting results.

Conclusion: With BCI-sift, we provide an accessible and versatile platform for feature selection in BCI research, enabling improved classification accuracy, automatic feature analysis, and enhanced interpretability. Although we validated BCI-sift with ECoG data, the underlying principles are equally applicable to other implanted recording modalities as well as non-implanted BCI data. We encourage researchers to explore and apply BCI-sift in these contexts as well.

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Intracortical neural representation of finger movements in a nonhuman primate preserved over 400 days

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Introduction: Most motor brain-computer interfaces (BCIs) require calibration on the day of use. To reduce the burden of calibration, the decoding algorithm, which maps neural activity to a control signal for a device, can be realigned from day to day or subject to subject [1, 2]. These approaches rely on the underlying principle that the neural inputs can be transformed into a stable representation across days, enabling a static decoder to infer motor movements. While these techniques were developed for single effectors, we investigated whether neural data can be transformed into a stable representation of multiple individuated finger movements using latent factor analysis via dynamical systems analysis (LFADS) [3, 4]. We also explored whether this stable representation can be inferred – without recalibration – from neural inputs conditioned only by channel statistics.

Material, Methods and Results: During 12 sessions spanning 427 calendar days, intracortical recordings in the precentral gyrus and movements from the index and middle-ring-small finger groups were recorded while one monkey (nonhuman primate) performed a finger-movement task. First, to illustrate how neural instabilities degrade BCI performance, we trained a ridge regression decoder on a single day (from the 12-day set) to predict finger flexion velocity from spiking activity and used this linear decoder to predict finger movements on all subsequent days (see Fig. 1a; yellow). Prediction performance decreased with the number of days since training (5.93e-4 correlation/day; p = 1.2e-8).

To understand whether a consistent latent representation existed across days for fingers, a multiday LFADS model with session-specific read-in and read-out layers was trained over all 12 sessions. The multiday LFADS model revealed latent factors that were qualitatively similar across days (see Fig. 1b). Quantitatively, consistent latent factors allowed decoding finger movements from the factors with a static decoder. Specifically, we found that finger velocities on one day could be accurately predicted using a ridge regression decoder learned on a previous day (see Fig. 1a; blue), with little drop in performance over time (-9.8e-5 corr/day; p = 0.07).

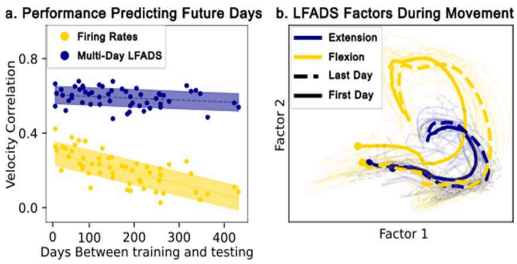

Figure 1: *(a) Finger velocity prediction performance using spiking activity (yellow) or multiday LFADS factors (blue). X-axis represents the calendar days between the day the decoder was trained and tested (b) Representative latent factors from the multiday LFADS model. Trial-averaged factors during both fingers flexing (yellow) and both fingers extending (blue) is shown in bold with thin lines representing individual trials. Results for trials during the first session (solid) and last session (dashed – 420 days later).*

Toward improving decoding without recalibration, we tested a static read-in network for the neural activity, which used an encoding of channel statistics (mean and covariance) as additional inputs. We trained an LFADS model with this static read-in network during the 12 sessions. On 7 held-out sessions using this pretrained model, a decoder mapping factors to finger velocity was trained on a single day and tested at the next session. This approach improved velocity predictions compared to smoothed spikes trained and tested on the same 2 days (delta corr = 0.1; p = 7e-3; paired t-test).

Conclusion: We demonstrate a consistent latent representation of fingers over 427 days using LFADs and present a pretrained decoding approach, which we are continuing to optimize and develop, that may reduce sensitivity to daily neural instabilities.

Acknowledgments and Disclosures: We appreciate the support of Eric Kennedy and the University of Michigan unit for laboratory animal medicine. There are no disclosures to report.

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A Transfer Learning Framework for Across-speaker Articulatory Movement Decoding in Sensorimotor Cortex

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Introduction: Severe paralysis resulting from medical conditions like neurodegenerative diseases and stroke can lead to speech loss. Recent advances in brain-computer interfaces demonstrate the possibility to restore speech by decoding articulatory movements from brain activity for participants who cannot speak intelligibly [1]. However, for individuals with vocal-tract paralysis, it is difficult to learn a mapping of brain data to articulatory movements without transferring from models trained on healthy individuals. Here, we propose a novel framework for 1) extracting articulatory features of spoken words shared across healthy speakers and 2) mapping them to the brain activity of individuals for whom we do not have articulatory movement data. Our findings show promising results for developing word decoding models for individuals with vocal-tract paralysis using group-level articulatory features derived from healthy speakers.

Materials and Methods: Articulatory data. We used articulatory movement data during word production from a publicly available electromagnetic articulography (EMA) dataset [2]. In the dataset, EMA were recorded in eight healthy participants. They were required to speak 97 Dutch words. Each word was repeated twice. In our study, we included seven EMA sensors: three on lips (upper lip, lower lip, and right side of the upper lip), three on the tongue (dorsal part, body, and tongue tip), and one on the chin. We analyzed articulatory movements in the front-back and the up-down directions. We applied a tensor component analysis (TCA) [3] to extract group-level low-dimensional articulatory features per word from EMA. We used dimensionality [4] as a metric to evaluate each participant's contribution to each articulatory feature. If all participants contribute equally, dimensionality is close to the number of participants. *Brain data.* High-density electrocorticographic (ECoG) recordings were obtained over the ventral sensorimotor cortex (vSMC) of the left hemisphere in three participants (P1, P2 and P3). Each participant spoke the same set of words as in the EMA dataset. TCA was applied to the ECoG recordings to extract neural features for each subject separately. We used a gradient boosting regression model to decode across-speaker articulatory features from neural features of each ECoG participant. The decoding performance was measured as the Pearson's correlation between decoded and target group-level articulatory features. Reported correlation values are cross-validated across all individual words using a leave-one-out procedure.

Results: The mean dimensionality of the extracted articulatory features was 7.61±0.14, which means the extracted articulatory features captured articulatory patterns shared across EMA participants. The mean correlation of the articulatory features between repetition 1 and 2 was 0.95±0.01, while the correlation of extracted neural features between repetition 1 and 2 was 0.70±0.07, 0.37±0.04 and 0.49±0.06 for ECoG participant P1, P2 and P3 respectively. These results demonstrate the robustness of the articulatory and neural features across repetitions. We decoded generalized articulatory features with the mean correlation of 0.78, 0.54, and 0.51 for ECoG participant P1, P2 and P3, respectively.

Conclusion: The proposed framework can extract articulatory features shared across healthy speakers and decode them from brain activity of unseen speakers. Our framework may provide a new way to develop speech BCI applications for people unable to make mouth movements.

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Temporal Dynamics of Neural Activation and Inhibition Patterns During Motor Imagery

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Introduction: Motor Imagery (MI), the mental simulation of movement without actual physical execution, plays an important role in motor learning and rehabilitation. Previous studies have identified the involvement of specific brain regions and suppression from supplementary motor area to M1 during MI [1], [2]. However, the precise temporal dynamics of neural activation and inhibition patterns across different phases of motor imagery remain uncovered, due to the limitations in temporal resolution of conventional neuroimaging techniques such as functional magnetic resonance imaging. Based on the high temporal resolution of stereo-electroencephalography (sEEG), this study used sEEG to investigate neural activation and inhibition during the preparation phase and the execution phase of motor imagery. We aim to provide more detailed insights into the rapid neural processes underlying motor imagery that have been elusive in previous fMRI-based research.

Material, Methods and Results: A total of seven epileptic patients were collected in this study and implanted electrodes were distributed in seven different brain regions. Participants were implanted with SEEG electrodes for presurgical assessment of seizure focus. During the experiment, participants were asked to imagine either moving their left/right hands or dorsiflexing their left/right foot. The sEEG signals were downsampled to 1000Hz and a notch filter was used to remove the powerline noise. No epileptic activity was observed in the data. After that, the data was re-referenced using the bipolar re-referencing, where each channel was re-referenced to its adjacent channel on the same electrode shaft. Then, power spectral density (PSD) was calculated using the Welch method with 1000 ms Hann window and 500 ms overlap. From calculated PSD, 8–33 and 65-116 Hz averaged broadbands were calculated, and the signed r-squared cross-correlation was calculated between PSDs of rest and preparation, preparation and imaging stage [3]. An unpaired two-sample t-test was performed for each channel and each movement type. For each movement, the features were screened for all significant levels ($p < 0.05$) in the different phases and their corresponding relevance were multiplied to calculate the trend of each channel, reflecting its dynamic contribution in the different phases. In multiple patients, we observed some suppressions in the high-frequency band within the caudal anterior cingulate cortex, inferior part of precentral gyrus and the pars triangularis of right inferior frontal gyrus. Regardless of lateralization or the specific body part involved in motor imagery, a notable suppression was detected during the transition from the resting state to the preparatory phase ($Rp = -0.453 \pm 0.016$). Conversely, a strong activation emerged during the transition from the preparatory phase to the motor imagery phase ($Rp = 0.693 \pm 0.030$).

Conclusion: Our findings show a unique pattern of neural activity during MI, where in some specific brain regions, high-frequency inhibition occurs in that brain region prior to the onset of real imagined movement. And this temporal variation is independent of both imagined limb site and lateralization type.

Acknowledgements and Disclosures: The authors acknowledge the support of Huashan Hospital for providing access to data collection. The authors declare no competing financial or non-financial interests.

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Toward EEG discrimination of fingers movements during motor imagery vs passive movement

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Introduction: BCIs based on finger motor imagery (MI) show promising potential but limited performance, due to the proximity of the cortical areas dedicated to the fingers of the same hand and the low signal-to-noise ratio of EEG, which results in overlapping signals [1]. To delve into this challenge, previous studies have demonstrated that calibrating BCIs using passive movement may offers a more efficient alternative to MI, particularly by reducing the cognitive and physical load on participants [3]. The goal of our study is to determine whether passive finger movements can induce significantly stronger modifications in the motor cortex compared to when those same movements are imagined.

Material, Methods and Results: Twenty-six healthy participants completed a 2-hour experiment where they: (1) performed MI and (2) experienced passive movements (applied by a custom-built exoskeleton), while their EEG data was recorded using 20 active electrodes (g.USBAmp, g.tec). The motor tasks involved flexion and extension of the index, middle and ring fingers independently, as well as simultaneous movements of all 3 fingers. The sequence of conditions and tasks was randomized, with 30 trials per movement type per condition. Signal from 24 participants was filtered using notch filter and a 0.5-40 Hz band-pass filter. Automatic artifact rejection, independent component analysis and common average reference were applied to limit artifacts. Time-frequency representations were computed using Morlet wavelets. Significant effects ($p \leq 0.05$) were identified with a non-parametric cluster-based paired t-test, and averaged across participants (see Fig. 1).

In the α (8-12 Hz) and sub-part of β (20-25 Hz) bands, a greater number of significantly stronger event-related desynchronizations (ERDs) were observed during the passive movement tasks than during the MI tasks. A repeated measures ANOVA on ERDS values between 8 to 36 Hz and 1 to 5 s after task onset revealed a significant effect of the experimental condition ($F = 19.77$, $p < 10^{-3}$, $\eta^2 = 0.12$) and the movement type ($F = 8.16$, $p < 10^{-3}$, $\eta^2 = 0.02$) on these values. However, the interaction between condition and movement is not significant ($F = 0.87$, $p = 0.45$, $\eta^2 = 10^{-2}$), indicating two independent factors.

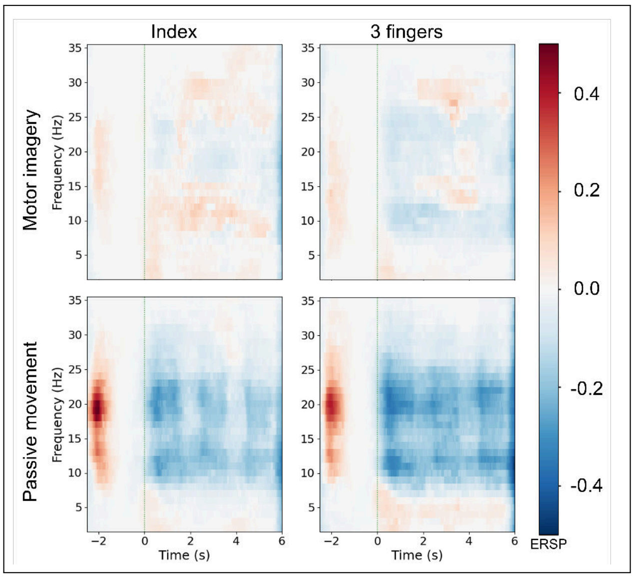

Figure 1: *Grand-averaged ERSP at C3 for MI and passive movement tasks for right index finger and three-fingers movements.*

Conclusion: In accordance with the literature, passive movements consistently elicited stronger contralateral ERD in the motor cortex compared to MI [2]. Interestingly, significant ERSP differences were found between the different finger movements. Future analyses will examine whether training classifiers on MI data or movement data results in the greatest accuracy when tested on MI data.

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Manifold-Based Diffusion Models for Generating Synthetic Motor Imagery EEG

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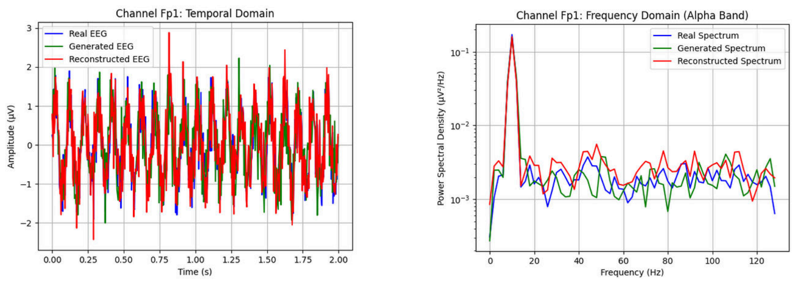
Introduction: Generating realistic synthetic EEG can alleviate dataset size, privacy, and session variability concerns in motor imagery (MI) brain–computer interfaces. Conventional diffusion-based models risk off-manifold artifacts, ignoring the manifold structure of EEG in space and time[1]. We employ *Symmetric Positive Definite* (SPD) matrices derived from EEG covariance to capture electrode correlations. Constraining diffusion on this SPD manifold yields higher-fidelity reconstructions and generated signals for MI tasks[2].



(a) Time-domain comparison of Real (blue), Generated (green), and Reconstructed (red) EEG signals for Channel Fp1.

(b) Spectral comparison of Real (blue), Generated (green), and Reconstructed (red) EEG signals, emphasizing alpha-band retention.

Figure 1: Combined time-domain and spectral comparisons of real, generated, and reconstructed EEG signals for Channel Fp1.

Material, Methods, and Results: We used the BCI Competition IV dataset 2a (BCIC-IV-2a), which includes four-class motor imagery EEG from nine subjects, with 288 trials per session recorded over 22 electrodes at 250 Hz. Preprocessing steps involved noise reduction, down-sampling to 128 Hz, and segmenting 3.5-second epochs, producing 22×22 covariance matrices on the SPD manifold. A forward stochastic differential equation (SDE) was defined,

$$d\mathbf{z} = f(\mathbf{z}, t)\, dt + g(\mathbf{z}, t)\, d\mathbf{w},$$

where $\mathbf{z}$ represents latent SPD coordinates, and $f(\cdot), g(\cdot)$ regulate manifold-constrained noise injection. The reverse-time SDE was approximated by a neural network using mean squared error and cosine similarity, incorporating *log* and *exp* mapping operations alongside a multi-scale diffusion strategy. Synthetic SPD outputs were mapped back to time-domain EEG through Cholesky factorization. Figures 1a and 1b demonstrate that the generated signals preserve amplitude fluctuations and alpha-band peaks (10–12 Hz), improving classification accuracy and reducing Fréchet distance compared to Euclidean baselines.

Discussion and Significance: Constraining diffusion to the SPD manifold minimizes off-manifold artifacts and preserves critical temporal and spectral features of the MI EEG. The overlap between real and synthetic signals demonstrates the retention of inter-electrode correlations and alpha oscillations, making this approach valuable for data augmentation in small-sample or privacy-restricted scenarios. Future work could refine Riemannian metrics, extend to multi-class MI tasks, and validate on larger clinical datasets, solidifying manifold-based diffusion as a reliable method for generating realistic EEG data.

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Theta-to-Alpha Frequency Ratio as an Indicator of Mindfulness During Binaural Beat Listening

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Introduction: Mindfulness is a measure of an individuals ability to be in the present and can vary due to many factors effecting their day-to-day life. Studies suggest that meditation techniques can help individuals enhance mindfulness, yet beginners often find meditation challenging. Binaural beats (BBs) are an auditory illusion that can aid users in meditation, although they can also cause distraction for different individuals [1]. Moreover, there is no definitive explanation for how or why BBs either facilitate or hinder mindfulness during meditation. In this preliminary study, we employ the theta-to-alpha frequency ratio (TAR) as a neural indicator to determine whether novice meditators experienced benefit or hindrance while listening to BBs during meditation.

Material and Methods: 17 participants were recruited to meditate on two separate days, one day with the BB audio and another without with each meditation session lasting 10 minutes. The BB frequencies were set to 126Hz for the left ear and alternated between 134Hz to 140Hz for the right ear, ensuring the frequency difference consistently fell within the alpha range. Seven electrodes were placed in the frontal lobe as shown in Figure 1 left, as a reduction in the TAR in this area when meditators are attentive rather than mind-wandering [2]. After each meditation session, participants were asked to complete the Toronto mindfulness scale to record user experience. After all data was collected, the TAR was averaged across all electrodes. A one-tailed Pearson Correlation test calculated the correlation between the survey and the extracted TAR.

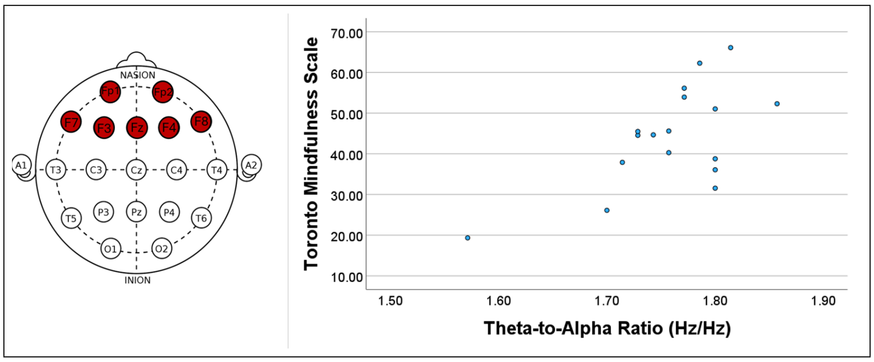

Figure 1: *(Left) The EEG montage chosen for the study. (Right) A scatter plot showing the correlation between the results of the Toronto Mindfulness Scale and the theta-to-alpha frequency ratio for all 17 participants during the binaural beat session*

Results: As shown in Figure 1 right for the Toronto Mindfulness Scale and the TAR during the BB condition, a correlation coefficient of 0.641 ($p=0.003$) indicating a strong correlation.

Discussion: This correlation between mindfulness and TAR wasn't present during the no audio condition, suggesting that this relationship is BB dependent. This discovery may offer additional understanding of the mechanism underlying BBs and their potential use as a tool for meditation.

Significance: This index can offer instantaneous insights into a person's level of mindfulness or distraction during BB-mediated meditation sessions, and if applied in a closed-loop neurofeedback setting, it could enable the audio to be adjusted to optimize mindfulness.

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Riemannian-Based Convolutional Neural Networks for EEG Classification

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Introduction: Electroencephalography (EEG) data are essential for BCI tasks such as motor imagery and mental state analysis. Traditional Euclidean approaches overlook the manifold structure of multi-channel covariance matrices, which reside on *Symmetric Positive Definite* (SPD) manifolds. This neglect diminishes accuracy and obscures critical inter-channel relationships[1]. Recognizing these limitations, researchers have turned to Riemannian geometry to analyze the inherent structure of SPD matrices. This paper adopts a Riemannian-based convolutional neural network (CNN) paradigm that integrates geometric insights into feature extraction and classification steps. In doing so, it maintains important spatial dependencies among EEG electrodes and takes advantage of the interpretability afforded by manifold-based representations[2].

Materials and Methods: We used the BCI Competition IV dataset 2a (BCIC-IV-2a), which provides four-class motor imagery data from nine subjects. Each session comprises 288 trials collected over 22 electrodes at a sampling rate of 250 Hz. Initial preprocessing includes noise reduction, down-sampling to 128 Hz, and extraction of 3.5-second epochs to focus on the most discriminative time window. This procedure yields 22×22 covariance matrices per trial, and these matrices are then viewed as points on the SPD manifold. In our approach, we first feed the raw EEG signals into a CNN-based feature extractor to learn preliminary spatial and temporal filters. However, instead of applying standard Euclidean operations, we compute covariance matrices from the learned features to preserve the inter-channel structure in a geometry-aware manner. A Stiefel manifold transformation reduces matrix dimensionality while maintaining orthonormal constraints, which is critical to avoid distortion of manifold geometry. We then map these lower-dimensional SPD matrices into a tangent space using the matrix logarithm, allowing subsequent linear layers to handle the features more effectively. Throughout training, orthonormal constraints on the Stiefel manifold are enforced via a custom optimizer that corrects parameters after each gradient update. This design adheres to a geometry-aware classification pipeline. Rather than flattening or ignoring inter-channel correlations, we exploit the SPD manifold structure to reflect the nuanced relationships among electrodes. By localizing covariance in a Riemannian tangent space, the model aligns with intrinsic EEG signal geometry and is better positioned to overcome the non-linearities often overlooked by purely Euclidean CNNs.

Discussion and Significance: By integrating Riemannian geometry into CNNs, we address the misalignment between Euclidean assumptions and the manifold nature of EEG covariance data. Evaluated on the BCIC-IV-2a dataset, this approach achieves a validation accuracy of approximately 80% for four-class motor imagery, representing a 10% improvement over purely Euclidean CNN approaches, credited to its faithful representation of channel dependencies and covariance-based noise robustness. Beyond boosting accuracy, this geometry-aware model improves interpretability by revealing global spatio-temporal patterns and effectively generalizing across subjects. Its promise extends to cognitive workload assessment, neurorehabilitation, and adaptive BCIs, where inter-channel dynamics are crucial. Future directions include exploring alternative Riemannian metrics and developing manifold-aware neural layers for end-to-end geometry-preserving representations, underscoring the potential for deep learning and Riemannian geometry to further advance EEG-based BCI systems.

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BCI Games for Cognitive Assessment: A Scoping Review

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Introduction: Traditional assessment tools, such as the Montreal Cognitive Assessment and the Wechsler Intelligence Scale for Children, rely on verbal or motor responses, presenting challenges for individuals with limited communication or mobility [1], [2]. Brain-computer interfaces (BCIs) present a transformative solution, allowing direct measurement of brain activity, particularly through BCI games, promoting active participation without motor or verbal demands [3]. Despite their potential, there is limited research on BCI games, especially in understanding their applicability and effectiveness across diverse populations [4]. This scoping review investigates the current state of BCI games for cognitive assessment, analyzing their application across diverse populations, the cognitive skills measured, the types of games utilized, and the BCI technologies employed.

Methods and Results: 7 electronic databases were systematically searched using Arksey and O'Malley's scoping review framework and PRISMA-ScR guidelines. Studies implementing BCI games to assess cognition were included and reviewed, focusing on game types, BCI paradigms, electrode placement, brainwave frequency, and cognitive skills targeted. We synthesized data on study designs, population characteristics, and standardized assessments for comparison. Of 4735 studies in the title and abstract screening phase, 33 met the inclusion criteria, encompassing a total sample size of 694 individuals. Most studies investigated adults 61% and neurotypical individuals 76%, with 33% children and 6% older adults. Most of the participants were neurotypical individuals 72%, while fewer had conditions such as attention deficit hyperactivity disorder 18%, mild cognitive impairment 5%, autism and hearing loss 2% each, cerebral palsy 1%, and developmental disorders 1%. Most studies, with some examining multiple cognitive skills and others focusing on just one, focused on attention at 88%, followed by memory at 27%, inhibition at 18%, and spatial perception at 12%. Commonly used technologies included MindWave 39% and Emotiv EPOC+ 21%, highlighting a reliance on EEG-based devices for real-time monitoring of brainwave activity. β and θ brainwaves were the most analyzed. Nine studies compared BCI games to standardized cognitive assessments, with 67% demonstrating moderate to strong correlations. BCI games outperformed traditional tools in engagement and adaptability in some of those studies, achieving up to 98% classification accuracies in attention-related tasks.

Conclusion: This review underscored the potential of BCI games as inclusive and adaptive tools for cognitive assessment. Gamification using BCI enhances engagement, particularly in BCI applications, providing immersive environments for active participation. While validation against standardized tools remains limited, existing studies often demonstrate their validity. The current focus on healthy adults establishes a baseline for this emerging field, but future research should explore diverse age groups and conditions to address specific needs and ensure inclusivity. Predominantly assessing attention, BCI games align well with fundamental cognitive skills; however, broader evaluations of cognition are needed [5]. This review informs future research by addressing these gaps and paves the way for advancing BCI-based cognitive assessment tools.

Acknowledgments and Disclosures: We thank Janice Kung, who supervised and approved the implementation of the search strategy.

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EEG-based correlates of attention in intracortical BCI motor tasks

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Introduction: Intracortical brain-computer interface (iBCI) performance varies within and across sessions. A few studies have demonstrated that attention is one factor which can affect performance, but most have used EEG-BCI rather than iBCI and focused on simplistic tasks. To investigate the impact of attentional load on iBCI performance and the movement-related activity in motor cortex, we induced attentional load using a dual-tasking paradigm and measured the effects.

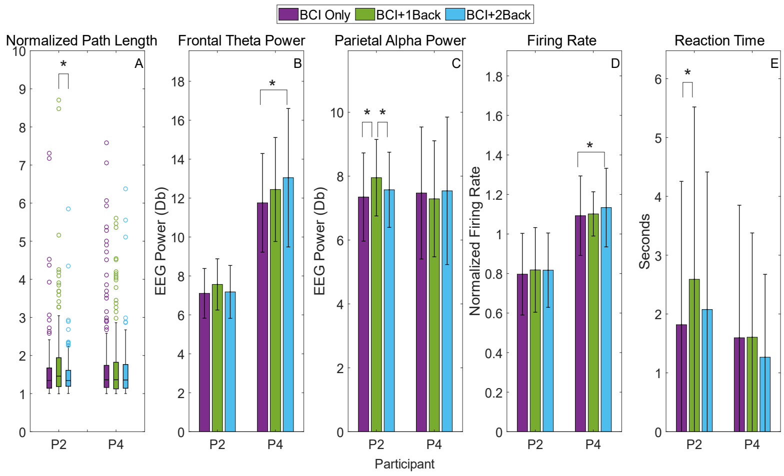

Figure 1:A) Normalized path length in P2 is highest in BCI + 1Back. B) Frontal theta power increases in both participants. C) Parietal alpha power increases in BCI + 1Back in P2. D) Firing rate increases for P4. E) Reaction time increases for P2

Materials, Methods, and Results: Two participants used an iBCI as part of a clinical trial under an FDA Investigational Device Exemption (NCT01894802). Participants performed a complex 2D computer cursor translation + click iBCI task alone (BCI Only) or paired with an N-Back (BCI + 1Back and BCI + 2Back) to induce attentional load. EEG (g.tec, 16 channels, 256 Hz sampling rate, 1-59 Hz bandpass filter) was recorded to quantify neural measures of attention including frontal region theta (3-7 Hz) power, expected to increase with attention, and parietal region alpha (8-12 Hz) power, expected to decrease with attention. BCI performance was quantified as trial completion time, normalized path length, and success rate. Performance was robust to changes in attentional load induced by the N-back with only one participant (P2) showing any significant differences across conditions, indicating iBCI's resilience to high attentional load. P2 experienced a slight increase in normalized path length in the BCI+1Back condition compared to BCI+2Back, (Fig.1**A**). Further, P2 showed increased attention, indicated by significantly higher theta and alpha band power, in the BCI+1Back condition (Fig.1**B**). Finally, P2 demonstrated slower reaction times (time to peak firing rate) in BCI+1Back compared to BCI only (Fig.1**E**). Participant P4 demonstrated increased attention (indicated by increased theta band power) (Fig.1**C**) and a higher firing rate during the BCI+2Back condition, reflecting a stronger motor signal (Fig.1**D**). Overall, P2 displayed greater changes in performance and attention compared to P4 with the BCI+1-back task combination having the greatest effect. P2 may have had more difficulty with the dual-tasking conditions because his implant duration is significantly longer than P4 (~9 years vs. < 2 years) and therefore has lower signal quality. P2 may have required more effort to maintain stable performance.

Conclusion: iBCI performance is robust to attentional load with only minor changes in performance in one participant. BCI+1Back required the most compensation for P2 as indicated by iBCI performance metrics, EEG attention signals, and reaction time estimated from intracortical firing rates. This study demonstrated the successful use of EEG to measure neural correlates of attention during iBCI performance, which provides a foundation for further exploration of BCI performance in additional participants and conditions.

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Advancing speech BCIs towards conversational speeds in people with paralysis

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Introduction: Intracortical speech Brain-Computer Interfaces (BCIs) have shown promise for restoring rapid communication for individuals with paralysis by decoding the neural representation of speech into text [1, 2, 3, 4]. However, current speech BCI systems still operate at speech rates below that of typical speech, possibly because BCI participants naturally set their own pace at slower speeds (20–70 words per minute) that are approximately half that of natural conversational speech (160 words per minute) [1, 2, 3]. We hypothesize that participants are speaking slower as a natural result of their dysarthria during articulation and vocalization. It remains unknown whether people with dysarthria can comfortably increase their speech rate when instructed to do so, and if so, whether decoding accuracy is affected by this change in preferred speech behavior.

Material, Methods and Results: We tested the maximum speech rates achievable by BrainGate2 clinical trial participant T12, who has two 64-channel microelectrode arrays in speech motor cortex, using various verbal behaviors. Imagined speech reached conversational speeds (120-160 words per minute), while even attempted speech at higher instructed rates surpassed T12s typical pace (100 words per minute compared to her usual 60). We then tested how decoding performance varied across four attempted speaking rates using non-vocalized, mimed speech (attempted mouthed behavior): 15, 30, 60, and 120 words per minute, using an open-loop karaoke-style task (Figure 1b) to help T12 pace her speech. In offline evaluations with a limited 50-word vocabulary, we found that decoding accuracy decreased with increasing speech rate, with the optimum decoding accuracy occurring at 30 words per minute. (Figure 1c). Finally, we examined the neural correlates of speech rate and found sentences spoken at different rates were largely stretched or compressed versions of a consistent neural activity template.

Conclusion: Encouragingly, these results suggest that, at least for the participant studied here, speaking rates can be increased substantially when instructed, and the resulting neural activity remains decodable (although accuracy declines). Additionally, the maximum speech rate for each verbal behavior indicates imagined behaviors can achieve average conversational rate while potentially being less tiring and uncomfortable, though trade-offs with decoding accuracy will need to be addressed.

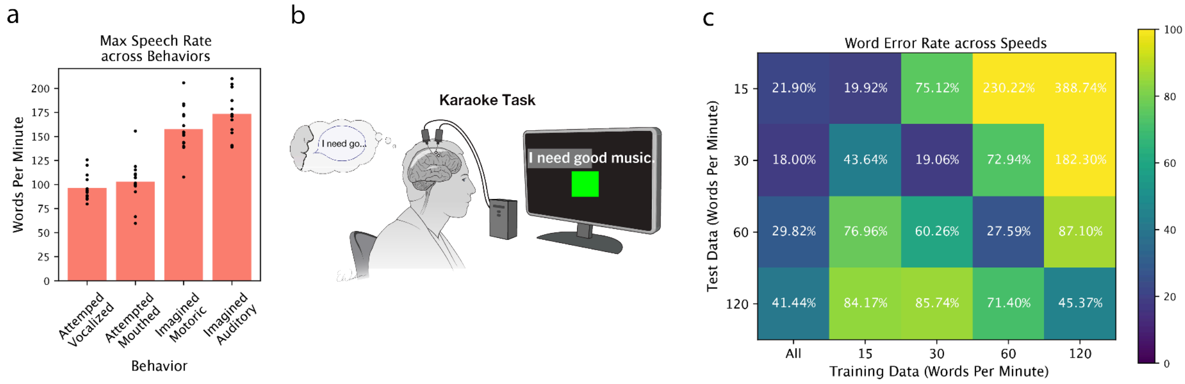

Figure 1: Maximum speech rate across behavior (a), karaoke task design (b), and word error rate for offline decoding when trained and tested at different instructed speeds (c).

Disclosures: The MGH Translational Research Center has a clinical research support agreement (CRSA) with Axoft, Neuralink, Neurobionics, Precision Neuro, Synchron, and Reach Neuro, for which LRH provides consultative input. FRW is an inventor on intellectual property licensed by Stanford University to Blackrock Neurotech and Neuralink. JMH is a consultant for Neuralink and Paradromics, serves on the Medical Advisory Board of Enspire DBS and is a shareholder in Maplight Therapeutics. He is also the co-founder of Re-EmergeDBS, and an inventor on intellectual property licensed by Stanford University to Blackrock Neurotech and Neuralink.

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µECoG Array with 3,072 Electrodes for High-Density and Large-Area Cortical Recordings Based on Scalable Thin-Film Electronics

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Introduction: Large-scale neural implants, involving hundreds of electrodes and spanning multiple cortical areas, are emerging in clinics and neuroscience laboratories [1][2], however their accessibility remains limited. These technologies are based on cutting-edge flexible materials and rely on advanced integrated circuits for their acquisition, and therefore are only produced in research environments at high costs. We propose a novel system, including an industrially manufactured multi-thousand channel µECoG implant, and a commercially available acquisition tool, resulting in a full neural implant solution, easily integrated in any laboratory environment.

Material, Methods and Results: Our µECoG can simultaneously record neural signals in the 1-200 Hz ECoG bandwidth, with 3,072 multiplexed electrodes. The embedded metal-oxide thin-film transistors used to switch between electrodes have previously been established by our group [3], and are now being manufactured in an industrial foundry. Moreover, we have shown their biocompatibility according to ISO standards [3]. Their new low-cost and rapid production yields scaled devices, optimized for high conformability to the brain tissue with an 18 µm thick polyimide substrate. High resolution and very high-density is achieved through iridium electrodes with 200 µm pitch and customizable size between 30*30 and 100*100 µm². We have developed a small headstage and flexible connectors which enable a smooth implantation of the devices. Interfacing printed circuit boards (PCBs) were designed to achieve a compact system connecting to a carefully selected standard acquisition tool for electrophysiology laboratories. Demultiplexing of the signals is performed in near real-time enabling monitoring of the signals during recordings. In-vivo experiments have shown the capability of the implant to delineate whisker movements in the somatosensory cortex of rodents and has revealed dynamics across several cortical areas.

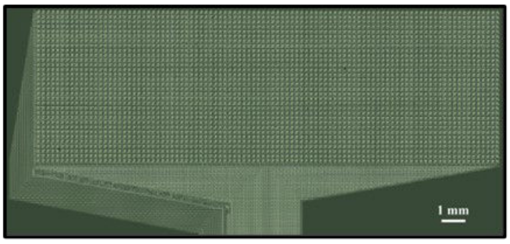

Figure 1: *Micrograph of the 3,072 electrode µECoG implant with 100×100 µm² iridium electrodes and 200 µm electrode pitch.*

Conclusion: The accessible µECoG system developed in this work yields unparalleled high-density recordings over large areas of the cortex. Thanks to its industrial production, the number of electrodes could be drastically increased compared to state-of-the-art implants and enables the rapid and low-cost manufacturing of the devices. Multi-thousand channel implants thus become easily accessible and can help push the boundaries of neuroprostheses.

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Quantizing the Growth in Clinical Trials for Implanted Brain-Computer Interfaces Addressing Motor, Sensory, and Communication Applications.

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Introduction: The total number of people living with motor control, sensory or communication impairments who have undergone long-term electrodes implanted to become a participant in implanted brain-computer interface (iBCI) clinical trials has more than doubled in the past six years [1]. In the past 18 months, two new electrodes have entered clinical trials: Neo by Neuracle Neuroscience and N2 by Neuralink. This emerging technology is demonstrating clinically viable results and is rapidly moving toward commercialization, yet there is no comprehensive data repository to guide the progression of the field.

Material, Methods and Results: An accurate and timely accounting that includes the increasing number of research groups, implanted participants, and electrodes in active clinical trials quantifies the rapid growth of the field. These parameters will be identified by surveying literature and ClinicalTrials.gov, requesting new participant information from known research groups, and reviewing university and industry press releases with a data collection date of 31 April 2025. These results will be compared with data collections ending December 2023 [1] and September 2024 (Figure 1) to provide the scale of growth in the iBCI field.

Conclusion: By demonstrating the growth in clinical trials, we propose an urgent need for the creation of an implanted brain-computer interface (iBCI) registry to act as a repository to provide accurate information to guide researchers, industry, investors, and regulators.

Acknowledgments: We thank all of the research groups who helped ensure the accuracy of this data by providing information for their labs, as well as all the participants and their support networks, without whom none of this would be possible.

Disclosures: KMPK and JLCV have no disclosures. IB is a consultant to Blackrock Neurotech and the FDA, and co-founder of the BCI Pioneer Coalition.

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[1] Patrick-Krueger, K.M., Burkhart, I, Contreras-Vidal, J.L. The state of clinical trials of implantable brain–computer interfaces. *Nat Rev Bioeng* ***3**, 50-67 (2025).*

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Quantifying Neuro-motor Relationships using Deep Learning for Deep Brain Stimulation Targeting in Parkinson's Disease

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Introduction: Deep brain stimulation (DBS) of the subthalamic nucleus (STN) is an established treatment for medication-refractory Parkinson's disease (PD) [1]. Optimal targeting of the DBS electrode within the sensorimotor region of the STN attenuates many PD motor symptoms [2]. Conventional techniques for intraoperative STN-DBS targeting rely on time-intensive clinical assessments of movement-related electrophysiological signatures in real-time [3]. This standard procedure is subjective, arduous, and requires advanced clinical expertise [3]. In this study, we performed a correlation between neuronal firing rate (FR) within the STN and volitional movements tracked using computer vision (CV) to inform more objective, efficient strategies for optimizing DBS targeting and programming.

Material, Methods and Results: Datasets from 4 patients with PD (N=5 hemispheres) were analyzed. During awake DBS surgery within distinct STN subregions, we collected single neuron activity synchronized with multi-camera video recordings while subjects performed repeated trials of upper extremity motor tasks. Neural signal processing, markerless motion tracking, and deep learning-based kinematic feature extraction were used to evaluate STN neurophysiological dynamics in relation to CV-tracked movements (Fig. 1A). Repeated-measures ANOVAs compared within-subject averages of normalized FR across STN regions, with post-hoc tests applied to investigate significant comparisons. In 3 hemispheres, mean neuronal FR was highest and increased most significantly during active movement, relative to baseline activity, in the dorsolateral STN (Fig. 1B).

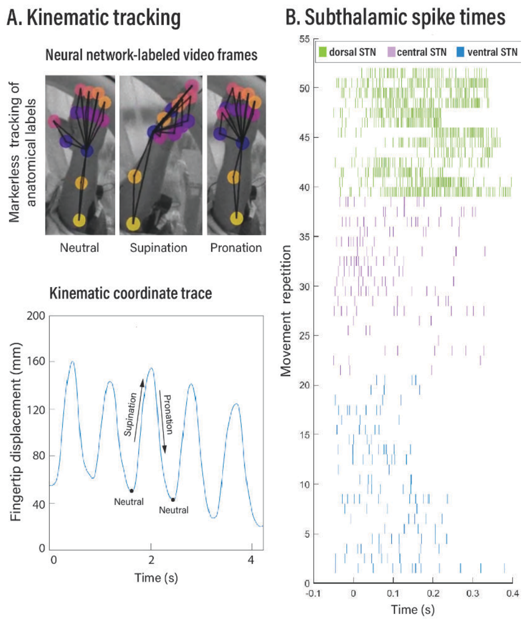

Figure 1: *A) Neural network-labeled video frames (top) and tracking of an anatomical coordinate (bottom) during repetitions of a Hand Pronation/Supination motor task; B) Raster plot of spike times during repetitions of the motor task (seen in A) at distinct STN depths: dorsal (green), central (purple), ventral (blue).*

Conclusion: Preliminary results support the hypothesis that correlation strength between neuronal firing rate and kinematic features provides a basis for predicting the sensorimotor region of the STN during DBS surgery. Computational tools that quantify relevant neuro-motor relationships may assist clinicians in optimizing DBS targeting for PD.

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Efficient and accurate cortical spike train decoding for BCI implants with recurrent spiking neural networks

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Introduction: Externally mounted pedestals of invasive brain-computer interfaces (BCIs) risk infection, requiring fully implanted systems. These systems must meet strict latency and energy limits with reliable decoding. While recurrent spiking neural networks (RSNNs) are well-suited for low-power neuromorphic hardware, it is unclear if they can provide both high decoding performance and low energy use.

Material, Methods and Results: To evaluate this, we trained a tinyRSNN to decode finger velocity from cortical spike trains (CSTs) of two monkeys (Fig. 1A-C). Our tinyRSNN outperformed classical Kalman Filter (KF) and max coefficient of determination (R^2) baselines in NeuroBench [1] (ANN3d, SNN3), though it fell behind AEGRU, the top R2 achiever in the IEEE BioCAS 2024 neural decoding challenge [2]. However, we can achieve comparable R^2 by scaling up our model to bigRSNN (Fig. 1D). The tinyRSNN, notably, consumed less energy in synaptic operations than the baselines for balancing high R^2 with low energy need in NeuroBench (ANN2d, SNN2) [1], while achieving much higher R^2. In particular, tinyRSNN consumed only around 1/2557 AEGRU's effective energy (Fig. 1E). To determine what contributes to this good trade-off, we show in ablation studies that dynamic synapses, recurrent connections, learnable heterogeneous time constants, and pretraining improved R^2, while synaptic pruning and activity regularization reduced energy use (Fig. 1F). Finally, tinyRSNN was deployed on an FPGA (VCU118), achieving low power (around 12mW) and similar R^2 to GPU-based results (Fig. 1G).

Conclusion: Our results thus show that tinyRSNN offers competitive CST decoding performance under tight resource constraints and can be deployed on low-power FPGAs without a loss in decoding accuracy.

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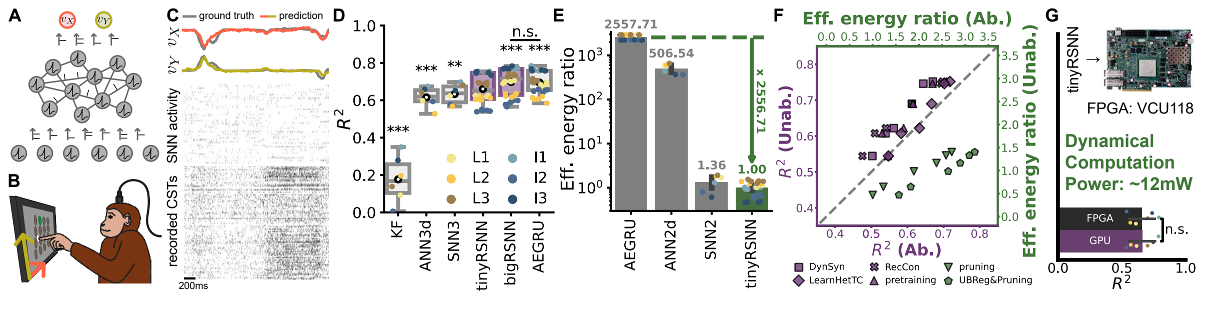

Figure 1: ***A***. *RSNN model: one input layer, one recurrent hidden layer (leaky integrate-and-fire neurons), and one output layer (leaky integrator neurons).* ***B***. *Two monkeys (L & I) perform a random dot reaching task [3].* ***C***. *RSNN activities: Bottom: recorded CSTs (input layer); middle: hidden layer spike raster; Top: output layer membrane potentials (predictions) vs. ground truth.* ***D***. *Decoding performance (R^2) of RSNN models vs. baselines. * denotes statistical significance of the proposed tinyRSNN and other models, based on paired t-test: **: $p < 0.01$, ***: $p < 0.001$. n.s.: not significant. Results are shown from six sessions (L1-L3, I1-I3) and five random initializations each.* ***E***. *Comparison of energy consumption (effective energy ratio).* ***F***. *Ablation studies for decoding accuracy (purple) and energy consumption (green). Each point (representing one session) should be interpreted according to the axis of its corresponding color. Ab. & Unab.: Ablated & Unablated results. DynSyn: dynamical synapses, LearnHetTC: learnable heterogeneous time constants, RecCon: recurrent connections, UBReg: upper bound neuronal activity regularization.* ***G***. *tinyRSNN implementation on the FPGA (VCU118) with its decoding accuracy and energy consumption.*

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Can sex be decoded from MI features in deep learning based BCIs?: an exploratory analysis

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Introduction: Deep Learning (DL) methods in Motor Imagery Brain-Computer Interfaces (MI-BCI) are promising models for capturing complex EEG representations. Nevertheless, biases based on attributes such as sex and age can, although inadvertent, be introduced [1]. Previous studies have explored decoding age and sex through various techniques [2, 3, 4, 5], but it remains unexplored whether sex-related information is present in the features of DL models trained for MI tasks. This study aims to examine if features in the intermediate layers of a MI-BCI DL model include such information.

Material, Methods and Results: Two datasets were used, referred here to as Cho 2017 [6] and Lee 2019 [7]. Preprocessing included band-pass filtering, re-referencing to Fz, and downsampling to 128 Hz. A 2-second EEG window (0.5–2.5 s post-MI cue) was extracted for channels C3, C4, and Cz. The EEGNet [8] was used as DL model. It was trained using Leave-One-Subject-Out cross-validation balanced by sex. Per each leave-out subject, 100 models were trained (20 data splits and 5 model initializations). We first verified that models were successfully trained for the MI task for both male and female subjects (Table 1, top). A consistent trend favoring female performance is observed, but no significant sex differences were found. Next, we assessed the presence of sex-related information in the learned features. To do this the MI models were modified by freezing all layers except the final classification layer, which was re-trained for sex classification. Results reveal that sex-related information is present for male subjects (significantly above chance level classification), while not for female subjects (Table 1, bottom).

Dataset	Global Accuracy	Female	Male
Motor Imagery Classification			
Cho 2017	0.709 ± 0.131 ***	0.755 ± 0.132 ***	0.682 ± 0.124 ***
Lee 2019	0.710 ± 0.115 ***	0.738 ± 0.111 ***	0.690 ± 0.120 ***
Sex Classification			
Cho 2017	0.591 ± 0.276 *	0.446 ± 0.309 n.s.	0.674 ± 0.248 *
Lee 2019	0.550 ± 0.258 n.s.	0.470 ± 0.297 n.s.	0.609 ± 0.254 n.s.

Table 1: Global accuracy values and sex-specific performances for each dataset for Motor Imagery (MI) and sex classification. A Wilcoon test was applied to each accuracy greater than chance level (Wilcoxon test). *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$.

Conclusion: Our results show that sex-related information in DL trained for an unrelated MI-BCI task is present in the features of the model. At the same time, we observe a slight (though n.s.) trend toward better performance for women in MI tasks in both datasets. In contrast, sex can be better detected from model activations in the case of male subjects, suggesting that spurious correlations with sex are detrimental to BCI performance. Our work thus raises a concern: if demographic information like sex are still present in features extracted by DL models (like EEGNet) trained with balanced by sex data, and this correlates with model performance, more complex architectures may amplify biases. Further assessment of these potential issues is crucial for ensuring fair, transparent, and robust DL systems for MI-BCIs.

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Evoking Facial Expressions by Functional Electrical Stimulation in Healthy Volunteers

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Introduction: Individuals with facial or full-body paralysis face significant challenges in expressing themselves, which greatly limits their ability to communicate with family and loved ones. Augmentative and alternative communication technology including brain-computer interfaces (BCIs) has so far prioritized enabling verbal communication for these people. Natural communication, however, involves emotional facial expressions and other forms of non-verbal communication that are lacking in currently existing solutions. The present study explores the feasibility of using functional electrical stimulation (FES) to evoke facial expressions in healthy participants. In the future, this could lead to combining BCIs with FES to restore facial movement in people with severe paralysis.

Material & Methods & Results: We conducted an experiment to evoke up to six basic facial expressions with surface FES in healthy participants. We used an ELPHA 3000 medical device with Axelgaard surface hydrogel electrodes (2,5 cm in diameter) to deliver stimulation. Eighteen participants never previously exposed to facial FES were included (15 female, 2 male, 1 unknown; mean age of 23). Per participant, up to six facial expressions were stimulated (five on average) by applying two-second-long stimulations on two target facial muscles (**Table 1**) simultaneously only on the right side of the face. After every stimulation attempt, participants rated their discomfort level on a five-point Likert scale. We started with lowest stimulation intensity possible and, if participants' discomfort level was low, increased stimulation intensity by 1 mA until movement was observed. At final settings, stimulation was applied three times consecutively and videorecorded. In addition, participants reported what facial expression they perceived upon stimulation by choosing one out of all six options and their certainty about their answer on a five-point Likert scale. The stimulation results are summarized in **Table 1**.

Table 1. *Results of FES stimulation of six facial expressions in 18 healthy participants.* ***Achieved observed movement*** *(%): percentage of participants in whom stimulated facial expression was successfully evoked based on movement observed by two researchers.* ***Self-reported correctly****: percentage of facial expressions reported by participants that matched the target of stimulation.* ***Certainty****: mean and standard deviation of participants' certainty regarding self-reported evoked facial expressions. Target muscles are the muscles stimulated per expression.* ***Intensity*** *is the stimulation intensity required to achieve observed movement.* ***Discomfort*** *is the discomfort level at which the observed movement was achieved (0 = sensation absent; 1-5 = sensation present discomfort rating).*

Facial expression	Achieved observed movement (%) [$n_{achieved}/n_{attempt}$]	Self-reported correctly (%)	Certainty (min: 1, max: 5)	Targeted muscles	Intensity (mA)	Discomfort (min: 0, max 5)
happy	94.4 [17/18]	43.14	3.5±1.50	*orbicularis oculi* (tighten the eyelid)	4.56±1.86	2.06±0.97
				zygomaticus major (elevate the lip corner)	7.18±1.32	1.94±0.97
angry	91.6 [11/12]	60.61	3.45±0.94	*corrugator* (lower the inner eyebrow)	6.32+1.12	3.20±0.79
				orbicularis oris (tighten/pucker the lip)	9.18±2.28	3.00±0.94
disgusted	100 [16/16]	58.33	3.18±1.39	*levator labii superioris alaeque nasi* (elevate upper lip)	7.06±1.42	2.27±1.16
				depressor anguli oris (lower the lip corner)	9.00±2.16	2.53±1.13
sad	88.9 [16/18]	20.83	3.33±1.64	*frontalis medial* (elevate the inner eyebrow)	5.88±1.04	2.85±0.99
				depressor anguli oris (lower the lip corner)	9.5±2.73	2.62±0.77
scared	100 [18/18]	14.81	3.00±0.93	*frontalis lateral* (elevate the entire eyebrow)	5.61±2.17	2.54±0.66
				depressor anguli oris (lower the lip corner)	9.44±2.50	2.46±0.78
surprised	85.7 [12/14]	33.33	2.44±0.67	*frontalis lateral* (elevate the entire eyebrow)	5.5±1.09	1.94±0.97
				masseter (lower the jaw and stretch the mouth)	7.76±1.70	1.94±0.97

Discussion & Significance: Present results show that FES can evoke noticeable movement at slight to moderate discomfort levels in more than 85% of tested participants for all facial expressions. Evoked expressions do not yet seem to be reliably perceived by participants as target expressions. Further work assessing perception of evoked expressions by independent observers will be done. Altogether, present work shows promising results for using FES to evoke facial movement for enabling non-verbal communication in people with severe motor paralysis.

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Development of Brain-Computer Interface Translational Research Platform in Canine Models

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Introduction: Brain-Computer Interface (BCI) applications require expertise in hardware, software, neurophysiology and signal processing, limiting their widespread use. To lower the entry barrier and to encourage potential clinical BCI applications, we are developing an open-source ecosystem in canine models combining the BCI2000 software environment and CorTec's Brain-Interchange (BIC) platform (see Fig.1). This ecosystem enables real-time signal visualization, analytical online processing pipelines for BCI applications, as well as both open & closed-loop stimulation paradigms across all 32 channels independently [1].

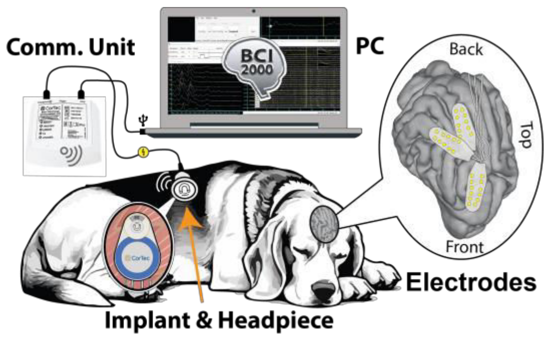

Figure 1: *CorTec BIC–BCI2000 recording setup. Implant is powered inductively by a magnetically attached headpiece. Data are transferred wirelessly to a communication unit and visualized on a PC running BCI2000 software.*

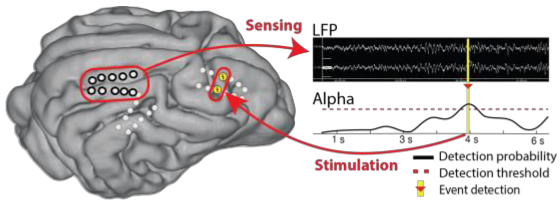

Figure 2: *Schematic figure of the closed-loop stimulation. Local field potentials (LFPs) are streamed to PC and signal power in band is calculated. After exceeding a threshold, stimulation is triggered.*

Methods and Results: We have implanted three canines with cortical or deep brain stimulation (DBS) electrodes. Following surgical recovery, canines were monitored on daily basis for over 23 months (in total), during which we evaluated in-vivo capabilities of the BIC, including the device's noise floor, packet loss rate and impedance fluctuations. We recorded signals during various brain states, including task-based movement & multi-sensory behavior, rest or sleep in all three canines. We triggered closed-loop stimulation based on different brain oscillations (see Fig.2). After almost a year post implant, we conducted series of simple functional tasks in one canine and successfully decoded brain activity by capturing broadband spectral changes associated with local neuronal activation [2]. Additionally, we recorded and quantified evoked response potentials triggered by single-pulse stimulation in all three of the canines and captured epileptic activity during sleep in the canine with natural occurring epilepsy.

Conclusion: We are developing a powerful open-source ecosystem that will bridge research and clinical settings, enabling closed-loop neuromodulation or BCI applications therapies for patients with various neurological disorders, such as ALS, stroke or epilepsy.

Acknowledgments and Disclosures: This research is conducted under Mayo Clinic IACUC protocol A00001713-16-R19. All dogs will be available for adoption at the conclusion of the research in accordance with the Minnesota state Beagle Freedom Bill. This work was supported by the NIH U01-NS128612 (KJM, GAW, PB). Sketches in the figures were created using generative AI.

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Closed-Loop Augmentation of Cognitive States

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Introduction:
Enhancing cognitive ability is crucial for improving decision-making and job performance in the future. In this study, our objective is to extend periods of optimal cognitive performance by applying neurostimulation to buffer participants against the effects of increased levels of stress, distraction, and cybersickness. We use OpenBCI's Galea biosensing headset to measure cognitive state and Spark Biomedical's Sparrow Link neurostimulation device to deliver external stimulation in a closed-loop system (figure 1).

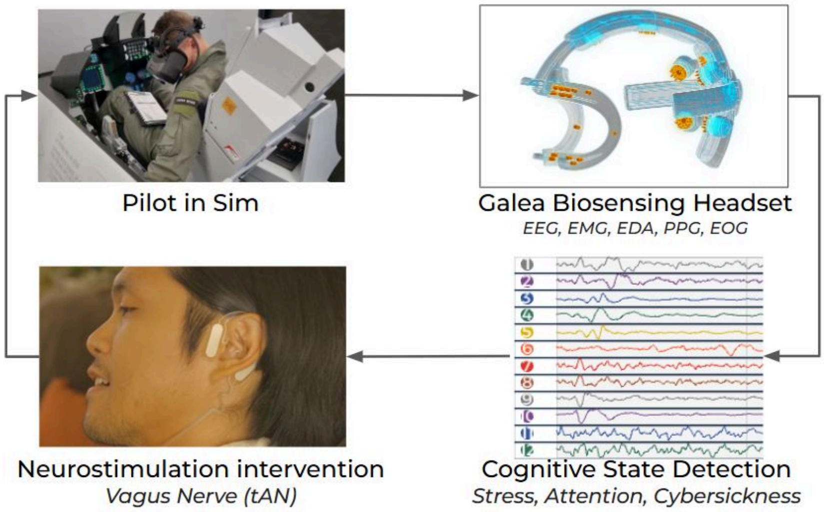

Figure 1: *Overview of the CAMSAN project. Pilots often use virtual reality to train for in-the-field scenarios. We can improve pilot performance during training by developing a closed-loop system to modulate performance. OpenBCI's Galea biosensing headset is used to record multi-modal biosignals during VR experiences. We interpret the signals to predict a users stress, attention and cybersickness. When these cognitive states cross a threshold, we apply neurostimulation on the vagal nerve using Spark Biomedical's Sparrow Link tAN system.*

Material, Methods and Results:
This study contains three phases of data collection. In Phase 1, participants completed four tasks in VR: Flanker [1], GradCPT [2], MATB [3] and a custom cybersickness task, while wearing the Galea headset without any neurostimulation. Galea simultaneously collects EEG, EMG, EDA PPG and EOG during these tasks [4]. In Phase 2, participants completed the same tasks, but with manual tAN applied based on cognitive state. In Phase 3, participants completed the same tasks with the automated closed-loop neurostimulation system. At the time of writing, we have collected Phase 1 data from 15 participants.

Conclusion: This study shows the potential for non-implanted technologies that improve cognitive performance using a passive closed-loop BCI system, and multi-modal biosensors.

Acknowledgments and Disclosures: All authors of this submission are employees of either OpenBCI or Spark Biomedical. As such, they may derive financial gain from the submitted work, whether in cash or in-kind, through mechanisms such as product sales, intellectual property, or other business-related benefits. This research is sponsored by the U.S. Air Force.

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Feasibility of Non-Invasive EEG Brain-Computer Interfaces in Neurologic Music Therapy for Attention Training in Children with Neuromotor Disorders

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Introduction: Neurologic Music Therapy (NMT) uses music-based interventions to enhance neurorehabilitation outcomes. Non-invasive EEG brain-computer interfaces (BCIs) have shown promise in clinical settings for recreational therapy in children with special needs [1]. In this study, we explore the feasibility of integrating BCIs with NMT for attention training in children with neuromotor disorders.

Material, Methods and Results: Three participants (ages 7–15) were each recruited for sixteen 45-minute sessions of BCI-NMT, alongside pre- and post-intervention attention assessments. To date, one participant has completed the study. Across all participants, 35 sessions have been conducted, with BCI data recorded in 33 sessions. Each session is facilitated by a certified music therapist and a BCI technician, and includes three NMT interventions using traditional musical instruments, followed by three BCI-NMT interventions. BCI activations were enabled by Mindset software [2] to control 1–2 switches that triggered prerecorded musical outputs. The BCIs were trained using three trials of each 5-second task of familiar mental imagery activities. All sessions were video recorded for subsequent analysis. No adverse events were reported during the study. All participants reported enjoyment with the BCI-NMT sessions and demonstrated high motivation for continued participation. One participant used a 32-channel BrainVision R-Net EEG headset throughout the study, while two others initially tried the R-Net but transitioned to the Emotiv Epoch X headset after reporting better comfort and tolerability. All participants consistently produced discernible brain signals for 1–2 active mental imagery tasks and rest, achieving 100% training accuracy across all sessions. With manual adjustments to the classification thresholds, all participants were able to use the BCI effectively for NMT activities during online tasks.

Figure 1: *Illustration of BCI-NMT setup. Music therapist tailored the intervention to the child's needs and provided musical cues for the child to follow. Mental imagery EEG was transmitted to Mindset then to switch musical outputs.*

Conclusion and Next Steps: This preliminary investigation demonstrates the feasibility of using non-invasive EEG BCIs for NMT in attention training for children with neuromotor disorders. Key to the success of these interventions were child-specific adaptations, including individualized headset selection, tailored control signals, task designs, and personalized music and instrument preferences. Future work will focus on annotating video recordings to evaluate real-time BCI accuracy and quantify attention-related outcomes across sessions. These findings aim to inform further development of BCI-enabled NMT for pediatric populations with neuromotor challenges.

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Proprioceptive and Visual Feedback Effects on iBCI Decoding of Hand Grasps

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Introduction: Intracortical brain-computer interfaces (iBCIs) enable people with paralysis to control assistive devices by decoding motor signals directly from motor-related areas of the brain. Augmenting visual feedback with somatosensory feedback, such as through haptic interfaces [1] or intracortical microstimulation [2], has been shown to enhance iBCI performance for users who have also lost the ability to feel with their hands. Meanwhile, the integration of iBCI decoding with soft robotic wearables presents an opportunity to restore movement of one's own limbs while incorporating information from residual proprioceptive pathways available to some users, such as those with ALS. Although proprioceptive signals have been observed in human motor cortex recordings [3], it remains unclear how these inputs interact with concurrent motor attempt–related activity. Here, we investigated how visual and proprioceptive feedback provided by a soft robotic glove (SRG) modulate neural activity in motor cortex and affect grip decoding performance for iBCIs.

Material, Methods and Results: Experimental sessions were performed by two BrainGate participants: T17, a 34-year-old man with advanced ALS, and T11, a 40-year-old man with a spinal cord injury (C4 AIS-B). T17 had six 64-electrode arrays implanted in his left precentral gyrus (PCG), and T11 had two 96-electrode arrays implanted in his left PCG. A fabric-based, pneumatically actuated glove and control system were manufactured and programmed to provide 4 grip states: power grip, pinch grip, open hand, and relax. Using the SRG, we recorded neural responses while participants actively attempted or passively observed hand grips in the presence or absence of proprioceptive feedback (SRG on own hand vs. on mannequin) and in the presence or absence of visual feedback (SRG visible vs. behind a barrier). For T17, 59% of neurons selective for grip type during the motor intention only condition (no sensory feedback, "M") were also grip-selective during passive movement of the hand with the SRG (proprioception only, "P"). Only 5% of neurons selective during M trials were selective during the visual feedback only condition ("V"). For T11, of the neurons identified as grip-selective during M trials, none were selective during P trials, but 30% were selective during V trials. Although the presence of sensory feedback (visual or proprioceptive) did not significantly affect decoding of grip attempts in T11, sensory feedback provided moderate decode performance gains in T17 (Fig. 1).

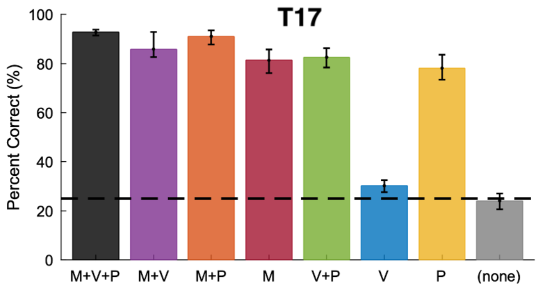

Figure 1: *Offline LDA grip classification performance on SRG grasps performed with concurrent motor attempts (M), visual feedback (V), proprioceptive feedback (P), and combinations.*

Conclusion: Our findings highlight the presence of sensory modulation in human PCG while confirming that iBCI decoding of attempted hand grasps remains robust when proprioceptive feedback is present and may further benefit from its inclusion. The results support the potential of soft robotics for the restoration of movement through iBCI decoding.

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The Application of Stereo-electroencephalography for Brain-computer Interfaces

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Introduction: Stereo-electroencephalography (sEEG) has grown to be the most prominent method in the treatment of medication-resistant epilepsy due to its minimally invasive nature and ability to target deep subcortical brain regions with high temporal resolution (Fig. 1). Despite its growing use in the clinic and in neuroscientific research, its potential for brain-computer interfaces (BCIs) has remained underexplored [1]. Over the past 5 years, our lab has investigated sEEG's potential in decoding a wide range of cognitive processes relevant for BCIs, including hand movement [2], speech [3], navigation [4] and decision-making [5]. We have also addressed key preprocessing challenges such as re-referencing, which arise from its unique electrode coverage.

Methods: We evaluated the impact of six re-referencing methods (bipolar, laplacian, electrode shaft, common average, common median, and a data-driven independent component-based method) on sEEG signal quality and decoding performance of two tasks in beta and broadband frequency ranges. Additionally, we applied machine learning techniques to evaluate the potential of decoding different cognitive processes from sEEG recordings: hand movement (grasping motion), speech (overt production), navigation (movement speed) and decision-making (arbitrary and informed decisions).

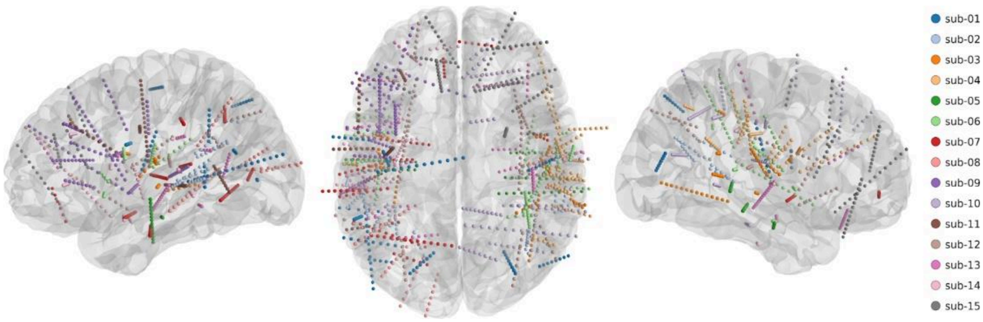

Figure 1: *Electrode locations on an averaged brain for the 15 stereo-electroencephalography participants included in the re-referencing analysis. Each color represents one participant and each sphere represents one electrode channel.*

Results and Discussion: We found that the optimal re-referencing method depends primarily on the frequency range of interest, where local references (bipolar, laplacian) are preferable for low-frequency activity and global references (common average, electrode shaft) for high-frequency activity. However, the choice should be tailored to the goal of the study. The remaining results show that we can decode meaningful cognitive states from sEEG data, across a wide range of different tasks and processes. The depth electrodes offer the benefit of reaching sulci and deeper nuclei that other common invasive neurotechnologies cannot reach.

Significance: This work provides valuable insights into re-referencing strategies and decoding applications for sEEG, highlighting its potential as a versatile tool for both clinical and BCI developments.

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Affective-Visual-Voice-Feedback Immersive Brain-Computer Interface Integrating EEG-Based Motor Imagery and Generative AI for Stroke Patients

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Introduction: Stroke patients often use the exoskeleton system in a passive mode during the rehabilitation period. Motor imagery (MI) is controlled by capturing rhythmic signals, which promote the activation of motor nerves in the brain and accelerate their remodeling. This study aims to evaluate the effectiveness of a robot-assisted system combined with proprioceptive neuromuscular facilitation (PNF) training compared to conventional treatment in subacute stroke patients. Affective, voice, and visual feedback can enhance the MI system's effectiveness.

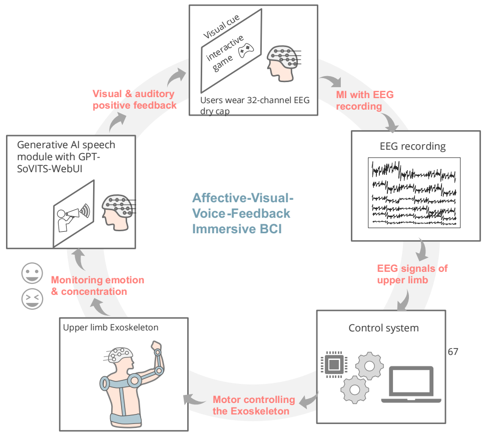

Figure 1: *Affective-Visual-Voice-Feedback Immersive Brain-Computer Interface.*

Material, Methods and Results: Patients in good condition wear a 32-channel EEG dry cap during the BCI rehabilitation process. EEG recordings are used to monitor brain activity and control the BCI. We have developed a new BCI system that integrates motor imagery, positive emotion recognition, visual-voice immersive environment, and generative speech AI, combined with an upper limb exoskeleton, to facilitate brain-computer loop rehabilitation and explore the relationship between neuroplastic changes and motor function recovery (see Figure.1). The detailed methods are as follows: **1. MI Recognition**: Event-related resynchronization energy changes in the primary motor area of the cerebral cortex are used to determine whether the subject is performing MI. **2. Development of a visual-voice immersive environment:** A Generative AI speech module, GPT-SoVITS-WebUI, is applied to imitate the voices and timbre of relatives to praise and encourage patients while using the upper limb exoskeleton to play an interactive rehabilitation game. **3. Emotion and Concentration Recognition**: Concentration indicator (β_{avg}/α_{avg}) and Valence-Emotion indicator ($\alpha_{F4}/\beta_{F4} - \alpha_{F3}/\beta_{F3}$) are used to monitor patients' mental states during the new BCI system usage. These indicators, together with the immersive environment system, are employed to enhance the effectiveness of interactive rehabilitation.

The visual and auditory feedback are based on the allows the brain to communicate directly with external devices without the involvement of the peripheral nervous system and muscle tissue, allowing paralyzed people to do so without the need for physical movement. Limb MI can activate the plasticity of brain cells as real limb movements and can accelerate the repair of neural functional connections between limbs and the brain from EEG recording. Results from three subjects showed that using this system effectively improved concentration by 16.67% compared to not using it. During the rehabilitation task period, the average results indicated that the subjects successfully performed motor imagery 52.67% of the time. Positive emotions were detected 39.3% of the time, with approximately 12% of positive emotions lasting more than 10 seconds.

Conclusion:

The proposed BCI system can recognition module to instantly identify the patient's movement intention, feed the results back to the interactive scene to control the movement of interactive objects and the state of the brain topography, forming a real-time interactive closed-loop control structure.

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Comparative covariance example selection: a weak labelling approach to MI BCI classification

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Introduction: Motor Imagery (MI) Brain computer interfaces (BCI) require a significant training period to train the user and the BCI system. The effectiveness of this training can be increased by providing feedback to the user [1], however if the feedback is incorrect, it can cause the user to perform "incorrect mental tasks". Labeling these examples as correct examples will negatively affect system performance and not knowing where after the cue these poor examples are creates a weak-labeling multi-instance learning problem [2]. In this paper we propose a method to select correct examples to train MI systems.

Material, Methods and Results: We opted to use a filter matching approach to select what we believe to be correct examples. After applying a 4-40Hz 4th order butterworth filter, each participant's cross-sessional left- and right-hand mental tasks were segmented into 1 second epochs. A "perfect" example of mu rhythm event related de-synchronization with the same epoch length is then generated by creating a sinusoid for each channel at 10Hz to mimic alpha activity using the equation $x_n = \sin((2\pi n f)/fs)$ where f is the desired frequency and fs is the sampling frequency of our signal. Using the same equation the channels C2 & C4 for left examples and C1 & C3 for right examples are set to a sinusoid at 20 Hz, mimicking the beta activation seen in motor imagery. We can then score the similarity between the cross channel covariance matrix of each example and the "perfect" example covariance matrix using the forbinius inner product ($score \subseteq \mathbb{R} = tr(\bar{A}^T B)$).
After normalizing each participants instruction scores we then select all examples with a score above a threshold. Applying this method to the Physionet BCI2000 motor imagery dataset [3] and selecting 15 electrodes over the motor cortex with a score threshold > 0.5, we achieved a statistically significant increase in a 5 fold classification accuracy compared to not selecting examples ($p < 0.05$, wilcoxon signed rank test) for each participant using a simple 4 component common spatial pattern (CSP) transformation followed by a linear class balanced SMV (Figure 2). A simple CSP classifier was chosen to assess the effectiveness of the proposed method and provide spatial information on the selected examples (Figure 1).

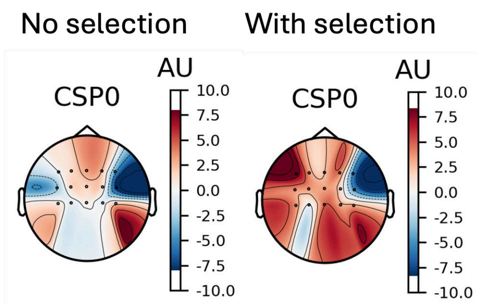

Figure 1: *CSP pattern plots of left and right hand motor imagery sets. Left is all examples while right is with example selection*

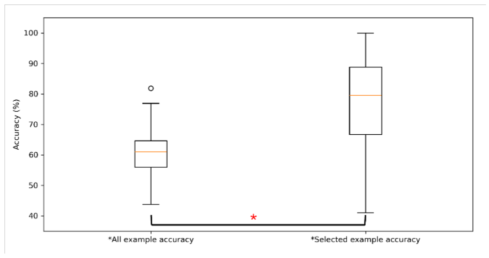

Figure 2: *Boxplot of classification accuracies per participant with and without example selection. * indicates a significant difference*

Conclusion: The findings of this study suggest that example selection methods can improve classifier accuracy and may provide more accurate feedback to the user during human in the loop MI BCI training. Further testing is required to assess the effectiveness during training and how it effects the accuracy of more complex classifiers.

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Large-scale fMRI dataset for the design of motor-based Brain-Computer Interfaces

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Introduction: Motor based Brain-Computer Interfaces (BCIs) can potentially be used to help children and young adults with severe communication impairment due e.g. Cerebral Palsy [2]. For implanted BCIs, the precise identification of electrode target areas prior to implantation is crucial for optimal performance. Functional Magnetic Resonance Imaging (fMRI), commonly used to map sensorimotor cortical organization, has been shown to predict BCI performance [1]. To date, it is unknown whether BCI targets can be determined adequately in younger age groups. Here we present the first large-scale fMRI dataset of 155 (able-bodied) children and adults performing a standardized set of motor and somatosensory tasks. Public availability of this dataset can lead to better insight into feasibility of identifying BCI targets for implanted BCIs in the younger population.

Material, Methods and Results: Data was collected from 155 participants (mean age: 35.5±21.3, range: 6-89; 11.6% (18) under age 12; 8.4% (13) aged 12-17; 49.7% (78) females, 88.5% (139) right-handed and 1.9% (3) ambidextrous). 63 participants were admitted to the hospital for diagnostic procedures related to their medication-resistant epilepsy (N = 60) or surgical removal of a tumour (N = 3). The remaining 92 participants were healthy volunteers in studies on functional mapping of movement. All participants and/or their parents gave written informed consent.

The dataset includes a total of 471 fMRI runs (repeated in various participants) involving the hand and fingers, tongue, and other limbs, such as the arms or legs. Participants performed one of six tasks: Motor2Class, Motor2ClassKids and Sensory2Class were block design tasks with two conditions: rest and active. The Motor3Class task is a block design task with one rest and two active conditions, being executed movements and imagined movements. The Mapping3Fingers task mapped the thumb, index and little finger using an event-related design. The Mapping5Fingers task likewise mapped thumb, index finger, middle, ring and little finger. Structural and functional images were acquired on either a 1.5T ACS-NT Philips scanner (20 runs), a 3T Achieva Philips scanner (434 runs) or a 7T Achieva Philips scanner (17 runs). For functional scans, a PRESTO (1.5T and 3T) or EPI (7T) pulse sequence was used. Data was converted to Brain Imaging Data Structure (BIDS). Data quality validation revealed that 30 participants had more than 10% motion outliers and 17 participants had framewise displacement larger than 4 mm. The dataset can be downloaded from the open public repository at https://openneuro.org/datasets/ds005366/ and the code used for validation is available in https://github.com/UMCU-RIBS/PANDA-fmri-dataset-validation.

Conclusion: This dataset is particularly relevant to study developmental patterns in motor representation on the cortical surface and for the design of paediatric motor-based implanted BCIs.

Acknowledgments and Disclosures: This research was supported by the Dutch Research Council (PANDA project, grant 19072), Dutch Technology Foundation UGT7685, EU ADV-320708 and USA NIH NIDCD U01DC016686. The authors declare no conflicts of interest to disclose.

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Speech decoding performance is influenced by perceiving auditory feedback or not: Implications for locked-in individuals

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Introduction: Recent developments in speech BCI technology have demonstrated its potential to restore communication in individuals who have lost the ability to produce intelligible speech by translating neural signal modulations associated with (attempted) speech into computerized speech [1, 2]. For the accurate production of speech sounds by able-bodied people, auditory feedback plays an important role, evidenced by the fact that speech output is directly affected when feedback is altered or absent. Importantly, individuals with locked-in syndrome (LIS) are unable to produce speech and articulator movements, and therefore lack auditory feedback. The question remains if the speech decoding performance levels reported recently for less severely impaired individuals can be attained by people with LIS as well. Here, we investigated if and how speech decoding performance differs in the presence and absence of auditory feedback.

Material, Methods and Results: High density electrocorticography (ECoG) grids were subdurally placed on the left SMC in three epilepsy patients. These participants completed two speech tasks, in which they were instructed to produce a sequence of seven syllables. In the first task they could hear themselves speak, while in the second their auditory feedback was masked by pink noise. After preprocessing the ECoG data and extracting the HFB power (65 – 95 Hz), electrodes with a significant increase in HFB power during speech compared to rest were identified by computing R2 values. Then, a support vector machine classifier was applied to the speech trials following a nested cross-validation approach to determine decodability of the brain signals in both tasks. A leave-one-group-out approach was applied, where on every fold one instance of each of the seven syllables was left out as test data. Decoding accuracies were compared between tasks.

Results showed that for both tasks, all participants displayed widespread SMC engagement during speech production. Decoding accuracies for all participants were well above chance, ranging between 36% - 62% (chance level 11%). There was a consistent difference in decoding accuracy between the two tasks, where each participant displayed significantly lower performance in the task with masked feedback compared to the task in which auditory feedback could be perceived.

Conclusion: The perception of auditory feedback during speech production influences speech decoding performance. This finding stresses the need to validate speech BCI performance with participants who are unable to produce any speech movements and sounds.

Acknowledgments and Disclosures: The authors thank the Utrecht-BCI team for their contributions to this study. This study is supported by the Dutch Science Foundation (SGW-406-18-GO-086), Dutch Technology Foundation (UGT7685), European Research Council (ERC-Advanced ‘iConnect’ project, grant ADV 320708), the National Institute on Deafness and Other Communication Disorders (U01DC016686) and the National Institute of Neurological Disorders and Stroke (UH3NS114439) of the National Institutes of Health, and EU EIC-101070939 project INTRECOM. The authors have no potential conflicts of interest to be disclosed.

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Jitter and Latency Characterization in Closed-Loop Neuromodulation during NREM Sleep in elderly and pathological population

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Introduction: Neuromodulation based on EEG is a promising therapeutic approach to regulate brain activity. Particularly, Closed-Loop Auditory Stimulation (CLAS) can be used to manipulate slow oscillations in sleep to influence memory consolidation [1,2,3]. However, enhancing individual oscillations by presenting a tone at a precise moment in time requires a highly controlled understanding of the feedback loop parameters. ***Material, Methods and Results:*** We developed a testbed stimulation sleep-monitoring device [4] based on ESP32 and the Cython board from OpenBCI [1] to measure latency and jitter of various closed-loop configurations and its impact on slow oscillations. Results show that to exert the stimulus at precise timing of the slow-wave cycle [3] requires a very low jitter and, more importantly, stringent low latency. **Discussion**: Based on the idea that N3 is mostly characterised as an oscillatory process, phase-locked acoustic stimulation (PLAS) was successfully applied to enhance the naturally occurring oscillations characteristic of young adults. However, in elderly or pathological populations, individual transient slow waves are more prominent [3] and more accurate and precise systems are required. **Significance**: In young adults, results have shown that CLAS procedure enhances slow-wave amplitude and memory consolidation. However, this is not the case with elderly or pathological populations, where we show that understanding the CLAS device's jitter and latency is fundamental. **Disclosures:** RR and CF are co-founders of NeuroAcoustics Inc., DE, US.

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Sequential Forward Selection (SFS) for Transfer Learning Source Selection in Motor Imagery BCI

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Introduction: The tedious process of calibrating a brain-computer interface (BCI) for control creates a barrier to the adoption of this technology, especially for children who have been neglected from fundamental BCI research despite high user need. Transfer learning leverages previously collected BCI data from other users (sources) to reduce the calibration needed to train a classifier for a new user (target) [1]. However, not all source data is beneficial, and some can be detrimental to the training of a new classifier. Despite this understanding, little work has been done to investigate what factors influence the 'transferability' of a source. One assumption is that the users with the highest within-session (WS) classification performance should be the most beneficial. We challenge this assumption by comparing the transfer learning with the top WS performers to a technique called sequential forward selection (SFS).

Materials and Methods: For this investigation we used previously collected left/right motor imagery data from 32 children [2]. We aimed to compare the performance of 3 source selection methods. First, the WS ranking method includes the top sources based on their within-session classification accuracy. Second, individual SFS started with an empty subset and iteratively added the source which most improved the AUC score. This continued until all sources were included. Third, SFS ranking attempted to build a measure of transferability, based on the SFS subsets, such that sources were ranked by how early, on average, they were added to the source subset. All methods used the same Riemannian recentering method for transfer, and minimum distance to the Riemannian mean for classification [1].

Results: Fig. 1 shows how the classifier AUC score varied with different methods and with subsets of different sizes. As expected, scores converge when all 31 sources are included. WS ranking method declined with the addition of the 6^{th} and 7^{th} ranked sources, indicating that these sources have poor transferability despite strong WS performance. Individual SFS demonstrated the strongest performance and did not include these detrimental sources until necessary. SFS ranking nearly matched individual SFS in terms of AUC score and does not include the detrimental sources until necessary.

Conclusion: WS performance is not always a good indicator of transferability for children performing motor imagery. Individual SFS is more robust and achieves higher AUC scores but has the tradeoff of requiring more target data to evaluate subsets. SFS ranking balances high AUC scores without requiring target data for evaluation. This work motivates greater investigation into other data-driven methods for source selection.

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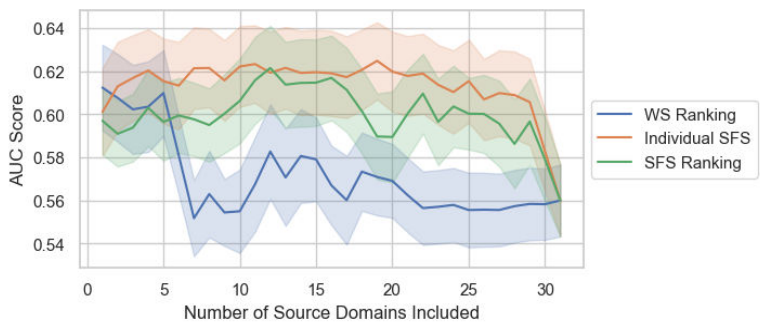

Figure 1: A plot of the AUC scores of different source domain selection methods with increasing numbers of included source subjects. Bold lines indicate the mean and shaded areas indicate the standard error of the mean (SEM).

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Combatting percept adaptation to intracortical microstimulation in humans

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Introduction: Without tactile sensation, even simple, everyday tasks become nearly impossible [1]. Intracortical microstimulation (ICMS) in the human somatosensory cortex (S1) can restore tactile sensations by using electrical stimulation to activate sensory neurons in the brain that would normally respond to touch [2]. Typically, ICMS trains consist of unmodulated single-channel stimulation with a constant amplitude and frequency. These stimuli evoke vivid tactile percepts originating from the participants' own hands. Unfortunately, the perceived intensity of these sensations can rapidly decrease during stimulation, falling below the perceptual threshold in tens of seconds [3]. Desensitization may occur, in part, because these ICMS trains do not resemble naturally evoked neural activity.

Material, Methods and Results: Two microelectrode arrays were implanted in both the motor and somatosensory cortices of 3 participants with tetraplegia as part of a clinical trial (NCT01894802). We designed two ICMS encoding schemes leveraging biological principles: biomimetic ICMS, which mimics natural spatiotemporally modulated neural activity, and interleaved ICMS, which takes advantage of overlapping sensory fields to distribute stimulation across multiple electrodes. For biomimetic ICMS, we co-modulated frequency and amplitude (40 to 80 µA at 100 to 200 Hz) with a large but brief (200 ms) onset and offset transient stimulation bursts. For interleaved ICMS we used four electrodes with overlapping projected fields and cycled through each electrode using 200 ms of ICMS at 40 µA at 100 Hz, parameters that were above threshold for each of the four electrodes. To test percept resiliency, participants either watched a clock face and were asked to report how long the sensation lasted or used a tablet to continuously report the stimulation intensity. Stimulation durations were randomly chosen from 1 to 180 s intervals. Preliminary results show that unmodulated ICMS led to rapid adaptation, biomimetic stimulation increased the perceived duration, and interleaved ICMS completely eliminated percept adaptation (see Fig. 1, n = 7 electrodes). In fact, sensations from interleaved ICMS could be reliably felt for over a minute.

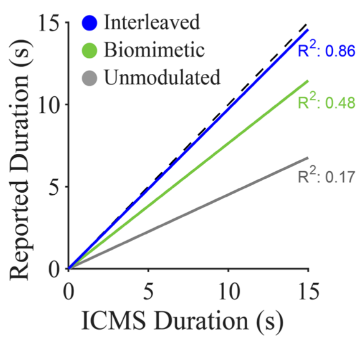

Figure 1*: Best-fit lines comparing true stimulation duration to the reported perceived duration. Lines below the dashed unity line indicate percept adaptation, where perceived duration is shorter than the actual stimulation duration.*

Conclusion: These experiments demonstrate that both biomimetic and interleaved ICMS encoding schemes greatly extend the perceived sensation duration compared to traditional unmodulated stimulation. These improvements likely arise from dynamic and distributed stimulation patterns, which may reduce neural adaptation. Notably, biologically inspired ICMS overcomes a critical limitation for the practical use of ICMS in restoring sensation, providing reliable and uninterrupted sensory percepts for neuroprosthetics. Future experiments will expand these experiments to additional electrodes and participants.

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Functional ultrasound neuroimaging through a human cranial window for decoding of movement effector somatotopy in primary motor cortex

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Introduction: Brain machine interfaces (BMIs) can help patients with disabilities achieve greater independence by using their thoughts to control assistive devices. However, they commonly require highly invasive brain surgery for electrode implantation while conventional non-invasive imaging techniques like fMRI and EEG lack sufficient spatial resolution for high-bandwidth BMI use. Functional ultrasound (fUS) is a novel neuroimaging technique that balances these tradeoffs and can image from outside the dura with high sensitivity, high spatial resolution, and large field of view [1], demonstrating potential for use in less invasive BMIs. Prior work demonstrated that fUS can be used to decode movement intention in non-human primates [2,3] and task state through a polymeric acoustic skull window in a human patient [4] – the first steps toward enabling a minimally invasive fUS BMI. In this study, we show that fUS can further be used to decode motor effector information from primary motor cortex (M1) in a human participant with an acoustic window implant, demonstrating the growing applications of fUS for BMIs.

Materials, Methods and Results: Experiments were performed on a human participant who had previously undergone a hemicraniectomy procedure and polymeric skull reconstruction including an acoustic window. We acquired fUS data from the left M1 as the participant performed randomized instructed movement tasks using different body parts or “effectors” and repeated the movement over a block of time to amplify signal.

We first looked into general effectors – right finger, right wrist, lip, and tongue. Using general linear modelling (GLM) analysis, we identified statistically significant regions of interest (ROIs) linked to each effector, indicating a dorsomedial to ventrolateral distribution for finger, wrist, lip, and tongue, respectively. This matches canonical somatotopic mappings in M1. Furthermore, we found that average fUS activity for these ROIs was tuned to each corresponding effector. Using classwise principal component analysis (CPCA) and linear discriminant analysis (LDA), we were able to significantly decode motor effector at above chance level. We conducted additional experiments on distinguishing contralateral individual finger representation in M1, which requires more refined spatial resolution given the more mixed representation of fingers in M1. Using the same analysis and decoder as the prior experiment, we were similarly able to identify ROIs tuned to each individual finger and significantly decode individual finger movements above chance level.

Conclusion: This work demonstrates that fUS is a robust neuroimaging technique that can be used to map and decode movement effector information in a human subject with an acoustic window implant. This presents significant progress in the development of a fUS-based BMI for decoding higher-level functions in humans and highlights the potential of fUS as a minimally invasive alternative for BMIs in the future.

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Neural Mechanisms of Dual Motor and Language Processing

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Introduction

While the human cortical grasp network—which includes key regions such as the primary motor cortex (M1), the anterior intraparietal area (AIP) and inferior frontal gyrus (IFG) —has historically been regarded as specialized for motor functions, emerging evidence indicates that it also supports language-related tasks, challenging traditional models of functional specialization. Multiple studies based on intracortical Brain-Machine Interfaces (BMIs) have demonstrated that areas within this network (namely, the motor and premotor cortices) exhibit dual-task representation [1], [2], suggesting that motor and cognitive functions may coexist within overlapping neural populations. However, the neural mechanisms enabling this versatility remain unclear. Additionally, it is unclear whether this versatile functionality generalizes to other regions within this network.

Materials, Methods, and Results

This study focuses on AIP and IFG, two regions classically associated with motor planning and execution. Neural activities were recorded using chronically implanted microelectrodes in a human subject with C3/C4-level AIS B Spinal Cord Injury during experiments involving two tasks: speech motor processing (overt versus covert word enunciation) and motor execution (closed-loop grasp aperture control in a virtual reality environment). Multi-unit neural activities in both regions were analyzed to examine task-specific and shared neural representations. Our results revealed that both AIP and IFG exhibit dual-tuning, allowing them to flexibly encode information for both motor and language tasks as shown by significant cross-validated decoding accuracies. We then explored multiple hypotheses to identify a neural mechanism that best explained the co-existence of information about different tasks within the same neural population. Using a previously developed metric for assessing tuning selectivity[3], we found that dual-task representation in both AIP and IFG was supported by mixed selective (as opposed to task-specialized) neural populations that flexibly reconfigured their functional architecture between tasks. Consequentially, we observed that the low dimensional subspaces within which the two tasks are embedded are not entirely independent, showing a degree of overlap that could represent generalizable patterns between tasks. This cross-task subspace overlap underscores the grasp network's efficient and economic architecture.

Conclusion

This study makes two primary contributions to the understanding of the cortical grasp network. First, it extends previous findings on the network's versatile functionality by demonstrating the multi-functionality of two additional regions, namely, AIP and IFG. Second, it provides novel insights into the functional architecture of the grasp network, uncovering mechanisms that enable neural populations to flexibly represent multiple tasks. These findings fill a critical knowledge gap and lay the groundwork for developing advanced BMIs capable of seamlessly integrating communication and motor functions, meeting the diverse needs of individuals with paralysis.

Acknowledgments and Disclosures

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EEG decoding of gait for clinical rehabilitation and assessment

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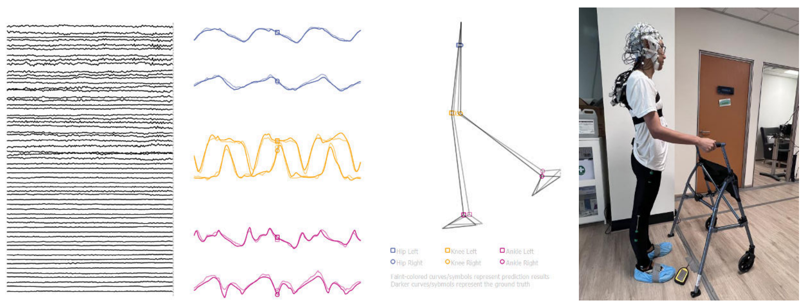
Introduction: The reconstruction of lower limb movement patterns using non-invasive EEG is a relatively less explored area of neural signal decoding [1]. Accurately and continuously tracking the movement of lower limb joints holds significant clinical potential for advancing the rehabilitation of motor impairments. To achieve a comprehensive and objective assessment of gait performance and functional improvement in stroke survivors, EEG-based decoding can offer a more sophisticated and neurophysiologically sound measure.

Material, Methods and Results:
To address this, our research focuses on predicting gait patterns through deep learning using EEG data. Our team proposed a multi-model attention network (MATN) that utilizes self-attention to adaptively learn the temporal dynamics of spatio-temporal EEG features [2, 3]. The network learns the neural foundations through a two-stage training approach, where a teacher model is first trained and later assists the student model in training on data from separate recording session. The core components of our base model include temporal, spatial, and separable convolution, and a fully connected layer. In the student model, a self-attention block is integrated after the spatial convolution block. We evaluated the proposed network using the mobile brain-body imaging (MoBI) dataset [1]. Our results summarized in Fig.1(c) show that, compared to state-of-the-art methods in EEG regression, MATN achieves the highest Pearson's correlation coefficient of 0.752, surpassing the best baseline model performance by over 18%.

Conclusion: Using the proposed approach with data from healthy subjects, we found a correlation of 0.752 between the recorded and predicted joint angle values. Building on this, we are currently evaluating our proposed method on clinical data and refining our techniques for robust predictions on large-scale healthy participant datasets as well. Currently, a clinical trial is in progress to assess stroke survivors through clinical metrics and EEG predictions at three time points, four weeks apart. The findings indicate that the proposed approach is feasible and that EEG decoding holds promise as an effective tool for rehabilitating and assessing lower limb impairments.

Acknowledgment: This work was supported by the RIE2020 AME Programmatic Fund, Singapore (No. A20G8b0102).



(a) (b)

Algorithm	PCC	Number of Parameters
Linear	0.626±0.127	
CNNLSTM	0.562±0.209 0.58±0.223	54876 14910
LSTM	0.57±0.171 0.586±0.209	7270 20678
TCN	0.527±0.161 0.634±0.184	18486 52326
EEGNet	0.63±0.155 0.625±0.186	2358 11430
SAM	0.641±0.178 0.629±0.236	3446 9446
MMN	0.702±0.165 0.682±0.169	6060 14668
MATN	**0.752** ± 0.172	10796

(c)

Figure 1: *(a) Illustration of reconstructed gait patterns of the participant (b) A subject preparing to walk, wearing EEG and goniometer sensors. The use of walking aids effectively minimized potential confounding effects of upper body movements on EEG signals. (c) Summary of results.*

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A BCI Robotic Glove System for Hand Motor Rehabilitation

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Introduction: Although several brain-computer interfaces (BCI) have been developed for upper limb rehabilitation, most primarily target gross motor functions and place limited emphasis on the fine motor control of hand [1]. To address this gap, we developed a novel integrated BCI robotic glove rehabilitation system specifically aimed at training hand movements in individuals recovering from a stroke.

Material, Methods and Results:
The clinical study is designed as a three-arm assessor-blinded randomized controlled trial, assessing the efficacy of a combined intervention of BCI robotic glove training and conventional occupational therapy (COTS), compared to COTS alone and robotic glove training with COTS. The proposed BCI detects motor attempts made by the user their affected hand. The system components are illustrated in Fig.1. Accurate detection of attempts to open and close the hand triggers the robotic glove to execute the corresponding movements, thereby providing precise motor training. The system delivers both robotic and visual feedback to promote neuroplasticity. An attention-based temporal convolutional network is employed for the detection of hand open and close attempt by the user. The network utilizes multihead self-attention and temporal convolution layers to efficiently derive relevant EEG features [2, 3]. To evaluate whether the BCI system can identify distinct patterns generated by the user during more precise tasks, we conducted a screening session. Users are required to achieve an accuracy of 70% or higher to qualify to undergo the proposed training. We propose 6 week training in which the users participate in three 45-minute training sessions of BCI training every week. The results obtained from the screening session are summarized in Table 1. Over 73% of the patients achieved over 70% accuracy and were recruited for training. The training of these patients is currently in progress.

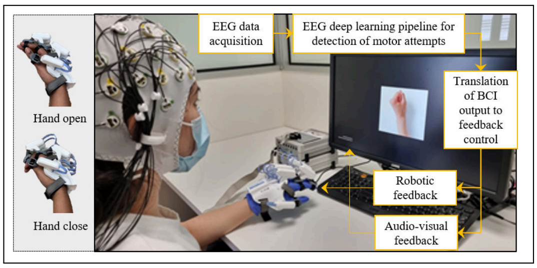

Figure 1: *Schematic of BCI robotic glove rehabilitation system.*

Table 1: Classification accuracies (%) for all participating patients in the screening session.

Subject	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Mean (±STD)
Open	74.00	80.50	79.50	67.50	85.00	84.00	75.50	92.00	86.00	50.00	89.00	55.50	79.00	95.00	49.00	76.10 (±14.08)
Close	84.00	85.00	83.00	63.00	96.50	90.00	70.50	93.00	81.50	65.00	89.50	54.50	90.50	97.00	69.50	80.83 (±12.75)
Average	79.00	82.75	81.25	65.25	90.75	87.00	73.00	92.50	83.75	57.50	89.25	55.00	84.75	96.00	59.25	78.47 (±12.92)

Conclusion: Preliminary results show the system detects hand opening and closing with an average accuracy of 78.47% (±12.92%), highlighting its potential for upper limb rehabilitation. Future research will investigate its clinical efficacy in fine motor rehabilitation following a stroke.

Acknowledgments and disclosures: This work was supported by the RIE2020 AME Programmatic Fund, Singapore (No. A20G8b0102).

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EEG-based classification of awareness in disorders of consciousness

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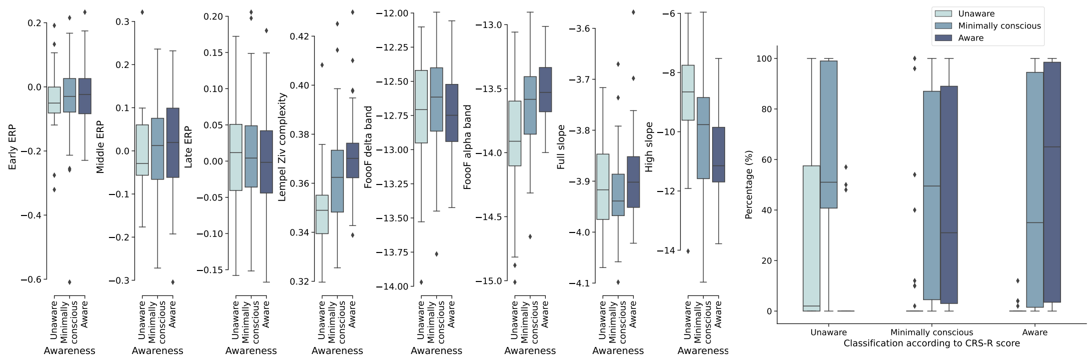
Introduction: Reliably assessing consciousness of patients with disorders of consciousness (DOC) is crucial for clinical decision-making. The Coma Recovery Scale-Revised (CRS-R) is commonly to differentiate between coma, minimally conscious state, and locked-in syndrome. Recent neuroimaging advancements allow motor-independent assessment of consciousness.

Material, Methods, and Results: EEG data were recorded from 84 patients with DOC (23 female, age range=18–84, CRS-R range=0–23). We excluded seven due to incomplete data. For the remaining n=77 patients, 202 sessions were available. One third of the sessions were reserved for testing. Full experimental and preprocessing details can be found in [1] and [2]. We used features including event-related potential (ERP) amplitudes (0–200, 200-500, and 500–1000 ms), Lempel-Ziv Complexity, the periodic component of delta (1-3.5 Hz) and alpha (8-13 Hz) bandpower computed with FoooF [3], and spectral slopes between 1–45 and 20–40 Hz [4]. We augmented our data by generating 50 bootstraps of size 50 from the auditory close trials from each session and averaged across each bootstrap (i.e., 50 "bootstrap trials"/session) and across electrodes for each feature. A random forest classifier was trained to categorize patients as Unaware, Minimally Conscious, or Aware. Distributions of feature amplitudes for each class are shown in Fig. 1a. Performance was evaluated with leave-one-session-out cross-validation, and classification results are shown in Fig. 1b.



(a) (b)

Figure 1: *(a) Distributions of feature values in the train set across all classes for each feature. (b) Percentages of bootstrap epochs that are classified as each of the classes, separately for each class.*

Conclusion: Our model performs well in distinguishing minimally conscious from aware states, but it shows misclassifications within the unaware category. Notably, for all classes, these errors tend to occur between adjacent classes (e.g., no unaware cases are misclassified as aware). Although no machine learning is perfect, there is always the possibility that some patients have been misdiagnosed. This dual challenge—imperfect machine learning and potentially noisy labels—underscores the importance of developing an objective alternative to the CRS-R to improve clinical utility.

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Star-Burst paradigm: implementation of an "invisible" dry-EEG reactive BCI

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Introduction: Code Visually Evoked Potentials (c-VEP) have become increasingly popular in the rBCI community, leveraging pseudo-random visual flickers that offer shorter calibration times compared to Steady State VEP [1]. However, the application of c-VEP-based reactive BCIs has largely remained confined to laboratory settings due to the reliance on wet EEG systems and synchronous paradigms with fixed decoding times. To address these challenges, our team used innovative repetitive visual stimuli called StAR (Stimuli for Augmented Response). These stimuli are engineered with specific, mostly invisible textures that elicit neural responses ranging from retinal ganglion cells (contrast detection) to visual cortex cells (orientation selectivity) [2]. Our StAR stimuli are activated using a burst-code VEP paradigm, featuring brief, aperiodic visual flashes presented at a slower rate of three flashes per second. This approach elicits stronger visual evoked responses compared to traditional maximum length sequences [3]. Each stimulus (e.g., a letter or digit) is presented with its own unique pseudo-random code comprising an alternating sequence of '1' (on) and '0' (off). This innovative approach dramatically reduces calibration time to under one minute, as the algorithms only need to differentiate brain responses to the presence (visual ERP) or absence of a flash (no visual ERPs).

Material, Methods and Results: The online StAR-Burst rBCI was developed using Timeflux framework [4]. This system was specifically designed for an 11-class classification task to predict participants' attention in real time based on visual stimuli. It utilizes a combination of XDawn spatial filtering and Riemannian-based tangent space classifiers for optimal performance. The 11 commands corresponding to the T9 keypad were encoded using 11 unique burst codes [3], carefully designed to maximize discrimination between commands. The classification pipeline was followed by a correlation-based accumulation method, allowing flexible, self-paced decoding time. Eighteen participants were equipped with an 8-channel dry EEG system (Enobio), with electrodes placed over the occipital and parieto-occipital cortex areas (PO7, O1, Oz, O2, PO8, PO3, POz, PO4) to capture visually evoked potentials (VEPs). They underwent an 40-second calibration procedure before performing an online T9 pinpad self-paced task consisting of 10 sequences, each containing four targets, resulting in a total of 40 targets per participant. The StAR-Burst rBCI demonstrated high performance, achieving a mean accuracy of 96.3% (SD = 4.79) and a mean decoding time of 4.2 seconds (SD = 5.5). A video showcasing the BCI can be seen here https://nextcloud.isae.fr/index.php/s/dxLqYXRAMEep98C.

Conclusion: Collectively, these findings highlight the transformative potential of StAR-Burst paradigm driving the evolution to make BCIs more user friendly and efficient. Our implementation achieved high accuracy levels with a dry EEG system, requiring only minimal calibration data (40s). This paradigm, characterized by comfort and subtle perceptibility in peripheral vision, show potential for applications in various reactive BCI paradigms such as P300 speller, SSVEP, and oddball-based BCI. The application of the proposed StAR approach may be extended beyond technological innovation to fundamental cognitive neuroscience research, providing a valuable avenue for exploring cognition.

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Movement decoding: dealing with neural signal drift

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Introduction: Recent BCI hardware advances have enabled long-term implantable devices in humans, allowing extended interaction with the environment and diverse BCI strategies. However, achieving stable decoding with minimal recalibration remains challenging due to the ever-changing nature of neural signals and electrode properties, as well as individual variability. In response, researchers are increasingly adopting advanced deep learning approaches, as they hold promise for meeting these demands.

Material, Methods and Results: We develop and evaluate real-time decoding methods using electrocorticography (ECoG) data collected across multiple subjects over several months. The experiments involve upper-limb motor tasks, focusing on wrist, elbow, and shoulder joint movements in non-human primates. We analyze the drift in the underlying structure of neural signals over time and propose methods to compensate for this drift to improve decoding reliability. Specifically, we leverage manifold alignment techniques via self-supervised learning, employing a generative model to detect the drift in the manifold space and align neural data accordingly. This alignment enables a pretrained decoder to maintain comparable accuracy across time without retraining. We demonstrate the application of our alignment approach in online experiments using a real-time decoding platform, achieving state-of-the-art latency and robust performance.

Conclusion: This study presents a self-supervised manifold alignment approach using ECoG data that effectively compensates for neural signal drift, enabling stable, real-time decoding across time without retraining.

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Minimal calibration MI-BCIs via inter-subject transfer learning with optimal transport

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Introduction: The prolonged calibration phases required to record user-specific electroencephalography (EEG) data for training decoding models constitute a significant barrier to the practical implementation of motor imagery-based brain-computer interfaces (MI-BCIs). When deep learning (DL) models are used to decode brain data, these calibration times might need to be extended even further. A potential solution to this issue is leveraging available EEG data from other subjects to train the model. However, the inherent high inter-subject variability of EEG signals requires effective adaptation methods to enable transfer learning across subjects. Here, we use a supervised version of the Backward Optimal Transport for Domain Adaptation (BOTDA) [1] approach to align the DL features of the target subject with the feature distribution of the training set derived from other users.

Material, Methods and Results: Experiments were conducted using three right vs. left hand MI publicly available EEG datasets: Lee2019_MI [2] (training dataset), and Cho2017 [3] and Dreyer2023 [4] (testing datasets). EEG data from only three channels (C3, C4, and Cz) were employed. The EEGNet [5] was used as the DL model. It was trained with the full Lee2019_MI dataset with the default AdamW optimizer and the cross-entropy loss for 500 epochs. The learning rate was set to 0.001. For each target subject from the testing datasets, the 10 first trials of each MI class were kept as adaptation/fine tuning data, while the remaining trials constituted the testing data. In our approach, the full model trained from the Lee2019_MI dataset was kept frozen at the evaluation stage. The representations preceding the classification block were used as DL features, with adaptation applied at this level. Our approach was compared with two reference methods: (a) trained model without adaptation, (b) trained model fully fine-tuned for 100 epochs using subject-specific adaptation data. The mean classification accuracies across all testing subjects were: 0.88 ± 0.13 for DL+BOTDA, 0.61 ± 0.11 for the no-adaptation DL reference, and 0.62 ± 0.12 for the fine-tuning method.

Discussion: The results presented highlight the effectiveness of DL+BOTDA in overcoming the challenges of high inter-subject variability in EEG data for MI-BCIs. By applying adaptation at the feature level, a substantial improvement in performance was achieved with the proposed method, outperforming the no-adaptation baseline and the fine-tuning approach. It is important to note that although fine-tuning is a widely used method to adapt pre-trained models to subject-specific characteristics, it does not perform well with limited target subject data, reinforcing the advantage of the BOTDA method in this scenario.

Significance: Reducing subject-specific calibration data to only 20 trials could enhance and empower the usability and practicability of MI-BCIs, especially in motor rehabilitation scenarios.

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An efficient protocol to optimize ICMS encoding of artificial sensation

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Introduction: Most prosthetic limbs lack proprioceptive feedback, which is essential for making complex movements [1, 2]. Intracortical microstimulation (ICMS) of the somatosensory cortex can be used to elicit sensory perceptions and guide active movements, which could serve as an artificial proprioceptive signal [3, 4]. However, movements guided by ICMS remain slower and less accurate than those guided by natural sensation. To improve sensory encoding via ICMS, we have developed a behavioral paradigm in freely moving mice to efficiently evaluate algorithms for encoding artificial sensory information via spatial and temporal patterns of ICMS.

Material, Methods and Results: C57BL/6J mice between 3-4 months were implanted with a TDT 8x2 microwire electrode array (N = 5). ICMS stimulation was controlled by a Ripple Neuro Grapevine Processor and behavioral data was tracked with DeepLabCut Live. Mice were trained to navigate to targets within the training cage guided by combined visual and ICMS feedback (Fig. 1a). Target location (distance and direction relative to mouse's heading) was encoded via patterned ICMS across all sixteen electrodes. For electrode i, stimulation frequency at time t was set to $f_i(t) = \delta(t) * e^{\kappa * cos(\phi_i - \theta(t))}$, where $\theta(t)$ is animal's heading relative to the target direction, $\delta(t)$ scales with distance to the target, and ϕ_i is fixed for each electrode. Stimulation pulses were cathode-leading biphasic symmetric pulses with a fixed amplitude between 10-20 μA and pulse frequency ranging from 10-200 Hz; stimulation parameters were updated at 10 Hz. Once subjects became proficient in the behavioral task, probe trials were introduced: ICMS-only, visual-only, and sham (no inputs). Mice quickly learned the task, achieving $\geq$80% accuracy on combined trials in 4-6 training sessions (400-600 trials). Mice could complete ICMS-only trials with $\tilde{7}0\%$ accuracy, which was statistically equivalent to their performance on visual-only trials (Fig. 1b). Animal performance on combined trials was statistically better than on unimodal trials (ICMS-only or dim visual-only), suggesting that the two signals were integrated (Fig. 1c).

Conclusion: Mice quickly learn the behavioral task and perform many trials (150-200) per training session. The speed and extent of learning that we present here support this approach for communicating multivariate sensory information (direction and distance) to the central nervous system. This behavioral paradigm can be easily adapted to further investigate how specific parameters of ICMS (such as the number of electrodes used) impact encoding accuracy. Using this approach, we can aim to delineate the limits and capabilities of using ICMS to provide artificial sensation.

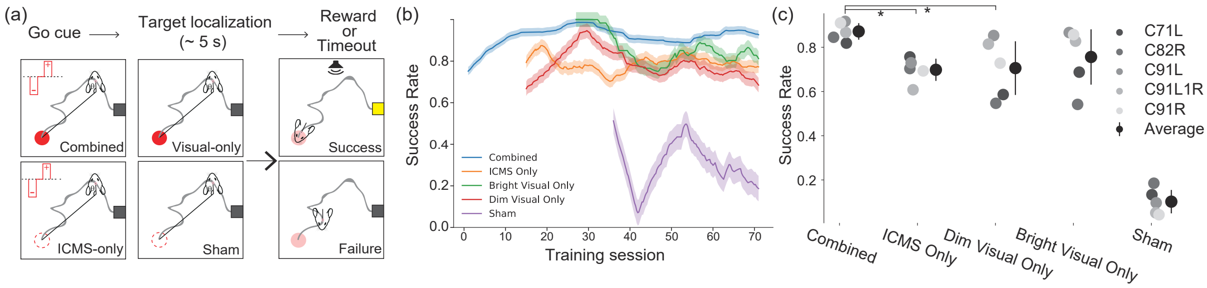

Figure 1: *(a) Trial structure: Target is randomly selected and trial start is indicated by go cue. Subject receives either combined visual-ICMS, visual only, ICMS only, or no feedback (sham) and have 5 seconds to reach the target. Successful trials are indicated by a success tone and rewarded with juice. A new trial starts 5-7 seconds after reward is collected or at the end of a failure trial. (b) Learning of task structure and ICMS, shown as the (smoothed) fraction of correct trials across training sessions for one subject. (c) Success rates for all subjects for each trial type over last five training sessions for each subject. Asterisks indicate significant difference in success rates between paradigms. Performance on sham trials was significantly worse than all others.*

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Multimodal Multivariate Granger Causality Between EEG and fNIRS during an Auditory Task

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Introduction: Multimodal noninvasive neuroimaging approaches, most often relying on simultaneously recorded electroencephalography (EEG) and functional near-infrared spectroscopy (fNIRS), have garnered interest in both open- and closed-loop brain-computer interface (BCI) applications by providing complementary information underlying neural function [1,2]. However, effective connectivity between electrical (EEG) and vascular-hemodynamic (fNIRS) responses remains poorly understood. Here we developed a multimodal multivariate Granger causal (mMVGC) framework to investigate the causal interactions between electrical and vascular responses during an auditory processing task designed to elicit the auditory steady-state response (ASSR).

Material, Methods and Results: Data were collected from 17 healthy participants using 15 EEG electrodes and 14 fNIRS channels spread across the Frontal/Fronto-Central (F/FC), Left Auditory (LA), and Right Auditory (RA) regions of interest. The task consisted of 72 blocks of auditory stimuli (15s) followed by a 15s resting state period. A full description of the experimental task and montage is provided in [1]. After rejecting artifactual independent components extracted from band-pass filtered EEG data (0.5-55 Hz), the amplitude envelope of the Hilbert transform of narrow-band filtered EEG signals was extracted for the α (8-13 Hz), β (13-30 Hz), and ASSR (38-42 Hz) bands. EEG features and fNIRS data were down-sampled to 4 Hz, filtered 0.02-0.5 Hz, and averaged within ROIs. For EEG, only the FC ROI was included for further analysis. Epoched signals were detrended and the temporal and ensemble averages were subtracted from each epoch. The Bayesian information criterion (BIC) was used to estimate the optimal multivariate autoregressive model order. mMVGC was estimated for the task and resting state periods separately using the MVGC toolbox [3]. Values were compared across conditions by using a permutation test with false discovery rate (FDR) correction. Selected results of this test are presented in Fig. 1. MVGC in the direction originating from RA fNIRS to EEG in the ASSR band (p = 0.001, Cohen's d = 0.88) was significantly different between the task and rest conditions.

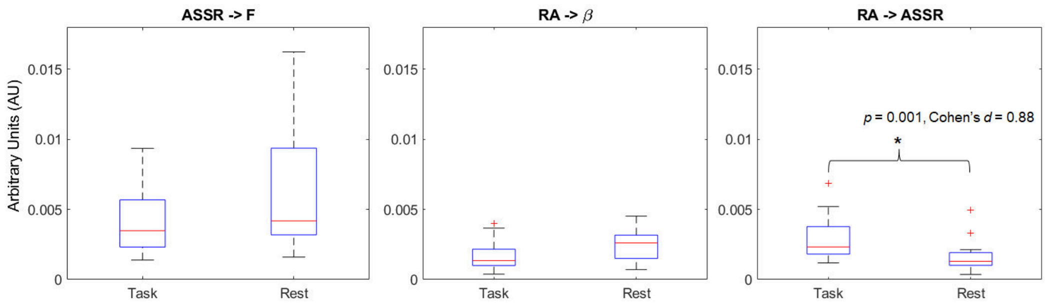

Figure 1: *Selected estimated MVGC values compared across the Task and Rest conditions. A significant difference between conditions was observed in the direction originating from RA fNIRS to EEG in the ASSR band, denoted with an asterisk (*).*

Conclusion: The difference across conditions in the direction originating from RA fNIRS to ASSR band EEG suggests that hemodynamic state in the auditory cortex may have a modulatory effect on the ASSR.

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Implementing a Wearable BCI with Patients with Disorders of Consciousness: An Inter-professional Approach

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Introduction: Patients diagnosed with disorders of consciousness (DoC) face incomparable challenges in communicating awareness. DoC encompasses a spectrum of impaired consciousness, ranging from coma to minimally conscious states, where limited or intermittent interaction with the environment may P300 occur. Research using functional magnetic resonance imaging suggests that approximately 1 in 5 individuals with DoC exhibit what is known as cognitive motor dissociation (also known as covert consciousness)- a state in which they are aware of their surroundings and can understand language but are unable to communicate. Wearable brain-computer interfaces (BCIs) offer a potential solution for providing prognostic insights and developing strategies to evaluate comprehension and communication abilities.

Material and Methods: Our feasibility trial was designed 1) to evaluate the technical and clinical challenges of successfully collecting physiological data derived from g.tec's mindBEAGLE P300 and motor imagery assessment paradigms among research participants with DoC 2) to establish data reproducibility and interpretability across multiple paradigms required for assessing and utilizing functional cognition and communication for the DoC population treated within the UPMC Rehabilitation Institute, 3) to characterize participant tolerance of training and communication within each paradigm. Our study focused on the Institutional Review Board (IRB) and data collection protocol development and refinements, as well as reporting individual case report results and preliminary inter-professional feedback regarding the acceptability of the protocol. Initial clinician training occurred over 5 days using a competency-based approach. Results indicated that a minimum of 35 hours of didactic and hands-on training was required for trainees to achieve competencies such as equipment set-up, cap fitting, electrode testing, executing paradigm assessments and recording data results. This training included multiple opportunities to perform the mindBEAGLE assessment and treatment protocols by troubleshooting common scenarios, identifying the key variables for clinical assessment and interpretation, and becoming familiar with the software and associated data management. Training considered how DoC participants might vary in terms of feasibility and implementation, data reproducibility and interpretation, and patient tolerance and conditioning over time for participation and considerations for measuring physiological changes and neurological improvement within and between sessions.

The initial protocol design approved by the University of Pittsburgh's IRB was revised early in the study to address identified challenges with inclusion/exclusion criteria, recruitment strategy (inpatient/outpatient), participant age range and diagnosis, participant availability, and the clinical environment. Protocol changes were made in collaboration with g.tec on how to manage artifacts due to participant movement, electrode placement, and software data capture and utilization. In addition, database development using REDCap provided for systematic data collection that required refinement in data structure an expanded menu of data elements.

Results and Conclusion: Our inter-professional approach allowed for ongoing protocol refinement and identification of implementation strategies and techniques to begin to advance feasibility and person-centered implementation goals needed for clinical sustainability. Exemplars demonstrating our progress with both inpatient and outpatient participants are provided across the various technical and implementation themes introduced. Multiple DoC participants were able to reproducibly communicate with yes/no responses using at least one mindBEAGLE paradigm. Our inter-professional approach will continue to advance this work into a T2-Translation to Patients Clinical trial.

Acknowledgments and Disclosures: The team wishes to thank the Beckwith Institute Clinical Transformation Research Program and the UPMC Rehabilitation Institute for funding and support, Ms. Jessa Darwin for Program Management, Vishruth Reddy and Celeste Picone for Data Management, and Jennifer Biller and Kim Huster for Research Coordination.

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Physiologic Manifestations of Communication & Learning in a Patient with Remote TBI & Disorders of Consciousness: Lessons from Establishing a Non-Invasive BCI Protocol

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Introduction: Patients with disorders of consciousness (DoC) can present with cognitive motor dissociation (CMD), in which they can follow cognitive commands without motor expression, limiting their interaction with their environment using traditional communication methods. The mindBEAGLE, a noninvasive brain computer interface (BCI), has shown promise in analyzing neuroelectrical activity such as event-related potentials (ERP) on electroencephalography (EEG) to assess communication and command following in DoC patients. Here we present results of a DoC patient using the mindBEAGLE in terms of physiological manifestations and command following. Our subject is a 28-year-old male who sustained a traumatic brain injury (TBI) in 2018 from a fall resulting in a multicompartmental hemorrhage.

Materials, Methods: Subject recruitment was based on the JFK coma recovery scale - revised (CRS-R) designating unresponsive wakefulness state (UWS) or minimally conscious state (MCS) patients. Our subject's CRS-R score upon evaluation was 7 out of 23, consistent with UWS. MindBEAGLE paradigms of auditory evoked potentials (AEP) and vibrotactile evoked potentials (VEP) using the P300 ERP approach, and motor imagery (MI) using the event related desynchronization/synchronization (ERD/ERS) approach were used as measures of functional brain activity. CRS-R scores and physiologic parameters such as blood pressure were collected before and after each session by a physician. Heart rate and blood oxygen saturation was collected intermittently over the course of multiple paradigms administered during each session. Relationships were analyzed using Pearson correlations between physiologic parameters and classification accuracies, and significance was evaluated using the student's t-test.

Results: The patient demonstrated an initial improvement in classification and yes/no question accuracy during the initial 3 evaluation sessions, but had a sharp decline in the 4th evaluation session; accuracy slowly improved into the 5th evaluation session and 2 subsequent treatment sessions (total 7 sessions). This accuracy pattern was positively correlated with changes in the patient's mean arterial pressure (MAP) ($r=0.48$, $p=0.00015$), and negatively correlated with changes in heart rate ($r=0.61$, $p=0.00062$). Quantitatively, after the first session, the CRS score increased from 7 to 10, and all subsequent CRS scores ranged from 8-10 pre-session and 9-10 post session. Qualitatively, the patient was initially only able to fixate and track his mirror image, but began to track the examiner's finger after the 3rd session. There were no significant associations regarding blood oxygen saturation.

Conclusion:
The mindBEAGLE was able to detect a DoC subject's attempts at communication and track paradigm learning over multiple sessions. Physiologic responses were suggestive of increased metabolic demand, conditioning, and potential conscious effort in cognitive tasks. Sessions were overall well tolerated and can be medically feasible in the chronic DoC population.

Acknowledgments: The authors do not have any conflicts of interest. We thank the Beckwith Institute Clinical Transformation Research Program and UPMC Rehabilitation Institute for funding support, Jessa Darwin for Program Management, Vishruth Reddy and Celeste Picone for Data Management, and Jennifer Biller and Kim Huster for Research Coordination.

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Changes in Brain Oscillatory Dynamics in Elderly Adults as a Consequence of Natural Aging

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Introduction: The oscillatory nature of slow waves during non-rapid eye movement (NREM) sleep has recently been proposed as crucial for the glymphatic system, facilitating the clearance of metabolic waste from the brain [1]. While aging-related reductions in slow wave quantity and amplitude are well-documented [2] and linked to this cleansing function [3, 4], we propose that the rhythmic dynamics in which slow waves occur may also play a critical role.

Material, Methods and Results: Thus, we introduce a novel classification of slow waves based on their temporal dynamics, categorizing them into isolated waves and oscillation trains. Using overnight EEG recordings from young and elderly adults, we compared the proportions of these wave types. Additionally, we analyzed train composition, including the proportion of slow waves that initiate a train (lead waves) and the lengths of the oscillation trains (number of consecutive slow waves initiated by one lead wave). Our results revealed that elderly adults exhibited a higher prevalence of isolated waves and a lower proportion of oscillation trains. Moreover, while elderly adults showed a higher proportion of lead waves, their oscillation trains were significantly shorter compared to those of young adults.

Conclusion: We propose that natural aging may result in a less oscillatory brain state, characterized by a diminished ability to produce sustained, periodic oscillations. This diminished rhythmicity could impair cerebrospinal fluid pulsation, potentially reducing the brain's ability to efficiently clear pathogenic substances during sleep. Given the established link between impaired glymphatic clearance and neurodegenerative diseases such as Alzheimer's, this diminished capacity to sustain slow wave trains may contribute to age-related decline in neurological functioning.

Disclosures: RR and CF are co-founders of NeuroAcoustics Inc., DE, US.

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Toward Home-Use BCIs: Development and Evaluation of ECoG WIMAGINE Neuroprosthesis

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Introduction: To restore autonomy and improve the quality of life of individuals with motor disabilities, Brain-Computer Interfaces (BCIs) need to evolve from laboratory-based prototypes to functional systems that are practical for daily, home use. This shift requires addressing three critical challenges: (1) developing integrated, compact, and autonomous hardware suitable for patients' independent use; (2) implementing low-power, fast algorithms that run efficiently on small devices; and (3) integrating effectors, that are easy to setup and capable of producing meaningful functional changes for the user.

Material, Methods and Results: The development of the electrocorticographic (ECoG) WIMAGINE BCI neuroprosthesis [1] aims at overcoming these challenges. We integrated all hardware for recording and communication into a small, portable design. We implemented a highly optimized signal-processing pipeline capable of real-time operation on low-power embedded systems. The algorithms demonstrated robust decoding of neural signals with low computational time (<100 ms). Finally, we integrated a wireless surface functional electrical stimulation (sFES) sleeve (FESIA-Grasp®) that translates decoded neural commands into functional movements. The neuroprosthesis setup is user-friendly, requiring minimal training for installation and operation, enhancing user independence. Testing was conducted with individuals with spinal cord injury [2,3] implanted for several years (up to 7) with stable signal quality. Results indicate high system reliability and usability, with users able to achieve functional tasks with minimal supervision.

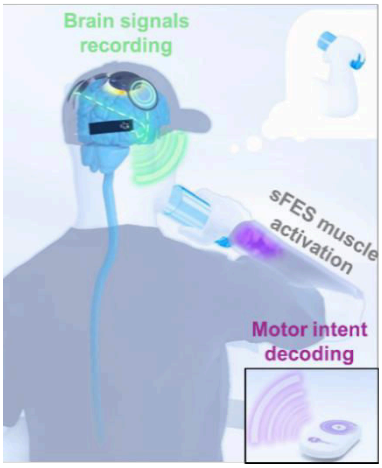

Figure 1: Principle of the home-use WIMAGINE BCI neuroprosthesis

Conclusion: This work represents a significant step toward enabling home-use BCIs. By integrating compact hardware, efficient algorithms, and functional effectors into the WIMAGINE neuroprosthesis, we have demonstrated the safety and feasibility of autonomous BCI systems for home applications. These advances pave the way for future developments aimed at improving the accessibility and practicality of BCIs outside clinical environments.

Acknowledgments and Disclosures: We would like to thank all the multidisciplinary technical and clinical teams at Clinatec (CEA-LETI and CHU-Grenoble Alpes) for their participation in the BCI&Tetraplegia clinical trial (NCT02550522 [2]), but also at EPFL and CHUV in Lausanne for their involvement with Clinatec in the STIMO-BSI clinical trial (NCT04632290 [3]). We also would like to thank all the participants in our clinical trials, who make this work possible. The work presented here is supported by the CEA, the Carnot Institute CEA-Leti, Horizon Europe – EIC NEMO-BMI ID101070891, the French National Research Agency (ANR), the Fonds Clinatec and the Neurotech project of CDP UGA.

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Neural control of a robotic hand prosthesis by posture-related activity in the grasping circuit

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Introduction: Spinal cord injury can severely limit hand movement capacity, making it a top recovery priority for patients [1]. Although significant progress has been made towards hand neuro-prostheses, these devices are still limited to basic grasping and cannot reproduce the rich set of configurations of the native hand yet. Despite evidence of abundant posture information in cortical hand areas [2], hand neuroprosthetic protocols have focused predominantly on the movement velocity aspect of control, using this approach to control hand joint synergies, or individual finger movements [3, 4]. We recently demonstrated that the cortical posture signal in hand-related areas can support accurate hand neuroprosthetic control for multiple DOFs in a virtual environment [5]. Whether this technique extends to robotic control is yet to be tested.

Material, Methods and Results: Working with a macaque monkey implanted in motor cortex, we demonstrate that posture signals in hand-related cortical brain areas can support neuroprosthetic control on a robotic arm and hand platform (Fig. 1). Our intention estimation protocol incorporates position and velocity control through re-fitting to kinematic trajectories. The protocol assumes that the subject aims to execute a transition in the space of hand configurations, extending intention estimation for velocity control to posture-based control. In the present work, we aim to determine the changes in neural activity required to support posture based control and the lessons learned when porting our protocol to the robotic platform.

Conclusion: We demonstrate our posture and velocity intention estimation technique can extend to a robotic device, opening the door to future implementations using this additional position signal.

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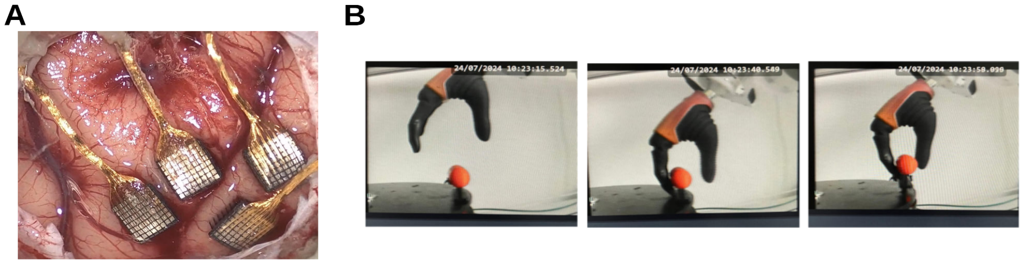

Figure 1: A. *Implant on areas M1 and S1 of monkey N. Only M1 was used for decoding. B. Example grasp and lift with the robotic platform.*

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Neurophysiologically-guided optimization of neuronal avalanches for BCI

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Introduction: Despite promising clinical applications, motor imagery-based Brain-Computer Interfaces (BCIs) fail to detect the intent of 15-30% of users. This limitation partly stems from a focus on local oscillatory patterns, neglecting inter-regional interactions and treating aperiodic signals as noise. However, recent evidence demonstrated the coexistence of burst events and sustained oscillations, each providing unique insights. Neuronal avalanches, cascades of activity bursts propagating through neural networks, could address these gaps by elucidating mechanisms underlying BCI performance [1, 2]. Identifying optimal neuronal avalanche parameters is crucial to effectively integrate neuronal avalanches into BCI paradigms [2]. This study examines the correlation between BCI performance and factors such as the occurrence of regions of interest (ROIs), mean avalanche duration, and entropy rate of the brain signature, aiming to guide experimenters in selecting neurophysiologically relevant parameters of neuronal avalanches for BCI applications.

Materials, Methods and Results: We analysed EEG data from twenty healthy subjects who alternatively performed a right-hand motor-imagery (MI) task and remained at rest [3]. Using source-reconstructed signals, we estimated an Avalanche Transition Matrix (ATM), which mapped the probability of avalanche propagation across brain regions. To identify and selected task-related brain regions, we applied the PageRank algorithm to the ATMs (Markov Chains) and conducted t-tests and joint diagonalization between resting and MI states. Then, to identify which brain regions were the most often selected, we computed the associated occurrence. By correlating the mean avalanche duration and the ATM's entropy rate with BCI performance scores, we optimized key parameters. Additionally, by correlating the occurrence of significant ROIs with the BCI score, we validated the possibility of dataset reduction. Spearman's correlation was used to perform both correlations, and their significance was confirmed using a t-test (p-value < 0.05) with FDR correction. Our analysis shows significant positive correlations between ROIs occurrence selection and BCI scores, particularly in the alpha band (8-12 Hz) (Fig. 1). Higher selection rates indicate less variability across parameter conditions. Neurophysiologically relevant regions, such as the left precentral and paracentral areas (linked to the primary motor cortex), emerged as key. In the initial 2 seconds of the trials, before providing the feedback, regions typically involved in task preparation showed stronger significant correlations. In contrast, visual and executive regions dominated during the second phase of the trial when the feedback was provided (last 3 seconds). The positive correlation between mean avalanche duration and BCI score is highlighted during the MI task with more significant values compared to resting state, suggesting that longer avalanches reflect more coordinated and sustained neural activity, which enhances BCI performance. In contrast, during the resting state, while a similar trend is observed, the correlations rarely reach statistical significance, indicating a less robust relationship. Additionally, a negative significant correlation between entropy rate and BCI score was found during the MI task with the longest avalanches, whereas the resting state showed a positive correlation with shorter avalanches. These findings suggest that longer avalanches are linked to sustained neural activity and reduced variability, both of which are linked to an improved BCI performance. Notably, the MI task exhibits less variability compared to the rest.

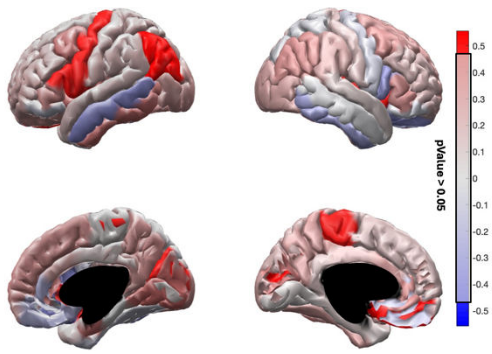

Figure 1: Correlation between ROIs occurrence selection and BCI-scores. During Task+Feedback Interval, Alpha-Band

Conclusion: This study provides a data driven approach to optimize the ATMs characterization and to ensure their neurophysiological relevance. Such a tool could be used during the calibration period to adapt the training program to the subjects' specificities. Taken together, our results offer guidelines to use the neuronal avalanches in the context of BCI experiments.

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A sEEG-based BCI for Brain-to-Chinese Language Decoding

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Introduction: Decoding language from neural signals can greatly improve the quality of life for individuals who have lost their ability to speak, such as those with ALS or stroke. Although significant progress has been made in brain-language decoding [1], relatively few studies have focused on Chinese—a representative syllabic language spoken daily by over one quarter of the global population. In our previous work, we introduced a decoding framework based on syllable elements [2]. In this study, we present our latest advancements in developing a Brain-Computer Interface (BCI) platform for Chinese language decoding, leveraging a medical sEEG system. This system demonstrates high performance processing with low latency, high inference speed, and competitive accuracy, showing great potential for both clinical and research applications.

Material, Methods and Results: A custom neural signal processing platform was developed to stream signals from a medical device intended for advanced epilepsy monitoring and research, specifically for long-term sEEG data acquisition. The platform can simultaneously process up to 1024 channels of streaming sEEG signals while recording and playing multimodal voice and video data, with automated marker labeling. With GPU acceleration, the platform performs numerical statistics, frequency processing and neural network inference. In our language decoding experiments, two epilepsy patients who had undergone sEEG electrode implantation participated during their inter-ictal periods. Chinese characters were presented to them sequentially on a screen, and they were instructed to read aloud after receiving a cue. The corresponding sEEG signal and voice signals were simultaneously recorded and processed by the platform. A short time window of sEEG data, with a margin to capture brain activity before and after sound production, was selected for processing.

The signal processing pipeline includes channel differential, filtering, standardization and frequency domain processing. The processed data was then fed into a neural network model for predicting the Chinese Pinyin initials corresponding to the sEEG signals. The network contains five convolutional for feature extraction and followed by a fully connected layer for the final classification decision. Causal convolution is adopted to prevent data leakage from future time steps. The experiment results showed that the top-1 accuracy for the initial prediction exceeded 50% and the top-3 accuracy achieved over 90% on the best performing subject, using an experimental corpus that contains 407 words with 23 distinct Chinese Pinyin initials. The platform is capable of performing over 200 inferences per second, with a processing delay of less than 20 ms.

Conclusion: This study demonstrates the feasibility and potential of a high-performance Brain-Computer Interface (BCI) for Chinese language decoding, we achieved promising results in real-time, low-latency, and high-accuracy predictions of Chinese Pinyin initials from neural signals. It lays the foundation for future research on extending the decoding capabilities to full words or sentences.

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Supporting the user learning process in MI-BCI based on backward adaptation and neurofeedback

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Introduction: To effectively command a motor imagery brain computer interface (MI-BCI), several sessions of practice are typically required. While the user learns how to control the BCI, the decoding algorithm should adapt to the brain signal changes that occur with learning. In electroencephalography (EEG) based BCIs for motor rehabilitation, such changes exacerbate due to multiple session usage. To support the user learning process, it is essential to assess and provide real-time feedback on their self-modulation skills. Moreover, such feedback should be clear and meaningful from the MI task viewpoint [1]. Here we present supportive backward adaptation (SBA), a method that allows across-sessions data adaptation while online assessing MI modulation proficiency. SBA is based on the backward optimal transport for domain adaptation method [2]. By means of SBA, a MI videogame for motor rehabilitation is designed with the aim of building co-adaptive BCIs to improve both the user learning process and the system decoding accuracy.

Material, Methods and Results: First, we assessed whether SBA is a reliable tool to measure MI-BCI skills in real-time. Real [3] and simulated [4] MI vs. rest EEG data were used. Data always comprised two sessions from two different days. Common spatial patterns (CSP) in combination with the linear discriminant analysis defined the decoding model. Training used data from the first session, while data from the second session was used for testing. SBA was applied at the CSP feature space level. The instructed cue information was used to guide the backward adaptation. The algorithmic support, i.e. the effort exerted by the model in performing the adaptation, was used as a measure of online MI modulation skill. Riemannian distinctiveness metrics [5] were used as gold-standard indices to assess users' BCI skills. Results showed that SBA algorithmic support is significantly correlated with the simulated MI capability as well as to Riemannian distinctiveness metrics. Then, we designed a videogame for MI-BCI in motor rehabilitation that uses SBA algorithmic support index to inform in real-time the BCI user on how well the instructed task was performed. Such feedback is presented as an energy bar. Feedback also comprises an avatar hand movement together with an audible tone indicating the predicted mental state. To encourage users, the goal of the game is to catch coins and maximize a score, which depends on the algorithmic support value. Pilot subjects claimed high agency and felt feedback was transparent.

Conclusion: SBA not only facilitates across-sessions adaptation but also measures in real-time the quality of the provided EEG patterns with respect to the indicated mental task. The design of meaningful feedback based on SBA algorithmic support has the potential to enhance users' MI-BCI control capabilities. Future plans involve the development of a longitudinal MI-BCI study to evaluate whether the neurofeedback based on the SBA algorithmic support metric fosters engagement, master MI skills, and ultimately, improve clinical outcomes in motor rehabilitation.

Acknowledgments and Disclosures: This work is partially supported by the OpenBCI Discovery Program 2020. The authors declare no conflict of interest.

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Development and Validation of a Fully Implantable Brain-Computer Interface System

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Introduction: Brain-computer interface (BCI) systems hold significant promise for restoring motor, sensory, and communication functions in individuals with neurological disorders. However, challenges such as miniaturization, biocompatibility, and high-channel-count neural signal acquisition remain critical barriers to clinical translation. Here, we present a fully implantable BCI system featuring advanced integration of high-density flexible electrodes, signal acquisition, and wireless communication technologies, designed to meet safety and performance standards for long-term implantation.

Material, Methods and Results: The system incorporates 256-channel or 1024-channel flexible electrodes with a custom-designed 256-channel signal acquisition integrated circuit (IC), a low-power Bluetooth chip, and a wireless power supply module. This configuration enables the acquisition, processing, and wireless transmission of up to 256/1024 channels of neural data. The system is miniaturized and highly integrated, utilizing biocompatible materials and advanced packaging techniques to meet implantable safety standards. Animal studies have been conducted to evaluate the safety and efficacy of the implantable BCI system. Results indicate successful neural signal acquisition and transmission with minimal tissue inflammation and no adverse effects observed during the study period. The system has demonstrated the capability to perform real-time neural signal processing and BCI control by the animals, which is a critical step towards its application in clinical settings.

Conclusion: We have developed a fully implantable BCI system that showcases high performance, miniaturization, and integration, suitable for long-term use in clinical environments. Preliminary validation in animal models has confirmed the system's safety and effectiveness. With the system's design meeting implantable device safety standards, we are poised to initiate clinical trials this year. The outcomes of these trials will be instrumental in determining the clinical utility of this BCI system for a variety of neurological applications.

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Meta-AlignNN: A Meta-Learning Framework for Stable BCI Performance Across Subjects, Time, and Tasks

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Introduction: Practical application of brain-computer interfaces (BCIs) requires stable mapping between neuronal activity and behavior through various behavioral contexts and for different individuals. Because recorded neurons as well as neural activity from same neurons could change over time, BCIs require frequent recalibration to maintain robust performance. Early approaches to addressing BCI stability issues mainly focused on tackling the challenge of neural activity changes over time. However, future BCI applications involve diversified scenarios and subjects, requiring solutions that address neural variability across time, subjects, and tasks. This study proposes a meta-learning-based algorithm for achieving BCI stability, referred to as "Meta-AlignNN." It provides a unified solution for maintaining BCI stability.

Material, Methods and Results: Recent studies have explored stability and consistency of neural population dynamics across subjects, time, and tasks, highlighting how these properties support the generation and learning of complex behaviors [1, 2, 3], which forms the theoretical foundation for effectiveness of Meta-AlignNN. We aim to develop a meta-learner capable of aligning neural activity across subjects, time, and tasks, regardless of the changes or drifts in neural activity recorded from cortical electrodes. With minimal data, this meta-learner can align varying neural activity to the stable and consistent neural population latent dynamics across different subjects, time, and tasks, thereby maintaining high BCI performance. Meta-AlignNN consists of a meta-aligner and a decoder. Specifically, the decoder is first trained on several sessions to learn the relationship between latent states (extracted from neural activity) and movement intentions. Data from other recorded sessions (across different subjects, tasks, and time) are used to train the meta-aligner. During meta-training, the meta-aligner is trained using Model-Agnostic Meta-Learning strategy, with the decoder's parameters fixed. The trained meta-aligner can align varying neural activity into stable and consistent neural population latent dynamics across subjects, time, and tasks. The fixed decoder can then seamlessly predict behavior from these aligned dynamics. In practice, this approach achieved significant success in various cross-time, cross-task, and cross-subject experiments (offline decoding and real-time brain control) conducted over nearly two years involving three monkeys and four tasks (center-out reaching task, random-target reaching task, whack-a-mole, and *Black Myth: Wukong*). The real-time brain control accuracy across time, tasks, and subjects reached approximately 98.2%. Notably, in the real-time brain control scenario involving *Black Myth: Wukong*, the task was completed in near-theoretical minimum time.

Conclusion: In this study, we present a unified meta-learning framework, Meta-AlignNN, designed to address the limitations of earlier approaches and to ensure BCI stability and robustness across subjects, time, and tasks. Tested over two years on four tasks with three monkeys, the approach achieved high real-time brain control performance. By capitalizing on the consistency of neural population dynamics and requiring minimal data for recalibration, this framework provides a compelling solution for clinical and practical BCI applications. Future work will explore its adaptability to diverse tasks and populations.

Acknowledgments and Disclosures: This work was supported by Lingang Laboratory (Grant NO. LG-GG-202402-06) and Shanghai Municipal Science and Technology Major Project (Grant NO. 2021SHZDZX). The authors declare no conflicts of interest or commercial financial support related to this study.

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Decoding of Lower-Limb Movement Intent from Scalp Electroencephalography (EEG) in Children

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Introduction: Brain-computer interfaces (BCIs) can be used to decode movement intent from brain signals and, thus, provide a direct communication link with external virtual or physical machines such as computers, exoskeletons or prosthetic limbs. Those signals can also be utilized to promote neuroplasticity in the central nervous system to recover motor functions. Although rehabilitation-based BCIs have been broadly applied to the adult population and showed promising results, these adult-optimized BCIs might not work well for the pediatric population. In a systematic review of children BCIs, Orlandi et al. found that only 12 publications published between 2008 and 2021 reported BCI performance. Out of those studies, only one non-invasive study addressed mobility, indicating the need for more studies in this field.

Material, Methods and Results: Two experiments were conducted. The first experiment (Cued Dataset, N=5, Age: 7.6 ± 2.3 years; single session tasks: visually-cued sit-stand transitions and walk-stop locomotion with at least 20 of each) involved visual cues to indicate the start of movement, which can be suitable for synchronous BCIs. The second experiment (Self-initiated Case Study, N=1, Age: 12 years, a total of 12 sessions collected in a course of seven weeks, Task: volitional sit-stand transitions and walk-stop locomotions with at least 20 of each) was self-triggered in terms of timing of movement and its category (Sit/Stand/Walk), which is appropriate for asynchronous BCIs. Acquisition of Electroencephalography (EEG) and electromyography (EMG) data was synchronized. To characterize EEG, the time-locked signals were processed for offline analysis. To close the loop and implement a real-time BCI, two types of state-dependent classification models were built for decoding movement intent from EEG and predicting the next transition. Two pipelines for pre-processing EEG data before utilizing them as an input to neural networks for classification were tested: one with the adaptive noise cancelling H-infinity filter, and the other with an ICA-based spatial filter designed to decompose EEG into independent sources. The convolutional neural networks implemented for training, validation, and real-time testing are composed of normalization, 1-D temporal convolution, rectifying linear unit, self-attention, fully connected, and SoftMax layers. Sensitivity analysis was performed with the input to the neural networks altered in terms of duration, frequency, and channels. For the offline analysis, movement related cortical potentials are observed clearly, especially in the channels closer to the central areas. Event-related spectral perturbation analysis indicates that all movement classes show a large decrease in power in the δ band. Moreover, an increase in power in the lower δ band starts to appear about one second before the movement onset. ICA and EEG dipole source localization investigation revealed the involvement of Brodmann Areas 6 and 8, areas known for their roles in motor planning, learning, and control. The sensitivity test results highlight the significance of the δ-band and window duration of 2 seconds for decoding. To investigate the capability of decoders to detect movement intent from single trials coming from completely an unseen session, models were trained on data from sessions 1 through 11 of the Case Study and tested on session 12. Overall, the mean F1-Score of the Seated Model was 0.80 (chance level≃ 0.5) whereas it was 0.54 for the Standing Model (chance level≃0.3).

Conclusion: This study demonstrates the feasibility of using EEG signals to predict movement intent in children for synchronous and asynchronous BCIs. EEG preceding movement onset was characterized in time, frequency, and IC domains. A prototype BCI based on the outcomes of this research was developed and evaluated. The findings of this research could substantially assist in developing pediatric BCIs that are capable of controlling walking exoskeletons and, consequently, improving their users' motor control. This work also promotes access of BCI systems to pediatric populations.

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Cognitive requirements for effective brain-computer interface (BCI) use in children with cerebral palsy.

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Introduction: Brain-computer interfaces (BCIs) requires specific user skills for successful operation. However, the cognitive demands remain relatively unexplored, particularly in pediatric populations, where developmental differences and cognitive variability significantly influence usability and performance. This is especially true for children with cerebral palsy (CP), who often face additional cognitive and motor challenges that can further impact their interaction with BCI systems. This review aims to examine existing research on the cognitive demands of BCI technology, with a special focus on children with CP.

Methods and results: A systematic search was conducted across six databases (Scopus, Web of Science, Embase, MEDLINE, PsycINFO, and CINAHL) for original research studies involving children aged 5-18 using BCIs for control purposes. Inclusion criteria focused on studies reporting cognitive factors relevant to BCI performance. Data extraction and analysis followed the PRISMA-ScR guidelines.

Initially, 724 articles were identified, with 446 screened after removing duplicates. Of these, 420 were excluded for not focusing on BCI, children with CP, and cognition. Full-text review of 26 articles excluded 19 that did not meet inclusion criteria, leaving five studies. Participants were aged 6 to 18 years. They included children with CP with Gross Motor Function Classification System (GMFCS) levels I to V.

Activities done with BCI varied, including cognitive assessments, spelling, and controlling devices like cars, games, and robots using P300- or MI-based BCIs. Cognitive areas crucial for BCI use included **attention**, which is critical for P300 tasks, and sustained focus, which is often challenging due to fatigue, long setup times, and unengaging stimuli (1–4). **Motivation and engagement** influence BCI performance (5). **Processing speed** and **fatigue**, both mental and physical, also impacted usability, particularly in synchronous systems (real-time) (1). Neuroimaging was noted as a valuable tool to help identify neuroanatomical changes that might affect performance, informing the electrode placement and ensuring eligibility.

Conclusion: These findings emphasize the need for customized, engaging, and developmentally appropriate BCI systems. The limited number of included studies underscores the need for further research to comprehensively understand the cognitive requirements for BCI performance.

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Enriching the Image: Does Combining Motor Imagery with Haptic Input Affect the Event-Related Desynchronization?

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Introduction: Motor imagery (MI), often combined with neurofeedback (NF), has proven effective in promoting neural plasticity and aiding motor rehabilitation. A key element of MI-NF applications is event-related desynchronization (ERD), which serves as a marker of neural activation and sensorimotor engagement. Stronger and more stable ERD modulation can help optimizing MI-NF protocols, particularly for neurorehabilitation and brain-computer interface development. Haptic input during MI may help achieving this. By bridging perception and interaction, haptic input may close the sensorimotor loop and support neuroplasticity mechanisms necessary for motor recovery [1], and could also strengthen the memory trace for movement during MI [2]. Despite its potential, the impact of haptic input on MI-induced ERD remains underexplored. This study investigates whether congruent haptic input amplifies ERD during simple and complex MI tasks, narrowing the gap between motor execution (ME) and MI.

Material, Methods, and Results: We analyzed 64-channel EEG data from 20 healthy, right-handed participants (12 females, 57-82 years, M and SD: 68.1 ± 7.6 years) performing ME and MI of a finger-tapping task. For the ME and the haptic input MI conditions, participants' fingers rested on the keys of a keyboard. In the no-haptic MI conditions, the hand was relaxed and suspended. Two task difficulty levels were implemented to explore the effect of task complexity on haptic input in the ERD. The simple variant involved tapping with a single finger, while the complex variant required executing a pre-learned and practiced sequence involving multiple fingers. Preliminary data analysis focused on contralateral mu and beta frequency range (8–30 Hz) ERD. Conditions were compared using ANOVA and *t*-tests. Descriptively, the haptic condition was associated with a slightly larger ERD then the no-haptic condition, but the difference did not reach significance. A significant effect of task complexity on ERD was evident, with more complex tasks eliciting stronger desynchronization. Additionally, ERD was significantly stronger during ME compared to MI.

Conclusion: While the haptic condition showed a slight trend towards a larger ERD compared to the no-haptic condition, preliminary results do not support that congruent haptic input alone can significantly amplify contralateral ERD during finger-tapping MI. The absence of a significant effect may be attributed to a small effect size, high variability in participants' ERD responses, or a combination of both factors. However, task complexity significantly enhanced contralateral ERD, supporting previous findings that more cognitively demanding MI tasks elicit stronger neural activation [3].

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Brain-Computer Interface (BCI) in Latin America: a scientometrics perspective

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Introduction:

Brain-Computer Interface (BCI) technology has gained significant attention, especially in fields such as medicine, rehabilitation, and human-computer interaction. Scientific productivity related to BCI in Latin America has been increasing, but comprehensive research on this trend is limited. This study aims to provide a scientometric analysis of BCI publications in Latin America, focusing on the distribution of research across countries, categories, and subcategories.

Materials, Methods, and Results:

Data were collected from PubMed, ScienceDirect, IEEE, Scopus, and Redalyc, considering articles in English, Spanish, and Portuguese. Articles were selected if they included at least one Latin American author and were relevant to BCI development or application. A total of 445 articles were analyzed after removing duplicates. The articles were classified into five main categories: Acquisition systems, Signal processing, Applications, Paradigms, and Others, each further subdivided. Descriptive statistical analysis was performed to explore the distribution of publications.

Brazil led BCI publications with 155 articles, followed by Colombia (79) and Mexico (62). In the Acquisition systems category, EEG was the most frequent subcategory (94.68%). In Signal processing, Classification models were predominant (63.14%), while Neuroscience led in Applications (43.24%). In Paradigms, MI was the most prevalent (63.11%), and in the Data Capture category, the "Yes" subcategory represented 60.65%.

Conclusion:

Brazil, Colombia, and Mexico are the leading contributors to BCI research in Latin America. EEG, Classification models, Neuroscience, and MI paradigms dominate the research focus. However, subcategories like fMRI, fNIRS, and Ethics are less explored, suggesting potential areas for further investigation. Despite the growing scientific productivity, thematic distribution remains imbalanced, indicating the need for broader research topics to advance BCI technology in the region. Additionally, while no specific reports on BCI in Latin America have been found, studies on scientific productivity in neuroscience in the region (Forero et al., 2019) and a market report projecting growth in the BCI sector in Latin America to US$ 361.9 million by 2030 (Brain Computer Interface Market Outlook, 2023-2030) reinforce the importance and potential of this technology in the region.

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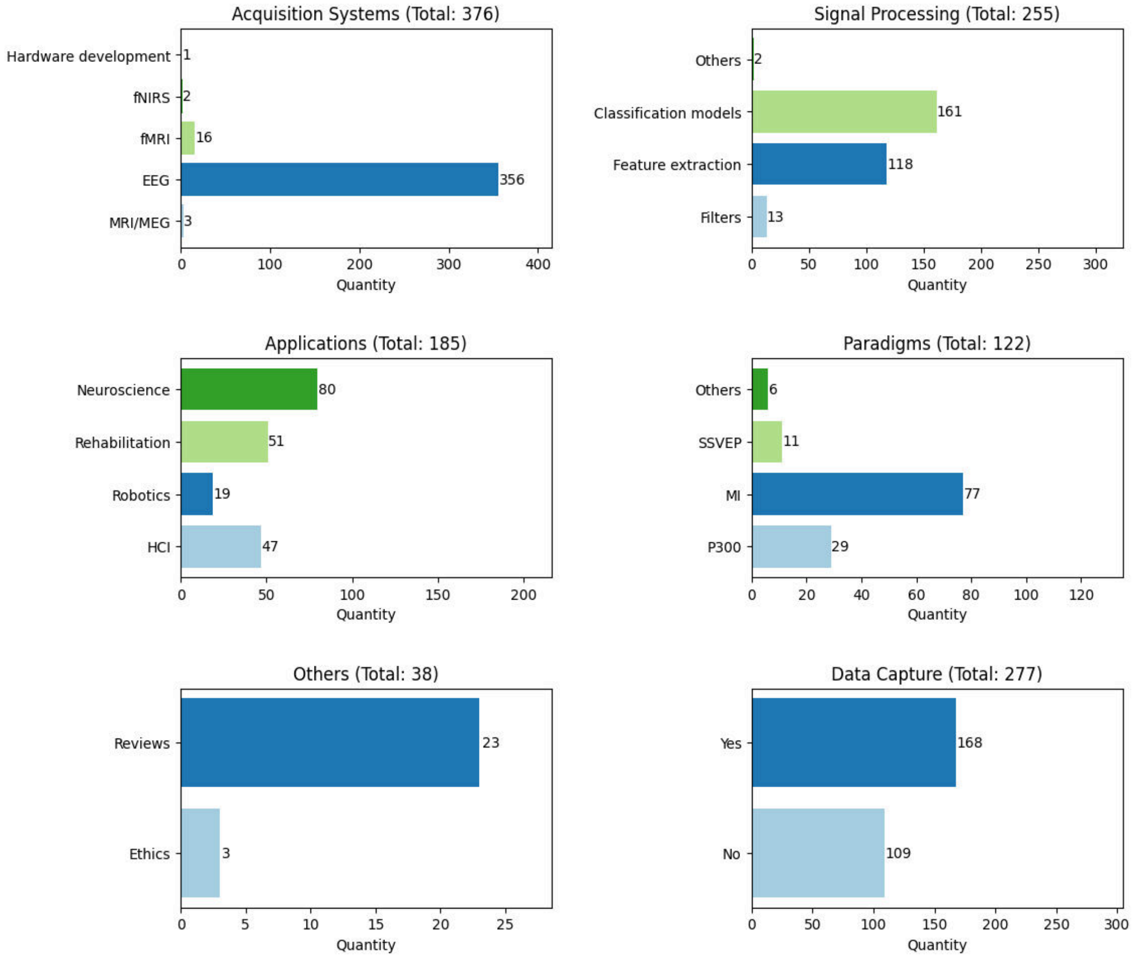

Figure 1: *Distribution of the six main categories and their respective subcategories in Brain-Computer Interface (BCI) research in Latin America. The categories include Acquisition Systems (EEG, fMRI, MRI/MEG, ECoG, fNIRS, hardware development), Signal Processing (feature extraction, classification models, filters), Applications (rehabilitation, robotics, neuroscience, HCI), Paradigms (P300, MI, SSVEP), Others (reviews, ethics), and Data Capture (Yes/No).*

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Real-Time Classification and Modulation of the Distractor Positivity with an EEG BCI

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Introduction: Every day, vast amounts of information compete for our limited attentional resources. Understanding how the brain filters out irrelevant stimuli is crucial, particularly for individuals with attentional deficits. In this study, we focused on the event-related potential known as distractor positivity (Pd), a positive voltage peak that occurs at parieto-occipital electrodes contralateral to salient distractors[1]. Pd amplitude has been linked to effective distractor suppression, whereas reduced Pd amplitude has been associated with severity of inattention symptoms[2]. Despite the significance of Pd, no prior studies have attempted to decode it in real time on a trial-by-trial basis or investigated whether it can be modulated via neurofeedback. Here, we demonstrate the feasibility of building a Pd-based decoder for real-time classification of distractor presence and of using closed-loop BCI to enhance Pd amplitude.

Material, Methods and Results: Five participants (2 males, mean age 25.4 ± 3.2 years) completed the additional singleton paradigm, where they searched for a target shape. On half of the trials, a salient red distractor appeared, creating "distractor present" and "no distractor" conditions. Participants underwent 3 sessions: calibration and online on day 1 and on day 2. Data from the calibration session was used to train a linear discriminant analysis (LDA) classifier to distinguish between distractor-present and no-distractor trials. During online sessions, participants repeated the paradigm while receiving real-time feedback based on the BCI output.

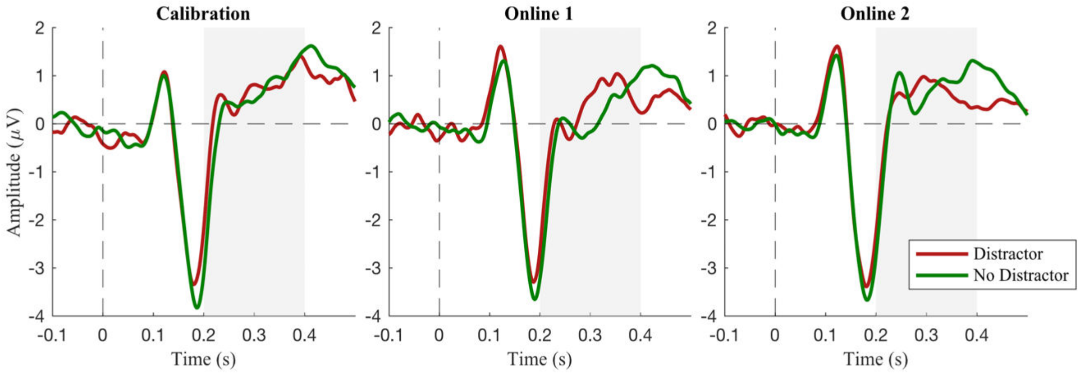

Figure 1. *Grand-average event-related potentials across 5 subjects during 3 experimental sessions: calibration, online 1 and 2. Shaded region indicates the time window selected for classification and amplitude analyses.*

We observed a significant interaction between condition (distractor vs. no distractor) and session in Pd amplitude ($F(2,8) = 4.74$, $p = 0.04$). From calibration to online session 1, the amplitude difference between distractor and no-distractor conditions increased, indicating successful modulation of the late Pd components (*Fig. 1*). The BCI achieved mean accuracies of 63±5% during calibration, 62±3% in the online session 1, and 62±6% in the online session 2 (*Fig. 2*). Remarkably, accuracy was stable across sessions. Nevertheless, across subjects, accuracy tended to decrease in the second online session, probably due to changes in the Pd components with respect to the calibration session. To test this hypothesis, we recalibrated the BCI for subject 5 (purple in *Fig. 2*) after the online session 1, leading to an accuracy increase in the online session 2.

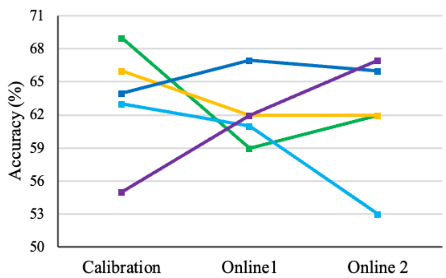

Figure 2. *Classification accuracy by subject and session. Each line represents accuracies from a single subject.*

Conclusion: This proof-of-concept study is the first to show the feasibility of a BCI for real-time decoding and modulation of the Pd components, a marker of distractor suppression. Results indicate that participants can learn to enhance Pd amplitude through BCI neurofeedback, laying critical groundwork for Pd-based interventions aimed at improving distractor suppression. Ongoing work includes additional measures to link enhanced Pd with behavioral improvements in attentional control, building better decoders that adapt to the changes of Pd induced by BCI feedback, and longer training sessions. As increased distractibility is observed in clinical populations (such as those experiencing cognitive aging), this line of research could ultimately inform novel treatment applications.

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Examining sEEG Traveling Wave Instances During Speech Production and Auditory Perceptual Contexts

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Introduction: Invasive brain-computer interfaces (BCIs) leverage a range of electroencephalographic (EEG) biomarkers across various contexts [1-3]. Identifying and characterizing additional unique EEG biomarkers could prove useful for the continued development of BCI technology. Recent studies suggest that traveling waves (TWs) observed in EEG may be predictive of cognitive and behavioral outcomes in specific instances [4-6]. However, to fully understand the potential role of TWs as biomarkers in BCI applications, they must be more comprehensively characterized across cognitive, behavioral, and sensory modalities.

Materials, Methods, and Results: In this preliminary study, we identified traveling waves in patients undergoing stereo-electroencephalography (sEEG) monitoring for intractable epilepsy at UCSD and VCU Health. Seven sEEG patients performed a cued speaking task and an additional nine patients performed a passive listening task. Traveling waves were identified using a uniform detection pipeline across tasks and participants. This pipeline first identified consecutive neighboring electrodes along a given sEEG shaft that share a common dominant spectral peak. Narrowband filtering at this dominant spectral peak and a Hilbert transform was then applied to extract instantaneous phase characteristics and confirm coordinated phase progression among the channels. Instances meeting these propagation and frequency criteria were tested for statistical significance via permutation testing. Statistically significant ($p < 0.05$) traveling waves were observed in the theta (3–8 Hz), alpha (7–13 Hz), low-beta (12–21 Hz), and high-beta (20–31 Hz) frequency bands. Preliminary results suggest that theta-band TWs occur more frequently at specific instances of the tasks such as during the onsets of speech or the acoustic stimuli.

Discussion and Significance: Previous studies have linked intracranial EEG traveling waves to predictive outcomes in specific cognitive and behavioral tasks. In this work, traveling waves were detected and characterized in sEEG recordings during both speech and auditory tasks. Further investigation is needed to fully elucidate the relationship between TWs and these tasks, including an examination of the directionality and brain regions associated with the traveling waves.

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Designing an Eye-Gaze Tracking System with Computer Vision to Enhance Children's Intention in BCI

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Introduction: BCI, while a promising solution for communication and interaction for children with severe disabilities, also introduces complexities in its use. Such children often suffer from impaired eye and head movement control as well as attention, decreasing efficacy of vision-dependent BCI paradigms. Often, the “good” electroencephalographic (EEG) signals obtained during visual fixation that are required for BCI to work are “contaminated” by noisy EEG signals when gaze is diverted. This study addresses these challenges by leveraging computer vision to analyze children's eye-gaze patterns. We aimed to develop an eye tracking system able to inform when the user is looking at the screen to integrate with BCI and reinforce children's intention.

Material, Methods and Results: Data were collected from 10 healthy control participants focusing on 17 predefined gaze positions (on- and off-screen) for 30 seconds each. Additionally, 10 five-minute frontal videos were recorded of 5 children with complex physical disabilities (GMFCS Levels 4 and 5) using the BCI through a motor imagery paradigm, where they mentally simulated movements without physically moving, during a training session with visual feedback on a screen. The videos were labelled to indicate on-screen and off-screen gaze moments. Eye-gaze features were extracted using Mediapipe's face blendshape function [1], an open-source component of Google's pre-trained models for markerless facial landmark detection. Although Mediapipe does not directly provide a dedicated eye-gaze model, a set of 14 eye-related features were extracted. These features were used to train a CatBoost model [2], a gradient-boosting framework known for its efficiency with categorical features and its ability to handle large datasets. To further enhance model performance, hyperparameter optimization was conducted using Optuna [3]. The model's performance was evaluated using Stratified K-Fold Cross-Validation and Group K-Fold Cross-Validation. The optimized CatBoost model trained with data from both healthy and children with complex physical disabilities was then deployed for real-time use. It detected landmarks from the integrated camera and used a sliding window of 30 frames (14 features each) to generate single output predictions aligned with on/off-screen eye-gaze intentions. The Stratified K-Fold Cross-Validation achieved an accuracy of 0.9558 ± 0.0010, this approach ensures that the distribution of class labels was preserved across all folds [4]. While the Group K-Fold Cross-Validation achieved an accuracy of 0.6851 ± 0.0523 by splitting data based on participant groups, ensuring that data from the same individual did not appear in both training and testing sets [5]. Our findings show that, despite lower accuracy, the Group K-Fold Cross-Validation approach reflects real-world variations by accounting for individual differences. This is crucial for developing models that generalize effectively to new participants.

Conclusion: Computer vision can detect eye-gaze on/off screen patterns, even in children with severe disabilities. This provides a foundation for integrating eye-gaze tracking with BCI systems, potentially improving accessibility and participation for these children.

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The Impact of Directed Attention on ICMS in Human Somatosensory and Motor Cortex

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Introduction: Intracortical microstimulation (ICMS) can be used to restore touch perception to individuals with spinal cord injury (SCI) using. Here we explore how top-down attention modulates ICMS-induced sensations in participants with Utah arrays implanted in the primary somatosensory and motor cortex. Attention is crucial for filtering relevant sensory inputs, a process which will be important for the effective operation of densely sensorized prosthetics. In this study we assess whether attention enhances or suppresses the perceptual clarity of ICMS sensations and if the locus of attention can be decoded from the sensorimotor cortices.

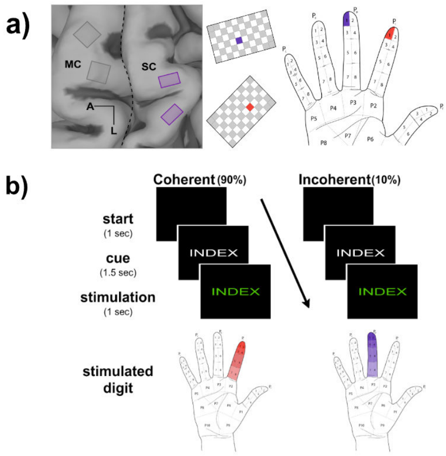

Figure 1. ***(A)*** *Left panel: Participant implants, showing two arrays in the motor cortex (left of the central sulcus, dashed line) and two in the sensory cortex (right of the central sulcus). Middle panel: Sensory arrays with two example electrodes highlighted. Right panel: Stimulation projection fields for the two highlighted electrodes.* ***(B)*** *The Posner-like detection task begins by directing the participant's attention to one of the two digits selected for the session, indicated by white text on a screen. Stimulation is delivered to the electrode corresponding to the cued digit, with the text turning green as feedback. The participant reports whether they perceived any stimulation. On 10% of trials, stimulation is instead delivered to the electrode corresponding to the unattended digit.*

Material, Methods and Results: Participants performed a Posner-inspired ICMS task to examine attention's effects on ICMS detection. Two electrodes targeting distinct fingers (Fig. 1a) were selected based on their projected fields. Psychometric detection functions were computed for each electrode during attention to the stimulated finger. A detection task followed, with trials interleaved between electrodes (Fig. 1b). On 90% of trials, participants were cued to the correct finger (coherent trials), while on 10%, stimulation occurred at the other finger (incoherent trials). Effects of spatial attention were minimal and inconsistent across electrodes, suggesting challenges in directing attention to individual fingers or the salience of unattended stimulation (Fig. 2a,b). Incorporating baseline stimulation may improve consistency. Some channels showed increased activity with digit-specific firing rate increases, while others decreased during the cueing period (Fig. 2c). Motor cortex activity increased relative to baseline during cueing, whereas sensory cortex activity decreased. Post-stimulation, ICMS-evoked responses were elevated and strongly digit-dependent in both cortices (Fig. 2d,e). The attended digit was decodable above chance from the motor cortex but not from the sensory cortex (Fig. 2f,g).

Conclusion: Spatial attention minimally influenced detection consistency, likely due to the salience of unattended stimulation. Neural activity revealed decreased sensory cortex activity during cueing and elevated ICMS-evoked responses in both motor and sensory cortices post-stimulation. Notably, motor cortex activity allowed above-chance decoding of the attended digit (Fig. 2f), unlike sensory cortex activity. This work advances the understanding of attention-driven ICMS modulation and suggests strategies for optimizing sensory prosthetics.

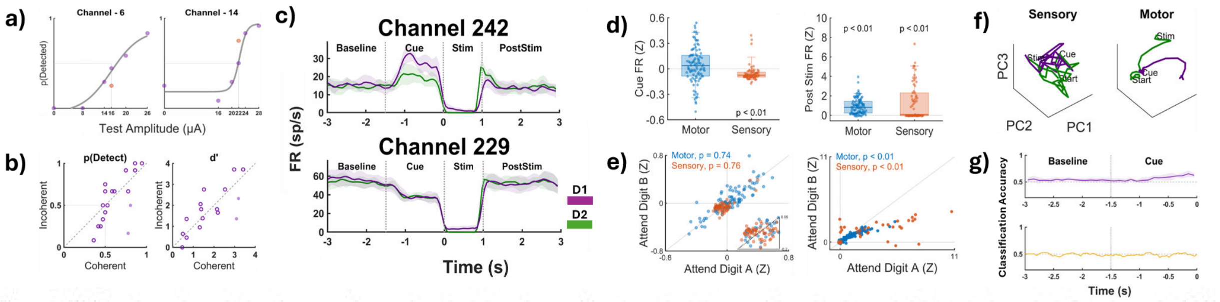

Figure 2. ***(A)*** *Example psychometric detection curves for two channels during coherent trials, where stimulation was delivered to the cued digit (purple data points). Detection at the DT-50 amplitude, where incoherent trials (stimulation was delivered to the unattended digit) were tested, is shown in orange.* ***(B)*** *Left panel: Scatterplot depicting detection performance for each channel at the DT-50 amplitude across coherent and incoherent conditions. Right panel: Corresponding scatter plot displaying d' (discriminability) values, a measure of sensitivity in distinguishing between signal (stimulation present) and noise (no stimulation) conditions.* ***(C)*** *Average firing rates for two representative channels across task phases, including baseline, cue, stimulation, and post-stimulation periods.* ***(D)*** *Left panel: Scatter box plot illustrating changes in average firing rate for all channels during the cueing period relative to baseline, separated by motor (blue) and sensory (orange) cortex. Right panel: Same analysis for the post-stimulation period.* ***(E)*** *Left panel: Scatterplot of Z-scored firing rates relative to baseline for "attend digit A" (x-axis) versus "attend digit B" (y-axis) during the cueing period, separated by motor and sensory cortex. Right panel: Corresponding scatterplot for the post-stimulation period.* ***(F)*** *Projection of neural activity onto the top 3 PCs for each digit for sensory vs motor arrays.* ***(G)*** *dashed line indicates deployment of attention. [top] The classification accuracy of the attended digit from motor cortex. [bottom] Control, to determine whether what we were decoding was actually motor intention to move.*

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Closed-loop applications for deep brain stimulation and code-modulated visual evoked potentials on Dareplane

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Introduction: The Dareplane platform [1], introduced as a modular open-source platform at the brain-computer interfacing (BCI) conference in 2023, enables BCI applications, ranging from classical BCI spellers to adaptive closed-loop deep brain stimulation ((a)DBS). We now present two use cases as proofs of principle with a single aDBS session using markers derived from electrocorticography (ECoG) signals, as well as results from three healthy participants using a code-modulated visual evoked potentials (c-VEP) speller, exemplifying a timing critical BCI application based on electroencephalography (EEG).

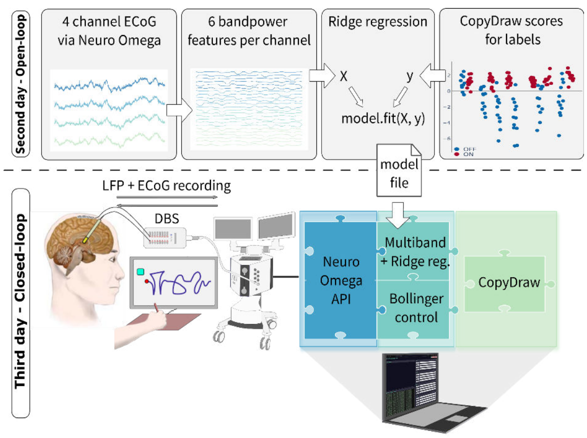

Figure 1: Schematic of the aDBS experiment with neural decoding model trained on the second day and applied on the third.

Methods and Results: An aDBS use case was conducted with a single patient receiving a DBS system for the treatment of Parkinson's disease. The patient temporarily obtained an epidural four-contact ECoG electrode over the left primary motor cortex. It was removed during the second part of a two-stage implantation. DBS and ECoG leads were externalized between stages. During three measurement days, the patient conducted the CopyDraw task [2]. We used the ECoG signals to decode the CopyDraw performance scores, thus extending our previous work on EEG [2]. Power estimates of six frequency bands per ECoG channel formed the input to a ridge regression model, leading to on average 71% Pearson's correlation between predicted and observed CopyDraw scores in a chronological 6-fold cross-validation on the second measurement day. On the third day, this model provided input to a Bollinger band control to realize a fully closed-loop aDBS strategy.

The c-VEP speller use case replicated the work of Thielen et al. [3], with an eight-channel EEG system and a speller layout with 63 symbols. Per participant, data from 10 cued trials (42 seconds) were used to train spatial and temporal filters of a decoding model, realized by a reconvolution embedded in a canonical correlation analysis [2]. Each subject then conducted three online runs of spelling a target sentence, resulting in on average 13 correct symbols per minute and an information transfer rate of 82 bits/minute.

Conclusion: These two proofs of principle provide evidence for the claimed closed-loop capability of the Dareplane platform, including its use in the clinical aDBS setting. The c-VEP experiment was configured using a simple setup script, which can be found at https://github.com/thijor/dp-cvep. It is a good starting point for exploring the Dareplane platform and allows for easy replication of the results, which are in line with previously reported performance metrics [2].

Acknowledgements: The project is funded by Hersenstichting and Health~Holland, The Hague, The Netherlands.

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Optimizing P300 Speller Performance through Uncertainty Quantification

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Introduction: Brain-computer interfaces (BCI) provide individuals with impaired motor movements the ability to control communication devices. One prominent application is the P300 speller, which leverages the P300 event-related potential (ERP) captured through electroencephalography (EEG) to enable communication [1]. However, challenges such as slow speed and low accuracy hinder the effectiveness of current P300 speller systems. In this study, we propose an adaptive threshold method that incorporates uncertainty quantification (UQ) to improve the P300 speller [2].

Material, Methods and Results: We implemented two strategies: early stopping, which terminates the classification process once sufficient confidence is reached, and trial rejection, which prevents making predictions with high uncertainty. The Riemannian Minimum Distance Metric (MDM) with Bayesian Accumulation (BA) classifier was used to evaluate the model [3, 4, 5]. For our experiment, we rejected samples where the predictive confidence did not meet a set threshold. Testing on a dataset from 8 patients with amyotrophic lateral sclerosis (ALS) [6] demonstrated that the integration of UQ significantly outperformed existing methods. Specifically, early stopping with UQ reduced the number of flashes by 12%. Trial rejection, on the other hand, improved accuracy to 94.1% (Fig.1) with coverage of 75.3%, representing a 14.1% accuracy increase over the state-of-the-art classifier by rejecting 24.7% of the data.

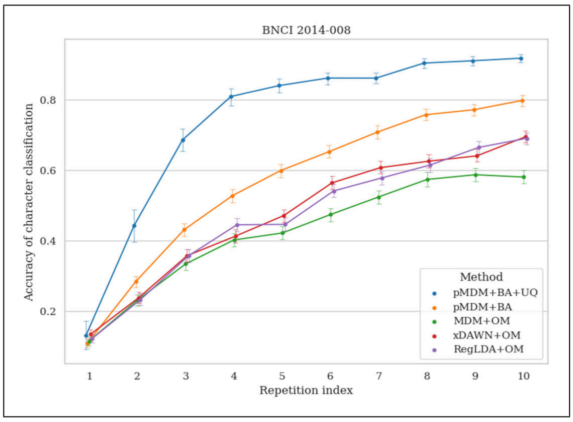

Figure 1: *Average accuracy versus repetition index across all the participants. The plot demonstrates that our model with UQ matches the state-of-the-art accuracy at the 4th repetition and achieves the highest overall accuracy.*

Conclusion: These results demonstrate the potential of UQ to enhance both the speed and accuracy of the P300 speller, offering a more efficient and robust solution. Our method could be further improved by combining early stopping and trial rejection techniques, as both utilize similar approach based on the highest probability outputs. Moreover, adopting a data-driven approach to optimize these parameters could minimize manual intervention.

Acknowledgments and Disclosures: We would like to thank dr. Sylvain Chevallier for the discussions and access to the implementation code. This research was conducted with no conflicts of interest.

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Error-Positivity Amplification with Alternating-Current Stimulation Augments Perceptual Skills to Detect Errors

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Introduction Accurate perception of visuo-motor errors is crucial for sensorimotor learning and corrective actions [1]. Our ongoing research has identified the error positivity (Pe) component of the error-related potential (ErrP) as a neural correlate of perceptual ability for visuo-motor errors [2]. We hypothesize that 20 minutes of transcranial alternating current stimulation (tACS) at a personalized θ frequency, targeting the frontocentral region, will increase Pe amplitude. To test this hypothesis, we evaluated the effects of tACS in a classic 1D error monitoring task involving discrete cursor jumps that induce expectation mismatches [3]. We expect similar Pe enhancement in a more cognitively demanding 2D continuous task, where visuo-motor perturbations introduce mismatches (Fig. 1a). Importantly, we also postulate that tACS will improve participants' perception of visuo-motor errors.

Material, Methods and Results Twenty-six healthy volunteers were randomised into two groups: 13 in the active stimulation group and 13 in the active control group (100-400 Hz transcranial random noise stimulation, tRNS). Stimulation was applied using a 4×1 montage (FCz: 2 mA; AF3, AF4, C1, C2: -0.5 mA). Participants attended two days, each consisting of one pre-stimulation and three post-stimulation sessions. On Day 1, they performed the 1D discrete task [3] with 100 trials (30% erroneous) before and after 20 minutes of personalized θ-tuned tACS or tRNS at rest. Post-stimulation sessions occurred immediately, 15, and 30 minutes later. Day 2 followed the same structure, with participants completing two runs of the 2D continuous task [2] per session. Each run included 36 trials where participants used a joystick to control a cursor along a straight trajectory. In 30% of the trials, the joystick-to-cursor mapping was altered with a small 6° visuo-motor rotation. Participants reported perceptual decisions via joystick button presses after each trial. Results showed that in the 1D task, tACS increased Pe amplitude, becoming significant at 30 minutes post-stimulation, with no effect in the control group (Fig. 1b). At this time point, tACS also enhanced Pe amplitude in the 2D continuous task, alongside improved error perception, while the control group showed no changes (Fig. 1c-d). Moreover, between-group comparisons showed significant differences in Pe amplitude and error perception in favor of tACS.

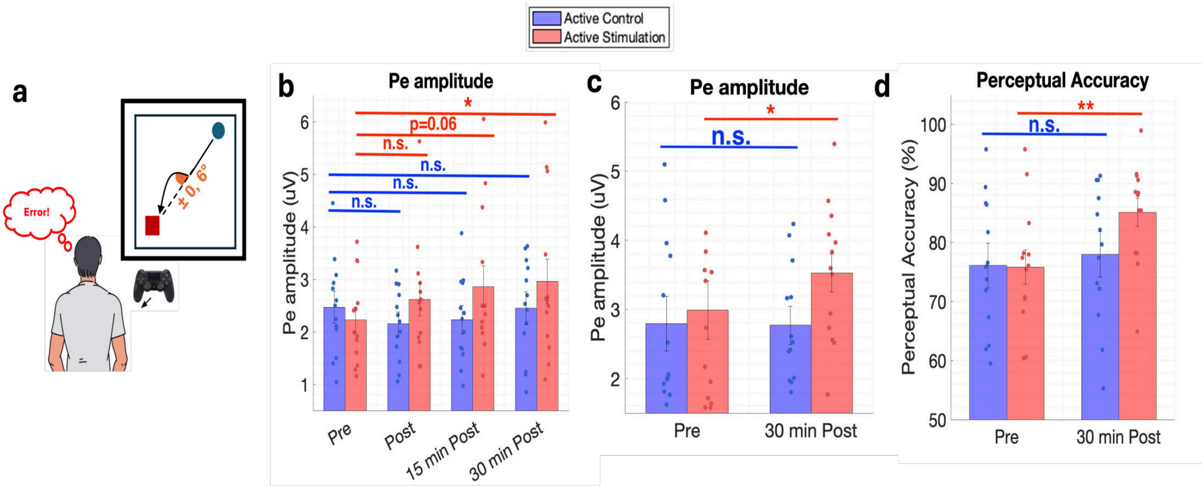

Figure 1: **a** *The 2D continuous visuo-motor error perception task.* **b** *Pe amplitudes at four time points (pre-, immediately post-, 15 min post-, and 30 min post-stimulation) in the 1D task.* **c** *Pe amplitudes at pre- and 30 min post-stimulation in the 2D task.* **d** *Perceptual accuracies at pre- and 30 min post-stimulation in the 2D task. Data for the active group (red, n=13) and control group (blue, n=13) are shown in panels b-d.* $*P < 0.05$, $**P < 0.01$, *n.s.* $P > 0.05$.

Conclusion The proposed brain stimulation approach offers a non-pharmacological, non-invasive foundation for addressing perceptual impairments in elderly and clinical populations, avoiding drug side effects and accelerating perceptual learning compared to conventional methods.

Acknowledgements and Disclosures Authors thank participants and declare no conflict of interest.

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Stereo-EEG Based Brain Computer Interfacing Across a Large Patient Cohort

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ABSTRACT:

Introduction Stereoelectroencephalography (sEEG) is a mesoscale intracranial monitoring method which records from the brain volumetrically using depth electrodes. Implementation of motor Brain Computer Interfacing (BCI) in sEEG has not been well-described across a diverse patient cohort. Here in we describe the application of sEEG-based motor BCI across a large patient cohort.

Methods: Across twenty-two subjects, channels with 65-115Hz power increases during hand, tongue, or foot movements during a motor screening task were provided real-time feedback to control a cursor on a screen. Power from 70-110 Hz, estimated using an autoregressive model, in one or more feedback channel(s) was used to control a cursor on a screen in one-dimension similar to previous ECoG studies[1] (Figure 1).

Results: Eighteen subjects established successful control of overt motor BCI, but only ten were able to control imagery BCI with accuracy above 80%. In successful imagery BCI, HFB power in the two target conditions separated into distinct sub-populations, which appear to engage unique subnetworks of the motor cortex compared to cued movement alone (Figure 2).

Conclusion: sEEG-based motor BCI utilizing overt movement and kinesthetic imagery is robust across all large cohort of patients and appears to selectively engage the motor network.

Acknowledgments and Disclosures: This work was supported by the NIH U01-NS128612 (KJM, GAW, PB).

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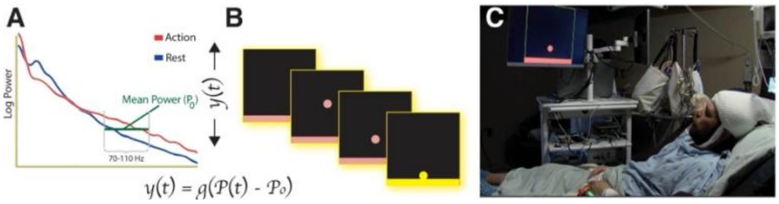

Figure 1. Schematic of online BCI feedback (A) Power from 70-110 Hz in the channel chosen in A determines the direction and velocity of the cursor on screen. (B) Targets are displayed prior to cursors to cue movement or rest and subjects attempt to direct cursors toward the rectangular target. (C) Subjects perform the BCI within their bed viewing a monitor 80-100 cm from their head.

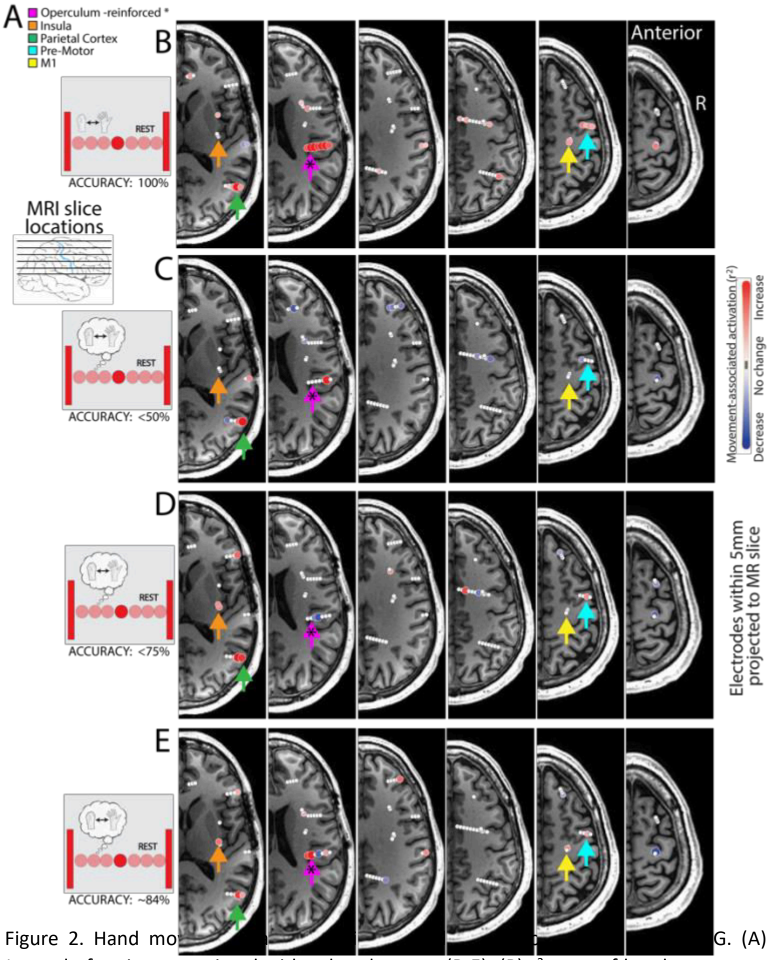

Figure 2. Hand mo G. (A) Legend of regions associated with colored arrows (B-E). (B) r^2 maps of hand movement vs rest (*No* feedback), broadband 65-115Hz power. (C-E) r^2 maps of imagined hand movement vs rest (*with* feedback), broadband 65-115Hz power. Each row represents increasing BCI control from chance (C) up to 84% (E).

Note reintroduction of feedback channel (*) activity once control Is > 80% (E) as well as the sharp drop off and gradual return of pre-motor activity as control in imagery BCI (C-E) control is established.

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Efficacy of Recalibration for a P300 Speller

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Introduction: Most P300 brain-computer interface (BCI) designs require calibration for an individual user to teach the BCI how to interpret the event-related potentials (ERP) in that user's brain activity [1]. Re-calibration can increase BCI accuracy and efficacy, however it is not clear how beneficial re-calibration may be over different periods of time. Users find re-calibration tedious, and the process takes 20-30 minutes. The time cost and tedium of calibration should be weighed against the benefit. Previous studies suggest that the time of day does not directly effect P300 ERPs, but other factors such as recent food intake do [2]. Our study was designed to compare calibrations taken on different days and at different times of day to inform recommend timeframes for recalibration.

Material and Methods: Participants were five people without physical impairments or previous experience with this BCI. Participants were two females, three males and had mean age of 45.8 years; range 26-61. There were six sessions (about one per week): one 8-hour session followed by five 2-hour sessions. Each 2-hour interval, starting on an even hour, was called a time-slot and included calibration, copying sentences with corrections, and typing novel text describing a picture, creating the test data for each time-slot (average 60.5 selections, range 31 to 116). Participants wore a 7-channel dry electrode VR300 headset (300 Hz, re-referenced to linked ears) from Wearable Sensing. A custom BCI2000 module interfaced with PRC-Saltillo augmentative and alternative communication (AAC) NuVoice software using Microsoft User Interface Automation standards to identify active keys, create stimuli over them, and activate the key selected by the user [3]. A Mann-Whitney test was conducted to evaluate if there was a significant difference in character-level accuracy between using the most recent calibration and previous calibrations, both at the individual participant level and at the group level.

Results: Recalibration showed a statistically significant improvement in character-level accuracy at the group level ($p < 0.001$). Mean improvement at the group level was 7.65 percentage points (%), ranging from -0.83% to 31.5% for individual participants. For four of five participants, recalibration produced a statistically significant improvement in accuracy ($p < 0.005$). However, for the other participant, recalibration did not produce a significant effect (mean -0.83%, range -15.5% to 22.7%). Fig. 1 shows offline analysis of how two participants' calibrations interpreted their data collected at different times and/or sessions.

Conclusion: Recalibration usually improves accuracy. However, the magnitude of improvement may not be worth the time, especially for users who already have a high accuracy. Further analysis will determine if time of day has an effect on recalibration. Future analyses will test how to predict the efficacy of recalibration and if small amounts of data can be used to select an effective prior calibration.

Acknowledgments and Disclosures: No conflicts of interest. Supported by PRC-Saltillo through National Institutes of Health grant SB1DC015142 from the National Institute of Deafness and other Communication Disorders.

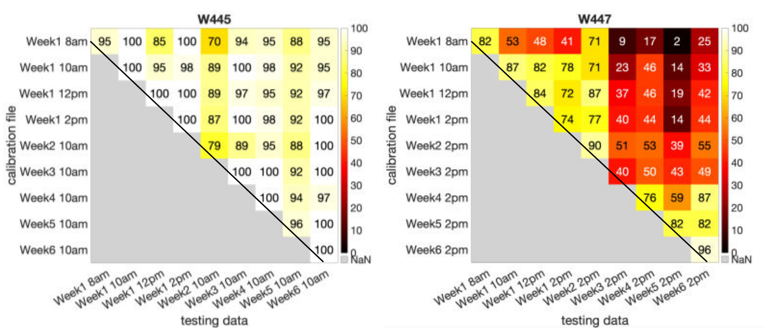

Figure 1: Heat maps show accuracy for the participants who had the median (left) and most (right) improvement with recalibration. The calibration (y-axis) for each time-slot was tested on that participant's test data for each time-slot (x-axis). Time is arranged from top-to-bottom for calibrations and left-to-right for test data. The diagonal line marks calibrations and test data for the same day and time. Lighter colors indicate better accuracy. The first four rows/columns show different time slots in session 1.

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Unlocking Neural Patterns: A Graph Neural Network Model to Classify and Analyze EEG Connectivity in Parkinson's Disease

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[3]*Children's National Hospital, Washington, DC, USA*

***Introduction**:* Recent advances in brain-computer interfaces (BCIs) have shown their potential for diagnosing and rehabilitating Parkinson's disease (PD) patients by promoting neuroplasticity [1]. These results support the development of personalized therapeutic interventions through techniques like motor imagery-based BCIs, enabling rehabilitation by recording electroencephalographic (EEG) signals during imagined movements. Unfortunately, traditional methods of analyzing EEG signals struggle to capture the complex neural patterns associated with PD [2]. Geometric deep learning network approaches such as graph neural networks (GNNs) have been used to express non-Euclidian spaces representing how information flows between brain regions observed by EEG electrodes [3].

***Material, Methods, and Results**:* We developed a deep learning pipeline using graph neural networks to classify the brain signals as PD or healthy. Data were collected from 15 PD patients and 14 healthy subjects using a 128-channel EEG system. They were instructed to visually imagine walking on a straight pathway and crossing a hurdle. EEG data was preprocessed and transformed into graph representations - each node represented an EEG electrode, and edges represented connections between electrodes. We split the dataset into training and test sets and trained our model with a two-layer graph convolutional network (GCN). Then, we performed hyperparameter optimization using Optuna and extracted weights from the first and second convolutional layers. The strength of each neural pathway was calculated by summing the absolute values of the weights for each electrode pair. The proposed GNN model achieved a mean test accuracy score of 83% in classifying EEG signals. The model demonstrated a mean precision of 0.88, a mean recall of 0.76, and a mean F1 score of 0.79. Figure 1 shows the connections between EEG electrodes critical for the model to make accurate predictions: the connection between the frontal midline electrode (Fz) and the right occipital electrode (O2) showed the highest importance for the model.

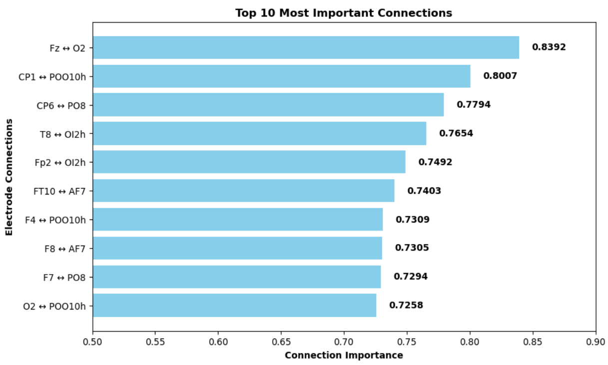

Fig 1. Connections between brain regions identified by our model as critical for classifying Parkinson's Disease during motor imagery.

***Conclusion**:* This study demonstrates the potential of using GNNs to identify PD patients using EEG signals recorded during motor imagery tasks. Finding specialized populations such as those with PD is a limiting factor for training conventional large-scale models because of the lack of a large quantity of high-quality data. Our model performed to a high degree of accuracy after training on only 29 patients. Our findings suggest that connectivity between the occipital and parietal lobes may play a more prominent role in motor imagery affected by PD than was previously known [4], [5]. Our work could help develop BCIs with improved diagnostic capabilities, reduced response times, and enable personalized therapeutic interventions. In particular, this deep learning model framework could help develop tools to support the rehabilitation of PD patients by identifying regions in real time that may be implicated in motor control with a high degree of accuracy.

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Simulated online typing performance in a cBCI using different language models

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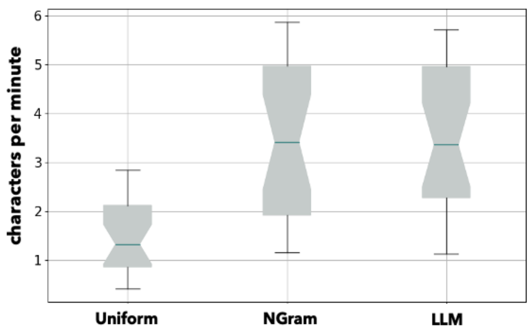
***Introduction*:** Communication Brain-Computer Interfaces (cBCIs) represent a crucial technological advancement for individuals with severe motor disabilities as they offer a direct pathway to express their thoughts and needs without physical movement. These systems commonly leverage the P300 ERP, a distinct neural response approximately 300–500ms after a novel stimulus. Language modeling presents a promising approach to enhancing the performance and usability of cBCIs. However, integrating language models with cBCI systems presents unique challenges, including balancing model complexity with real-time processing requirements and optimizing system performance parameters. This study utilizes simulations of online cBCI data to investigate the impact of different language models on typing rate and accuracy.

Figure 1: Simulated typing rate by language model.



***Methods, Materials, and Results*:** Twenty-four participants (22-49 years of age) were recruited for a cBCI study on mental effort conducted at Oregon Health & Science University (IRB #27415). The experiment consisted of participants writing using two interfaces using BciPy **[1]**: Rapid Serial Visual Presentation (RSVP) and Matrix presentation. Each presentation included a calibration phase followed by three tasks where participants spelled words. EEG data were collected at 300 Hz using the DSI-VR-300 (Wearable Sensing). Date were filtered using the default settings in BciPy: second order, 1–20Hz bandpass filter, 60Hz notch filter, and downsampling of two. The default signal model and settings (PcaRdaKde) were also used. Three conditions were compared: (I) UNIFORM: a baseline language model that assumes an equal probability for all characters; (II) NGRAM: a 12-gram statistical language model trained on conversational sentences; and (III) LLM: a 350M parameter version of the OPT large language model (LLM) that was fine-tuned on conversational sentences **[2]**. The effectiveness of each language model was evaluated using twelve phrases of varying complexity (six easy and six hard) from a previous study **[3]**. The average phrase length was 13 ± 4.7 characters. The copy phrase task implemented several thresholds for character selection: a maximum selection number of two times the phrase length, a maximum of eight inquiries per letter selection, and a decision threshold of 0.80. The backspace action was always presented and we used a starting backspace probability of 0.03. For each phrase and language model combination, the simulator performed 25 independent iterations using randomly sampled trial data from the earlier collected copy spelling tasks. The results were averaged across phrases and simulation runs for each participant using the three tested language models. Simulated typing rate was measured in characters per minute. The typing accuracy was calculated using the character distance between the final typed sentence and the reference phrase. The means between language models were compared using two-tailed t-tests with 10,000 permutations with statistical significance set at $p < 0.05$. As demonstrated in Figure 1, the NGRAM (M=3.5, SD=1.5) and LLM (M=3.5, SD=1.5) conditions significantly improved typing rate ($t(23) = -5.7$, $p < 0.0001$) when compared to UNIFORM (M=1.5, SD=0.8). However, there were no differences in simulated typing accuracy when compared to UNIFORM ($p > 0.5$) with the average accuracy being 83% for all conditions. There were no significant differences between the NGRAM and LLM conditions.

***Conclusion*:** These results show that integrating language modeling into a cBCI may benefit end-users by significantly increasing communication rate without compromising accuracy. The uniform condition, which had comparable accuracy to the more complex language models, did so by acquiring evidence more gradually. Further analyses of typed text across simulations and difficulty of phrases may yield more insights into language model performance in diverse contexts. These simulations demonstrated that language model integration could lead to a more efficient communication system for individuals dependent on this technology.

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An implantable brain-spine interface restoring lower limb movements in a patient with motor complete spinal cord injury

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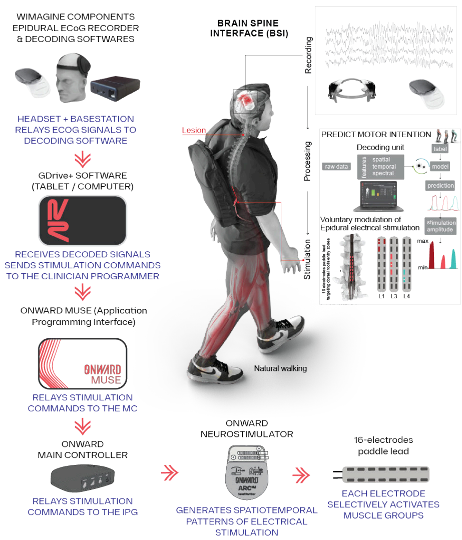
Introduction: A spinal cord injury (SCI) interrupts the communication between the brain and the spinal cord, resulting in sensory, autonomic and motor deficits below the level of the lesion. Applying electrical epidural stimulation (EES) over the lumbosacral region of the spinal cord can reactivate the dormant, yet functional, motor neurons that control lower limb muscles and produce walking. In order to restore voluntary motor control, EES should be controlled by the motor intentions of the patients.

Material, Methods and Results: Here we designed a clinical trial (Think2Go, NCT0624395) to evaluate the effectiveness of an implantable digital bridge (BSI) between the motor intentions recorded at the level of the motor cortex and EES to restore voluntary motor control after complete paralysis. The system is composed of one WIMAGINE® device (64 ECoG electrodes) implanted over the leg sensorimotor cortex to decode motor intentions, connected to the purpose-built ARC^{IM} Lumbar System (Onward medical) delivering EES. The system was implanted in one participant with severe chronic SCI (AIS-A, 39 y.o. female, 6 years post-injury). Raw brain signals were wirelessly streamed and decoded in real-time through classification algorithms, which generated online predictions of motor intentions. We are able to decode motor attempts of different lower limb joints with high accuracy. These intentions were translated into electrical stimulation commands that were wirelessly delivered to the neurostimulator targeting the dorsal roots of the spinal cord.



Conclusion: Within the first 3 days of use after implantation, we were able to calibrate a 3-states decoding model and connect it to primitive movements elicited through EES stimulation, producing brain-controlled stepping with assistance. Subsequently, we could decode up to 6 different movement intentions and link them to specific stimulation programs with high accuracy. The participant used the system during 4 months of rehabilitation including walking, single joint movements and standing exercises. The comparison of motor control performance between BSI^{ON} and BSI^{OFF} conditions, in different clinical tests and with various levels of assistance, demonstrates the effectiveness of the designed system as an implantable brain-spine interface for restoration of voluntary lower limb movements after complete motor paralysis.

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Optimizing Imagined Speech Decoders: A Comprehensive Study on Intra-Subject Classification

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Introduction: Imagined Speech (IS) refers to the mental pronunciation of words without emitting audible sounds. This task would allow the development of Brain-Computer Interfaces (BCIs) to facilitate communication for impaired people. Although deep learning (DL) algorithms have achieved promising classification rates in other neuroparadigms; their large data requirements, high computational demands, and training times limit their adoption in BCI-based IS, especially when multiclass IS tasks are involved.

Methods and Results: In this work, we analyzed the 2020 International BCI Competition dataset (Track #3) composed of 64-channel EEG signals from 15 participants imagining three words ("hello," "yes," "stop") and two phrases ("help me," "thank you") relevant for basic communication. Three preprocessing techniques were analyzed: bandpass filtering (0.1–45 Hz), detrending, common average referencing (CAR), and wavelet-based automatic tunable artifact rejection (ATAR), alongside 6 feature extraction techniques: statistical features, fractal dimension, discrete and continuous wavelet transforms (DWT, CWT), wavelet scattering transform (WST), and empirical mode decomposition-fractal (EMD-Fractal). Also, three classifiers (KNN, SVM and Random Forest (RF)) were evaluated in an intra-subject approach.

Statistical analysis identified CAR as the optimal preprocessing technique along with RF classifier. Three feature extraction techniques demonstrated comparable performance for IS classification, namely Fractal (58.0 ± 9.7%), WST (using KNN, 64.7 ± 13.0%), and EMD-Fractal (62.5 ± 11.2%) (See Fig. 1). Bayesian Optimization improved accuracy for 6 of 15 subjects, with average accuracies of 60.0 ± 10.3% (Fractal-RF) and 64.1 ± 8.4% (EMD-Fractal-RF). The proposed method achieves results similar to those reported in [1, 2], which used DL techniques with the drawbacks mentioned above. In contrast, the proposed methodology demonstrates training efficiency, with the best classifier (EMD-Fractal) requiring less than 1.5 minutes to train.

Conclusion: In this study, EMD-Fractal features which measure the complexity of EEG signals, were found to be important for IS decoding. Further, this study provides a comprehensive evaluation of different preprocessing, feature extraction, and classification techniques, resulting in a time efficient methodology for IS classification.

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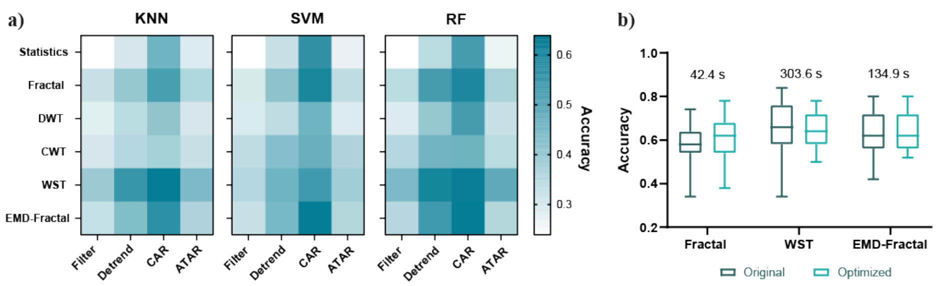

Figure 1: *a) Heatmaps show the average classification accuracy for each pipeline configuration (accuracy values are normalized from 0 to 1). b) Comparison of average accuracy for the best-performing pipelines before and after Bayesian optimization. All pipelines use CAR and RF, except WST Original, which uses KNN. Average training times (in seconds) are displayed above the boxplots.*

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Brain-Computer Interface Communication Application for Children with Diverse Learning Needs

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Introduction: The purposeful uses of communication include exclaiming, protesting, describing, and requesting, amongst others. Successfully communicating these intents is difficult, if not impossible, for children and adolescents with neurodiversity or neurodevelopmental conditions, such as cerebral palsy, genetic disorders, or Rett syndrome. This submission reports on an electroencephalography-based Brain-Computer Interface (EEG-based BCI) communication application delivered to children and adolescents with diverse learning needs using a Visual P300 event-related potential (ERP) oddball paradigm.

Materials: We used a research grade, seven-sensor dry electrode EEG system, the DSI-7 Flex (Wearable Sensing, San Diego, USA) in conjunction with a dedicated BCI communication software application built with Unity (Unity Software Inc., San Francisco, USA), and processed using an open-source, cross-platform toolbox called *BCI-Essentials* (Figure 1).

Methods: Our study used a within-participant pretest–posttest design with single baseline and control behaviors within an iterative testing approach. A four-week, 15 session intervention, applying the validated communication procedure, *The System for Augmenting Language* [1] was delivered within the contextually authentic school environment. Students learned to communicate a 'request' by visually focusing on the image that represented their desired choice. In each session, a Riemannian geometry classifier was trained on one of three or four objects available for students' selection, followed by online testing during which the software 'spoke' the estimated selection. A paired-samples t-test was conducted to determine the effect of the intervention on purposeful communication using BCI. We conducted offline analyses of the EEG data to inspect signal quality and consistency of the P300 signal.

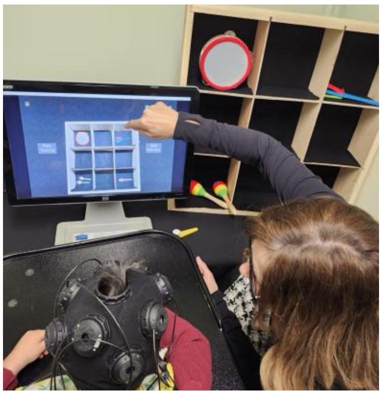

Figure 1. BCI Communication Application

Results: Trials are ongoing. Three trials of two participants each ($n = 6$; 4 girls, 2 boys; 6 - 13 years of age) are complete. Students' behavioral 'look to request' scores before intervention (M = 6.8; SD = 11.1) and after intervention (M = 15.8; SD = 16) indicated a significant average increase in visual focus to request an object [$t(5) = -2.9$, $p = 0.031$]. Offline analyses of the EEG revealed instances of P300 evoked potentials for each participant. However, the majority of trials contained no discernable P300, which we hypothesize were highly detrimental for training the classifier, leading to ineffective classification.

Conclusion: Our BCI communication application demonstrates early feasibility of teaching a purposeful communication behavior in a way that is accessible and engaging for students with complex learning needs. We continue to iterate and improve the BCI signal processing and classification systems to more reliably build a performant classifier based on the EEG signals from our diverse population.

Acknowledgments and Disclosures: This research is supported by the University of Calgary, Cumming School of Medicine, Transdisciplinary Connector Grant, and The Alberta Children's Hospital Foundation. We are grateful for the support of all the families and educators who cheerfully participated in this research.

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Decoding hierarchical elements of language from speech motor cortex to restore communication for people with ALS

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***Introduction**:* One of the most disabling symptoms of ALS is loss of communication. For people with dysarthria and loss of dexterous control of hand movement, commercially available augmentative and alternative communication devices can be used to maintain communication. However, these devices are often slow, error prone, and require frequent caregiver interaction, limiting their utility. Recently, intracortical brain computer interfaces (iBCIs) have been used to decode the neural correlates of intended speech, allowing users with speech-motor paralysis to communicate by attempting to talk [1, 2]. These systems work by identifying the phonemic components of intended speech based on neural activity recorded from speech motor cortex; however, they lack robustness for sub-optimal signal-to-noise ratio. Information pertaining to higher-order components of language, such as intended semantic content or sentence syntax, could be used to improve the speed and accuracy of speech decoding. It is unknown, however, which, if any, higher-order elements of language are encoded within speech motor cortex.

Methods and Results: In this work, we examine the cortical representation of linguistic information beyond the phoneme level, and characterize how this hierarchical linguistic information is encoded within speech motor cortex in two participants in the ongoing BrainGate clinical trial, both with ALS: participant T17, a 33-year-old man with quadriplegia, anarthria, and ventilator-dependence due to the advanced symptoms of ALS, implanted with six 64-channel microelectrode arrays in the dominant precentral gyrus, including four in the speech motor cortex (Brodmann areas 6v and 55b), and participant T15, a 45-year-old man with ALS, with tetraparesis and severe dysarthria, implanted with four microelectrode arrays in his left ventral precentral gyrus. To investigate the encoding of semantically and syntactically different stimuli in the neuronal activity within these areas, we asked the participants to attempt to speak one of four different types of visually-presented text [3]: (1) grammatically correct sentences, (2) agrammatic lists of words, (3) grammatically structured sentences with gibberish content words, or (4) agrammatic lists of gibberish words. Interestingly, our results show distinct, participant-dependent roles for areas 6v and 55b. Within area 6v, we find for both participants reliable decoding of phonemes that appears minimally modulated by sentence structure. In contrast, within area 55b, we observe a different behavior for the two participants: while for T15 area 55b shows similar characteristics to area 6v, for T17 we find strong encoding for the text category but minimal phonemic information. These results suggest that the area identified as 55b indeed encodes higher-order elements of intended language, however to different degrees for different participants.

Conclusion: Combining the data from the two participants, we show evidence for sentence-level representations in these motor cortex areas and suggest how this neuronal information can be used for improving the performance of iBCI speech neuroprostheses.

***Acknowledgments and Support**:* We thank T17, T15 and their families and carepartners for the time and effort they contributed to the BG2 trial. This work was supported by Office of Research and Development, Rehabilitation R&D Service, Department of Veterans Affairs (N2864C, A4820R, A2295R); NIH NIDCD (U01DC017844, R01DC014034, U01DC019430, K23DC021297, 1DP2DC021055); NIH NINDS (R25NS065743), AHA (23SCEFIA1156586); CDMRP (HT94252310153), Brown University Provost's STEM Postdoctoral Fellowship to S. Haro; A.P. Giannini Postdoctoral Fellowship to N. Card.

***Disclosures**:* CAUTION: Investigational Device. Limited by Federal Law to Investigational Use. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health, or the Department of Veterans Affairs, or the United States Government. The MGH Translational Research Center has a clinical research support agreement (CRSA) with Axoft, Neuralink, Neurobionics, Precision Neuro, Synchron, and Reach Neuro, for which LRH and SSC provide consultative input. LRH is a co-investigator on an NIH SBIR grant with Paradromics, and is a non-compensated member of the Board of Directors of a nonprofit assistive communication device technology foundation (Speak Your Mind Foundation). Mass General Brigham (MGB) is convening the Implantable Brain-Computer Interface Collaborative Community (iBCI-CC); charitable gift agreements to MGB, including those received to date from Paradromics, Synchron, Precision Neuro, Neuralink, and Blackrock Neurotech, support the iBCI-CC, for which LRH provides effort. Stavisky is an inventor on intellectual property owned by Stanford University that has been licensed to Blackrock Neurotech and Neuralink Corp. Wairagkar, Stavisky, and Brandman have patent applications related to speech BCI owned by the Regents of the University of California. Stavisky is an advisor to Sonera. Brandman is a surgical consultant to Paradromics Inc.

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Integrating BCI, FES, and social media for Rehabilitation of Upper Extremity Motor Function in Youth

Anna Bourgeois, Meghan Maiani, Araz Minhas, Brian Irvine, Ion Robu, Payton Shaw, Dejana Nikitovic, Zeanna Jadavji, Gregory Wilding, Nathan Brand, Mateo Ambrogiano, Emily Schrag, Nicole Romanow, Adam Kirton, Eli Kinney-Lang

Introduction:

Perinatal stroke can lead to lifelong physical disabilities, but even small improvements in function can significantly increase quality of life. There is a window of opportunity after perinatal stroke to harness brain plasticity to improve outcomes.[1] However, current therapies are minimally effective, in part due to the boring, unengaging procedures required to achieve adequate repetitions that are not suited to children.[1] The combination of functional electrical stimulation and brain computer interface (FES/BCI) has been shown to be effective for adults with stroke[2] and hemiparesis and appears feasible in children.[3] We designed a novel FES/BCI system that uses social media to better engage youth, called "FlickTok".

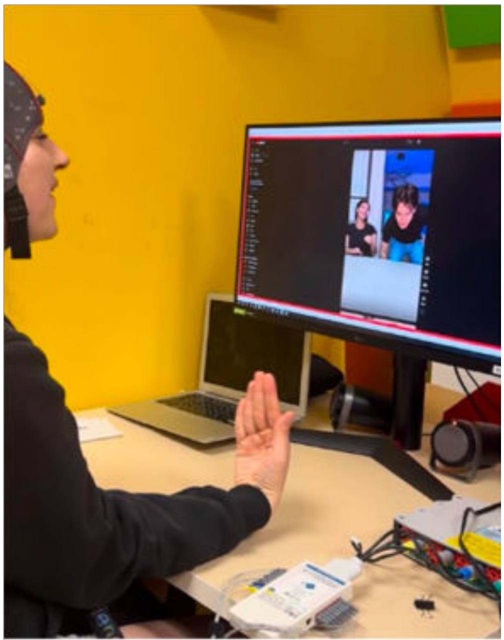

Figure 1. Patient Partner using Flick Tok app

Methods and Results:

The research protocol was informed through engagement with three youth patient partners with lived experience who developed and tested FlickTok. Each participant is fitted with a 16 channel EEG gel headset. The BCI training consists of 20 trials of attempted movement and rest which is then classified using a binary Riemannian Geometry based motor imagery classifier. After training is complete, participants can independently swipe through videos that are coordinated with FES. Data collected includes Cohen's Kappa and motor assessments of passive and active range of motion and the box and blocks (BB) test. Participants complete qualitative interviews to obtain enjoyability metrics to further improve the system. To date, 7 participants have completed at least one session. Early results indicate technical feasibility and increased enjoyability. Initial qualitative interviews have explored functional improvements and methodological changes that should be implemented in future studies. The BB assessment improved by 29% and 45% respectively after 3 sessions of FlickTok in 2 participants.

Conclusion:

Informed by users, simple EEG-based BCI can be integrated with FES and social media to perform upper extremity rehabilitation in youth with hemiparesis. This pilot trial will inform the design of future clinical trials required to evaluate efficacy.

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Perceptogram: Reconstructing Visual Percepts from EEG

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Introduction: Visual perception is an important aspect of human cognition and a gateway to understanding more complex cognitive processes such as visual mental imagery and dream visualization. EEG has spatial resolution limited by volume conduction which has resulted in its underuse in decoding visual representation. In this work, we reconstruct viewed images from EEG recordings with state-of-the-art quantitative reconstruction performance using a linear decoder that maps the EEG to image latents.

Material, Methods and Results: We used the preprocessed version of THINGS-EEG2 dataset [1]. In the experiment, each image is presented for 100ms followed by a blank screen for 100ms before the next image. The image presentation order is pseudo-randomized across the entire image set. All 10 subjects view the same 16740 images, of which the same 200 images are test images. Each training image is shown 4 times, and each test image is shown 80 times. The image reconstruction is a 2-stage process: the first stage maps the brain signal onto the latent space of a variational auto-encoder (VAE), which provides a rough visual representation. The second stage maps the same brain signal onto each token of the CLIP-Vision. The image generator ”unCLIP” [2] combines the CLIP and the encoded images from the VAE and produces the reconstructed images. The reconstructions often capture the semantic meanings as well as the visual features of the ground-truth images (see Fig. 1). The performance across subjects is relatively consistent with a small amount of variation.

Conclusion: We have demonstrated the surprising power of learned linear mappings to different latent spaces. When mapped to the CLIP and VAE latent spaces and reconstructed with unCLIP, realistic reconstructions are obtained that quantitatively and qualitatively outperform previous EEG reconstruction attempts, including those with much more sophisticated transformer-based decoding algorithms.

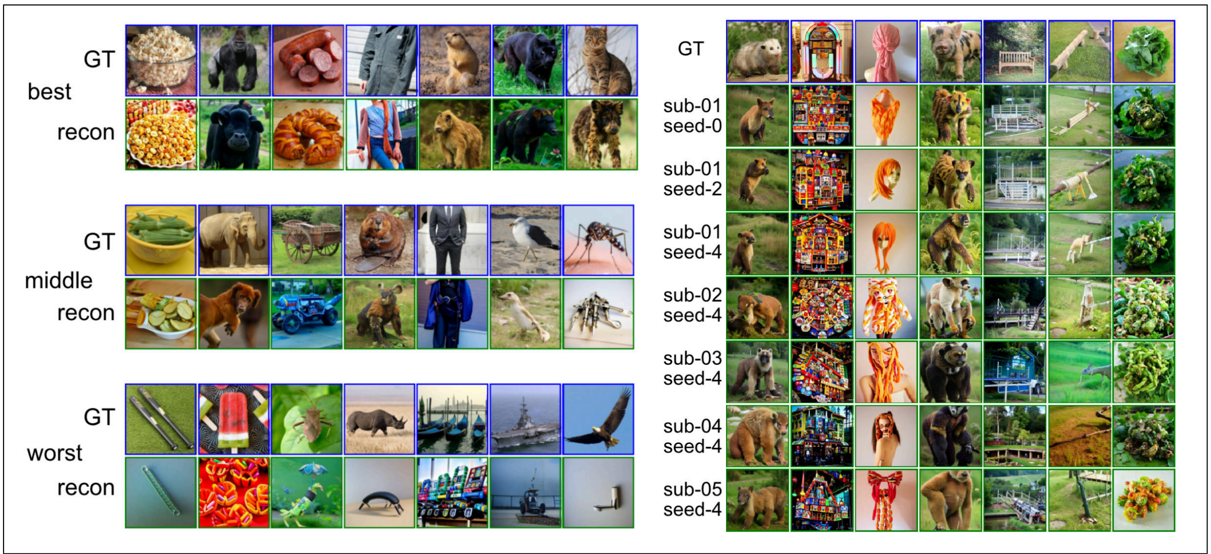

Figure 1: *Left: example reconstructions of viewed images using EEG recorded from the viewing participant. Examples of the best, middle, and worst reconstructions were selected by visual inspection from Subject 1. The rows labeled GT (ground truth) show the image that was shown to the participant. The rows labeled reconstructed (recon) show the image that was created by our system Examples are sampled from among the best (top) middle (middle) and worst (bottom) reconstructions observed. Right: Robust reconstructions across subjects and diffuser random seeds. Top Row: the ground-truth stimulus images; subsequent 3 rows: different random seeds for the same subject; Last 4 rows: robust reconstructions across subjects. This work was supported in part by UCSD Social Sciences grant, NSF IIS 1817226 and IIS 2208362.*

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A preliminary evaluation of a fully implantable speech BCI

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Introduction: Speech BCIs offer perspectives to restore natural communication in people with Locked-In Syndrome (LIS). Current speech BCI solutions have shown convincing demonstrations for intelligible speech reconstruction with either subdural ECoG [1] or intracortical Utah array [2] recordings over sensorimotor and premotor areas. Yet, these solutions still rely on implants that remain wired to external recording systems, creating risks of infection. Moreover, subdural ECoG and intracortical recordings have been shown to degrade over long periods of time. There is thus a critical need for speech BCI solutions relying on fully implantable wireless technologies offering stable signals over many years. In this context, we propose to use the epidural WIMAGINE implant [3], which has proven to have great recording stability over time [4], to build a chronic speech BCI. Here, we present a complete real-time speech BCI framework based on the fully implantable WIMAGINE technology and its preliminary tests in a patient able to speak and chronically implanted in the context of a clinical trial aiming at evaluating the WIMAGINE technology for the motor control of an exoskeleton [5] (NCT02550522).

Material, Methods and Results: Over the 64 implant electrodes covering the hand motor cortex, the 32 most ventral were used in order to be as close as possible to the dorsal laryngeal motor cortex [6]. In a first step, two open loop sessions were conducted during which the patient was asked to read aloud short French sentences and vowel sequences. The absence of acoustic contamination was verified [7]. This data was used to train a Vison Transformer (ViT) based decoder [8], which was then implemented in a real-time processing software developed in C++. This pipeline was then evaluated in subsequent online closed-loop sessions with the same patient in either a sentence-by-sentence or a frame-by-frame speech decoding paradigm.

Conclusion: A complete real-time closed-loop speech BCI framework has been developed for further evaluation in Locked-In individuals chronically implanted with the epidural WIMAGINE technology.

Acknowledgments and Disclosures: We thank participant CLIN1 for his cooperation. This work was supported by the FRM Foundation with the PhD grant ECO202206015553 of GS, and the French National Research Agency (www.anr.fr) for grants No. ANR-20-CE45-0005 (BrainNet project) and framework of the "Investissements d'avenir" program (ANR-15-IDEX-02).

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A stabilization approach to improve decoding performance using non-linear dynamical models

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Introduction: One of the key challenges in developing Brain-Computer Interfaces (BCIs) is the presence of noise in recorded neural signals. Such noise may result from the recording hardware or from fluctuations in the subject's internal state, both of which can occur independently of the intended motor command. To address this issue, we propose leveraging accurate predictions from nonlinear functional models of neuronal dynamics to extract a stabilized control signal for the interface.

Material, Methods and Results: This study was conducted using recordings from the primary motor cortex of non-human primates performing an 8×8 reaching task with simultaneous measurements of kinematic signals (finger position) and neural activity [1]. To infer the neuronal dynamics, we employed a shallow Piecewise Linear Recurrent Neural Network (sh-PLRNN) [2]. This architecture consists of two principal components: a latent model, which captures the temporal evolution of the underlying latent dynamical process $z(t)$, and an observational model, which captures how the latent representations affect the recorded neural activity $x(t)$.

Building on this framework, we introduced a stabilization approach aimed at reducing noise in the recorded neural data. As illustrated in Fig.*1A*, we use the inferred nonlinear sh-PLRNN model to generate multiple predictions of the latent state $z(t)$ based on the neuronal activity x recorded in a time window between $t - T$ and $t - 1$. While these predictions estimate the latent state at the same time t, each is influenced by independent noise realizations, and can be combined to obtain a signal with lower noise variance.

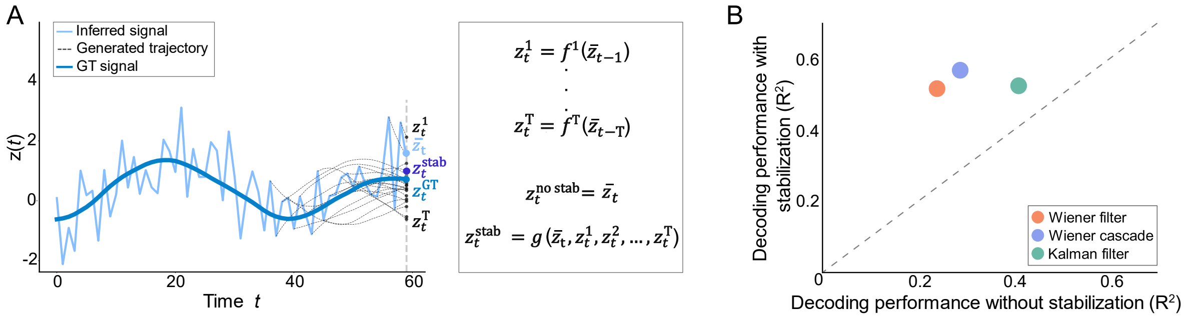

Figure 1: ***Stabilization approach for BCI:*** *(A) Schematic representation of the stabilization rationale. At each time t, the latent neural state z_t can be inferred directly from the recorded activity x_t, as $\bar{z}_t$ (in light blue), as well as from the past recordings $x_{t-\tau}$ through the inferred latent dynamics map f, as $z_t^\tau = f^\tau(\bar{z}_{t-\tau})$ (in black). By combining predictions from multiple past steps, $\tau = 0 \dots T$, we can then derive an estimate of the ongoing neuronal state z_t^{stab} which better approximates the ground truth state z_t (blue) than $\bar{z}_t$. (B) Decoding results. Scatter plot comparing decoding performances with or without stabilization for three types of decoders.*

To test the general applicability of this approach, we employed here three different decoders to estimate from the latent state $z(t)$ the monkey finger's position: the Wiener filter, the Wiener cascade, and the Kalman filter (Fig.*1B*). Our results show that the proposed stabilization approach improves decoding accuracy. This method provides a scalable solution for stabilizing noisy recordings, thus favoring a more precise and stable BCI control.

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Temporally Interfering electrical stimulation reduce interictal epileptiform discharges in rats

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Introduction: Epilepsy is one of the most common brain disorders[1], neurostimulation techniques such as deep brain stimulation (DBS) and vagus nerve stimulation (VNS) offer a new opportunity for patients with drug-resistant epilepsy who are unable to undergo surgery[2].However, these two treatment methods have disadvantages such as being invasive, having a high risk of operation, and being prone to infection. In contrast, Temporally Interfering electrical stimulation can take into account non-invasiveness, focus, and stimulation depth[3].

Material, Methods and Results: Sprague-Dawley rats were stereotactically injected with kainite to induce an animal model of epilepsy.Epilepsy rats were treated with electrical stimulation using a TI stimulator (Tianjin LuBao Technology Co., Ltd.). The current parameter is f_1 1000Hz and f_2 1130Hz, sine waves, and the current intensity was 1mA. The cumulative time was 40min, and the stimulation was performed once a day at the same time for 2 weeks. Before and after the treatment, EEG signals were collected and recorded by the SynAmps2 system (Neuroscan, USA), and the characteristic indicators of epileptic biomarkers interictal epileptiform discharges (IED), including spike amplitude and slow wave area, were analysed and compared before and after the treatment. The experimental results showed that non-invasive transcranial magnetic stimulation of the hippocampus of rats at a frequency of 130 Hz can reduce the characteristic indicators of epileptic biomarkers IED, such as spike amplitude and slow wave area, thereby improving the severity of seizures in rats(Fig. 1).

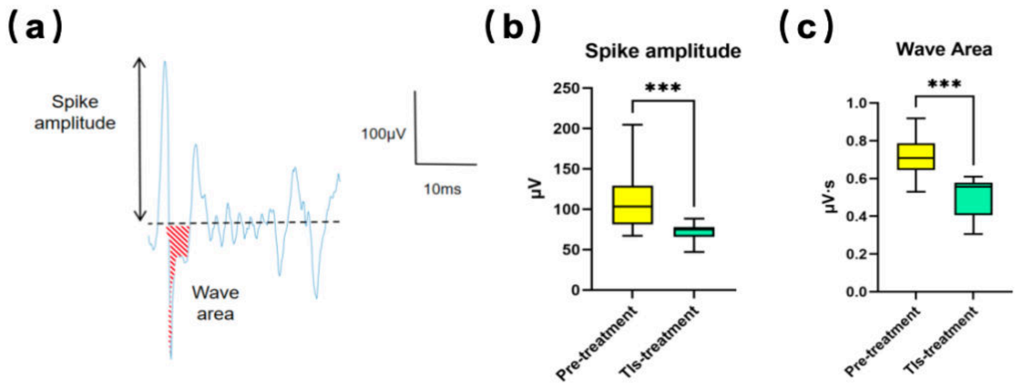

Figure 1: （a）*IED characteristic indicators: spike amplitude, slow-wave area*；（b）*IED spike amplitude*；（c）*slow-wave area*

Conclusion: This study proves that the use of non-invasive transcranial electrical stimulation can improve the severity of seizures in rats by regulating hippocampal neurons, providing important experimental evidence for the application of non-invasive transcranial electrical stimulation in epilepsy treatment.

*Acknowledgments and Disclosures:*This research was supported by the National Key Research and Develop-ment Program of China (2023YFF1203700).

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Preliminary Evaluation of the Safety of Single-Parameter Ultrasound Stimulation on the Visual Cortex in Rats

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Introduction: With the rapid development of Brain-Computer Interface (BCI) technology, ultrasound has emerged as a promising tool with significant potential for non-invasive applications[1]. However, a clear consensus on the safety parameters and evaluation protocols for ultrasound-based brain stimulation is still lacking, and existing data are insufficient to establish comprehensive guidelines[2，3]. This study investigates the safety of ultrasound stimulation on the visual cortex of rats under specific parameters, providing a multidimensional evaluation across three key aspects: blood-brain barrier integrity, histological analysis, and electrophysiological signal assessment.

Material, Methods and Results: This study used 12 male Wistar rats (260–300 g) and applied a 1 MHz focused ultrasound transducer to stimulate the left visual cortex. Stimulation parameters were: pulse repetition frequency (PRF)=1000 Hz, tone burst duration (TBD)=10μs, spatial peak pulse average intensity(I_{sppa})=3.15 W/cm², spatial peak temporal average intensity(I_{spta})=3.15 mW/cm², mechanical index (MI)=0.12, sound pressure=1.57 MPa, and a single stimulation duration of 60 seconds. Blood-brain barrier integrity was assessed using Evans blue dye injection, histological damage was evaluated with hematoxylin and eosin (H&E) staining, and steady-state visual evoked potentials (SSVEP) were analyzed with electrodes combined with LED. H&E staining and blood-brain barrier verification results are shown in Fig. 1. Results showed no blood-brain barrier disruption or tissue damage. SSVEP analysis indicated that ultrasound exposure did not alter the rats' steady-state responses to specific frequency visual stimuli.

Conclusion: This study demonstrates the safety of focused ultrasound stimulation on the visual cortex under specific parameters. A multidimensional assessment of the safety of ultrasound stimulation provides valuable data supporting the development of non-invasive BCI technologies.This foundation also provides insights for further optimization of parameter design and establishing standardized safety assessment protocols.

Acknowledgments and Disclosures: This research was supported by the National Natural Science Foundation of China (No. 62276183, 81925020, 81630051).

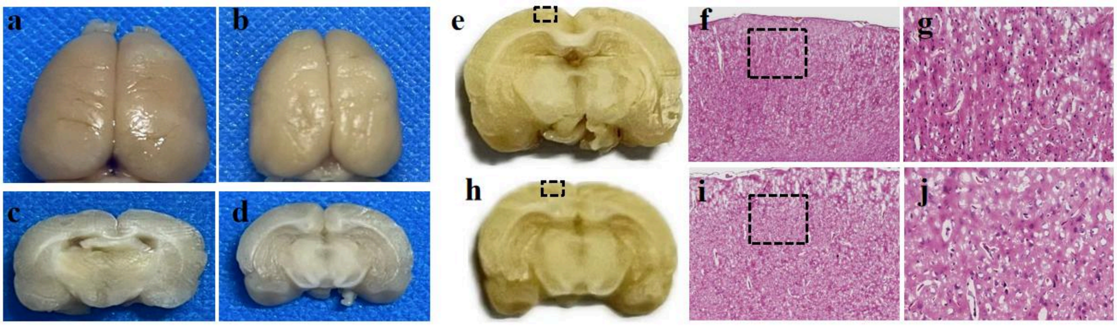

Figure 1: **a-b**: Evans blue dye extravasation for control and experimental groups; **c-d**:Coronal sections of brain tissues. **e–j:** Results of H&E staining; original magnification ×10 (f,i), ×40 (g,j). Black boxes represent the area depicted in the following panel.

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TMS-based neurofeedback facilitates motor imagery of different hand actions

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Introduction: Non-invasive brain-computer interfaces (BCIs) enable users to modulate brain activity in a goal-directed manner. Most non-invasive BCIs can decode only gross movements but many daily tasks require finer finger and hand control. We developed a novel BCI using motor imagery (MI) and transcranial magnetic stimulation (TMS)-based neurofeedback (NF) training to reinforce representations of complex hand actions in the brain. This proof-of-concept study investigates the utility of this BCI for training hand function via MI.

Material, Methods and Results: 12 participants (6 males, age 32.0 ± 2.7 years) completed 4 (1 motor execution and 3 motor imagery (MI)) sessions of TMS-based NF training on 3 right-hand actions (holding a bottle, turning a key, and opening the hand). There were 4 blocks in each session. The MI sessions comprised 1 no NF and 3 NF blocks but Session 4 had an additional no NF block as ending. During the training, a personalized, adaptive support vector machine (SVM) ensemble was used to classify coming MI trials and provide NF accordingly. An SVM classifier with leave-one trial-out cross-validation was used to derive block-wise average classification accuracy as an outcome measure to assess the training effect. We used a linear mixed-effect model with MI without NF data and noted that the accuracy of the final block (60.5%) showed nearly significant improvement compared to the first block (53.3%; $\beta = 0.091$, $t_{33} = 1.974$, $p = 0.057$; Figure 1). We used another linear mixed-effect model with MI+NF data to evaluate the learning effect and found that Session 3 accuracy (59.3%) was significantly higher than Session 2 (53.3%, $\beta = -0.080$, $t_{88} = -3.208$, $p = 0.006$) and Session 4 accuracy (58.2%) was marginally significantly higher than Session 2 ($\beta = -0.060$, $t_{88} = -2.421$, $p = 0.053$).

Conclusion: We developed and tested a novel, personalized, and adaptive MI and TMS-based BCI for complex hand actions. Our findings suggest that healthy adults could modulate brain activities for complex hand actions with the guidance of NF. This demonstrates that TMS-based BCI could be used for hand function training in individuals who are unable to produce overt motor output.

Acknowledgments and Disclosures: We would like to thank all participants for their participation in this study. The research was conducted at the Future Health Technologies at the Singapore-ETH Centre, which was established collaboratively between ETH Zurich and the National Research Foundation Singapore. This research is supported by the National Research Foundation Singapore (NRF) under its Campus for Research Excellence and Technological Enterprise (CREATE) programme. The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

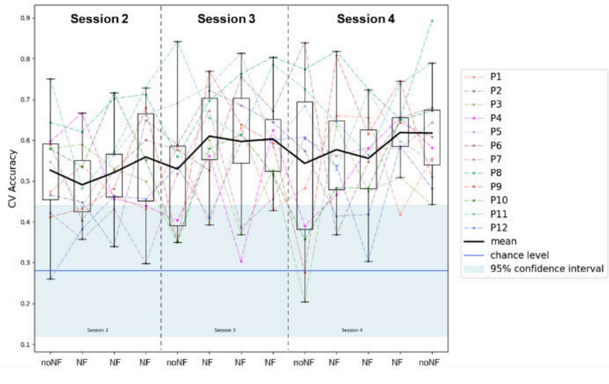

Figure 1: *Average cross-validation (CV) accuracy of all MI blocks. Overall, the CV accuracy increased with the training, indicating that participants could benefit from NF and retain the learning without NF immediately after the training as seen in Session 4.*

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A Brain-Computer Interface Approach to Music and Sound Generation

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Introduction: EEG-based BCI cannot directly provide the required bitrate to play music. However, digital instruments implement features that allow musicians to interact with them with minimal inputs and even generate entire phrases with different styles while requiring a low bandwidth.

Material, Methods and Results: MIDI (Musical Instrument Digital Interface) is a communication protocol that allows electronic musical instruments, computers, and other devices to connect and control each other. It transmits performance data—such as which notes are played, their intensity, timing, and modulation—rather than audio, enabling seamless interaction for music creation, playback, and production. A BCI software used to drive a videogame [1] was adapted to allow the output of MIDI messages.

Due to the low bandwidth provided by non-invasive BCIs, two classical paradigms were used:
1) mu-rhythm control, to deliver MIDI continuous and asynchronous control messages, such as Modulation Wheel, After Touch, Filter Cutoff, and resonance, allowing sound parameters to be modified during a performance. A preliminary calibration phase is required to acquire and compare relax epochs and motor imagery epochs. Differences in their power spectra are computed to train a regressor that will be used to deliver the selected MIDI messages and their corresponding values, which may vary in the range 0-127.

2) SSVEP, synchronized with the MIDI clock, to select notes, musical phrases, and samples or to program and drive a Drum Machine. A system with 16 flashing LEDs is employed. A single musical measure is divided into 8 eighth notes, each of which can be selected via a specific LED. The remaining 8 LEDs allow the selection of the drum instrument (kick, snare, hi-hat open and closed, and crash) to correct a mistake and to increase or decrease the speed of the pattern. This setup enables the selection of the instrument and its temporal placement within the measure, making it possible to construct a drum pattern (Fig. 1). Future implementations will allow the selection of pitched notes from the chromatic scale.

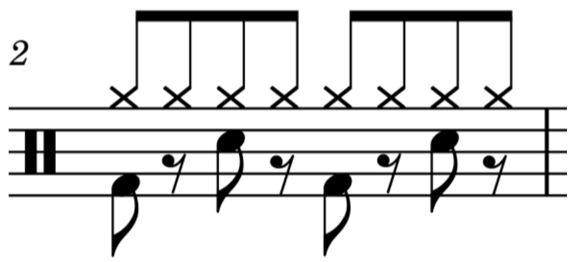

Figure 1: *A drum pattern generated with a BCI-based SSVEP paradigm*

Conclusion: Integrating EEG-based BCIs with MIDI protocols enables effective control of musical instruments with minimal input, overcoming the bandwidth limitations typically associated with non-invasive brain-computer interfaces. Using mu-rhythm control and SSVEP paradigms, musicians can manipulate various sound parameters and construct rhythmic patterns with high precision. These techniques provide a promising foundation for future developments in BCI-driven music performance, including the potential for more complex musical compositions and pitch-based note selection.

Acknowledgments and Disclosures: The authors declare that there is no conflict of interest regarding the publication of this article.

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Building a taxonomy of variability factors in active BCI

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Introduction: BCI performances are significantly affected by variabilities, both **inter- and intra-user** [1]. While there are advances in Machine Learning (ML) to deal with them, the understanding of the specific variability factors affecting BCI performance and EEG features remains limited. Thus, we are conducting a literature review to identify known variability factors and propose a taxonomy of them.

Methods: We conducted a literature review using the PubMed database, focusing on studies involving EEG-based active BCIs. The search query used was: ("Brain-Computer Interface" OR "BCI" OR "Brain Computer Interface") AND ("non-stationarit*" OR "non stationarit*" OR "nonstationarit*" OR "variabilit*") AND ("active" OR "mental tasks" OR "motor imagery" OR "spontaneous"). This search initially yielded 177 articles. We then excluded studies focusing on passive or reactive BCIs, those using a main neuroimaging method other than EEG, or those unrelated to the BCI domain, leaving 155 articles. Next, we classified the articles into four main categories: articles focusing on **"inter"** or **"intra"** user variability factors, those addressing **"both"**, and **"method"**—articles addressing ML methods to manage general inter- and/or intra-user variability without investigating its causes.

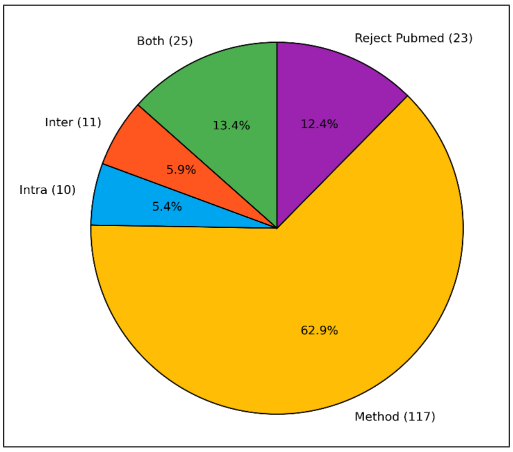

Figure 1: *Categorization of the 155 queried articles. 117 were classified under "Method" (yellow), 25 under "Both" (green), 11 under "Inter" (orange), 9 under "Intra" (blue), and 23 were rejected (purple). 8 papers were counted twice as they fall into two categories.*

Results: The majority of studies focuses on methods (62.9%) to manage variability, with limited attention to the factors causing it. Studies addressing inter-user variability constitute 5.9%, intra-user variability 5.4%, and both 13.4%, (see Fig. 1).

Discussion: This distribution stresses the need for more studies on the factors causing variability on BCI performance and EEG features, and on their effect. Inter- and intra-user variability factors can be broadly categorized as: **Experimental settings**: Experiment design or environment (e.g., electrodes position, task type, instructions, feedback, time of day, lab vs. home setting) [2]; **Individual traits**: User-specific demographic or cognitive characteristics (e.g., age, lifestyle habits, personality, attention span or visuo-motor coordination) [3]; **Structural Anatomy:** Anatomical attributes, such as gray matter density or cortical thickness [4]; **Physiological activity:** Non-neural signal (e.g., heart rate variability, muscular or ocular activity) [5]; **Psychological states:** Temporary mental or emotional states (e.g., mood, motivation, mental fatigue or frustration) [1]; **Neurophysiological activity:** Changes in brain activity (e.g., ERD/ERSs amplitude, Sensorimotor Rhythms at rest; band-power/spectrum fluctuations) [3]. Future work will include a more comprehensive review and a dedicated experimental campaign to systematically assess several variability factors, aiming to develop more robust BCIs.

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Passive Neuroart BCI for Health: A Perspective

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Introduction: Engaging with art can be beneficial for health and well-being [1]. Neural correlates of art perception related to attentional, affective and hedonic processes are already used in Brain-Computer-Interfaces (BCIs) [2]. Therefore, we think that positive effects of aesthetic experience (AE) can be optimized by BCI. This work elaborates on potential health applications combining neuroart and passive BCI for neuroadaptive art presentation. Finally, we offer perspectives on new methods to further the development of such applications.

Neuroadaptive art presentation: As AE is highly subjective [3], we hypothesize that health benefits of art perception could be optimized by neuroadaptive art presentation. Here, the user's brain activity would be monitored by passive BCI during art perception. This information would then be fed into a recommender system in order to present subject-specific art that evokes desirable neural and mental states. Different optimization targets would result in different applications. For example, brain activity related to stress and relaxation during art gazing could be monitored to select art works that minimize a user's stress level. As artworks particularly afford attention [4], we also see potential for neuroadaptive art presentation in attention training. Such a study would assess markers of sustained attention to inform the selection of art that engages attentional capacities, or, in the context of dementia neurobiomarker elucidation, to inform the design of reminiscent interior images, as outlined in [5]. Although this technology could be beneficial, ethical concerns exist. For example, brain responses to caricatures or nudes could reveal political or sexual preferences. Thus, data privacy and responsible use should be technically ensured.

Perspective on Methods: Current AE decoding approaches impose unnatural art engagement constraints on participants, e.g. rating tasks, which biases neural activity [2]. Therefore, novel and naturalistic BCI protocols are needed. Instead of subjective ratings, engagement time could be used to implicitly label trials according to art appreciation [6]. As users might then gaze at only a few artworks for a long time and training data could be sparse, we propose leveraging unsupervised federated learning (FL) as outlined in [7]. This collaborative technique offers several advantages in the context of neuroart passive BCI, because FL facilitates efficient training while ensuring participant privacy.

Conclusion: This research perspective demonstrates the potential of personalized and privacy-preserving neuroart passive BCIs for well-being interventions. Future research should address the unique challenges of implementing diverse art modalities (visual, auditory, somatosensory, olfactory, etc.) in neuroart BCI scenarios. Key areas of focus include, ensuring fairness and equity across diverse populations, enhancing the security of FL systems and optimizing AE decoding performance which remains challenging. Furthermore, rigorous randomized controlled trials are essential to evaluate the effectiveness of neuroadaptive art presentation in improving health and well-being outcomes.

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Blink Artifacts in EEG For Classifying Sight-read Music

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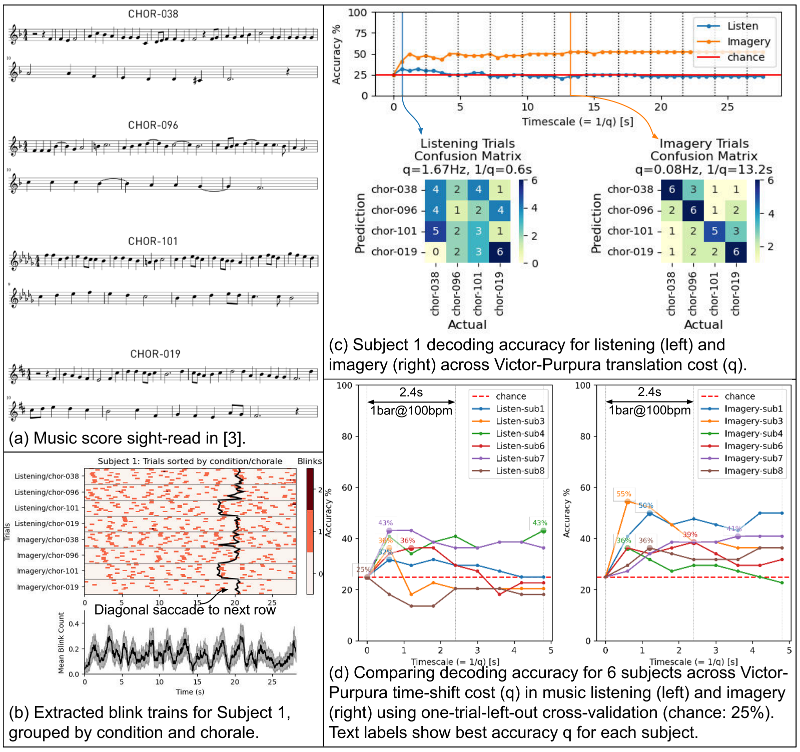
Introduction: Eye-movement related artifacts including blinks and saccades are significantly larger in amplitude than cortical activity as recorded by scalp-EEG, but are typically removed from analysis. Accumulating evidence indicates that spontaneous eye blinks are not necessarily random, and can be modulated by attention and cognition beyond just physiological necessities [1, 2]. In this exploratory analysis, we reanalyze a public EEG dataset [3] of musicians listening to or imagining music (Bach chorales) while simultaneously reading sheet music (Fig. 1a). We ask whether just eye blink activity during sight-reading in music listening and imagery is sufficient to identify the musical piece being read.

Material, Methods and Results: We analyzed data from [3], where musicians listened to or imagined one of four Bach chorales 11 times each, totaling 88 trials per subject. 6 subjects' blink times were extracted using BLINKER [4] and manual inspection for all trials (Subject 1: Fig.1b). A spike-train distance metric (Victor-Purpura distance [5]) was used to compare intra-subject blink timings between the four chorales and listening/imagery conditions, Fig.1c. One trial-left-out cross-validation was used to identify the music based on the left-out trial's blink-distance from the 10 remaining trials with above chance level accuracy (best subjects: ~50% in imagery, chance: 25%). Accuracy varied with subject, condition, and a cost factor q for shifting blink times, Fig.1c–d.



(a) Music score sight-read in [3].

(b) Extracted blink trains for Subject 1, grouped by condition and chorale.

(c) Subject 1 decoding accuracy for listening (left) and imagery (right) across Victor-Purpura translation cost (q).

(d) Comparing decoding accuracy for 6 subjects across Victor-Purpura time-shift cost (q) in music listening (left) and imagery (right) using one-trial-left-out cross-validation (chance: 25%). Text labels show best accuracy q for each subject.

Figure 1: *(a) 4 chorales were sight-read by musicians while listening to or imagining music with vibrotactile cueing at 100 bpm, (b) extracted eye blinks plotted as dashes for 88 trials (4 chorales × 2 conditions × 11 trials), with diagonal saccades between music rows, (c) Decoding accuracy for Subject 1 based on shortest Victor-Purpura distance of tested trial's blink timing against remaining 10 training trials, (d) decoding accuracies for 6 analyzed subjects.*

Conclusion: Artifactual eye-blink timing could still be task-relevant and may supplement brain decoding performance when utilized.

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Fostering Ethical Neurotechnology Leadership: Preparing BCI Innovators Through Education

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Abstract— As neurotechnology reshapes healthcare, industry and human-computer interaction, we have a rare opportunity to steer its burgeoning development with ethical leadership. Just as ethical principles guide engineering and medicine—ensuring public safety, trust, and accountability—they are equally important in neurotechnology. Programs that offer specialized education related to brain-computer interfaces (BCIs) must prepare future neurotech leaders to navigate complex ethical challenges associated with connecting minds with machines. Therefore, it is crucial that educational programs in this area not only develop technical expertise but also instil a sense of responsibility in advancing innovative technologies to enhance lives and benefit society.

The Neurotechnology Microcredential program (NTMC) at Queen's University offers foundational courses including The Neuroscience and Neurotech Primer, Neuro-electronic Recording and Processing, Neuroimaging, as well as a hands-on Capstone Project course. NTMC implements ethical practice as a core competency of neurotechnology training. Ethical considerations are integrated throughout each course via presentation of case studies covering topics including data privacy breaches and device abandonment.

Figure 1: *The first Cohort of students in the intensive NTMC Capstone Project Course pictured sitting with Program directors Dr. Boehnke and Dr. McIntosh*

As of Jan 2025, we have had 114 enrolments across courses. Demographics indicate that half were University students (mostly upper year undergrads and graduate students), with many mature learners (28% over 35) and gender parity (44% female). Only 52% were Canadian (22%US, 13% Europe, 9% Australia) despite being a Canadian programme. This composition reflects the growing interest in neurotechnology education worldwide. With a cohort reaching over 70 credentials issued from these the courses, the program is being expanded to offer Neuro-Entrepreneurship, Brain-Computer Interfaces, Neuromodulation, Behavioural Measurement and a focused course on Ethical Considerations in Neurotechnology.

A cornerstone of the curriculum is engagement with diverse, real-world challenges and perspectives. The program guides graduates to independently identify ethical challenges, practice humility, and engage in thoughtful, reflective discussions when co-creating solutions with the communities they serve. Reflections from executives of world-leading medical device companies, BCI startups and neuro-related corporations are integrated within the courses, providing practical context and insights for learning. Facilitators, with lived-experience, support students in grappling with challenges such as: access to therapies, risk of exploitation and regulatory challenges.

Conclusion— By emphasizing ethical leadership as a skill developed through the NTMC program, students think critically about the impact of their choices and about their approach to problem solving with BCIs. By equipping students with mentorship and practical strategies to navigate complex issues, the NTMC program lays a foundation for neurotech innovators to steer the field responsibly.

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DBS-evoked ECoG responses in depression: first characterization and possible implications for closed-loop applications

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Introduction: Deep brain stimulation (DBS) of the superolateral medial forebrain bundle (slMFB) has shown promising results in the treatment of patients with otherwise treatment-resistant major depression disorder (MDD) and patients with obsessive-compulsive disorder [1]. Inspired by DBS research in Parkinson's disease, for which DBS-evoked cortical responses are seen as candidate biomarkers for closed-loop DBS, we investigate for the first time the cortical responses of slMFB-DBS using ECoG.

Material, Methods and Results: During the implantation of two therapeutic bilateral slMFB-DBS leads, four patients with MDD additionally received a unilateral and epidural 4-channel ECoG strip placed towards the prefrontal cortex to ideally cover BA8. The ECoG strip was removed after four days. During the measurements on the ward, our aim was to screen several 2Hz-DBS parameters (stimulation channels, pulse width, and amplitude) over a series of 90-120 seconds runs during which the patients remained at rest. Due to two medical complications unrelated to our protocol, the measurements in two patients (P01 and P03) did not result in a comprehensive screening of DBS parameters. For the parameters screened, no clear evoked responses were observed. For P02, a comprehensive screening was possible, but no clear evoked response was visible. Interestingly, we found a fast and early (~2-10 ms) oculomotor response, measured via electrooculography, time-locked to the DBS pulses, despite the patient not reporting any side-effects at the screened DBS parameters. For P04, a very comprehensive screening was possible (Day 1: 11 runs, Day 2: 16 runs, Day 3: 25 runs). Consistent slMFB-DBS-evoked responses, distinct wr.t. timing (peak around 25 – 30 ms) and morphology from the oculomotor responses, were observed along a range of DBS parameters. These were modulated by the stimulation parameters, and stronger for the ECoG channels covering pre-frontal sites. Fig. 1 exemplifies the responses for P04 on ECoG01 when stimulating the left slMFB.

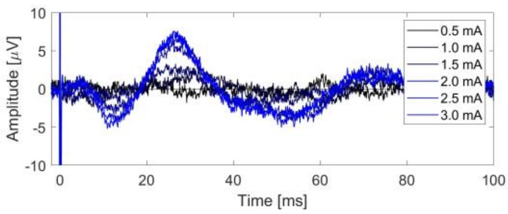

Figure 1: *slMFB-DBS evoked responses at ECoG01 for P04, day 3, for different amplitudes. Stimulation channel: 1, return channels 2-3-4, pulse width: 60 µs, frequency: 2 Hz (t = 0 shows stimulation artefact).*

Conclusion: Our first results indicate that it is possible to measure DBS-evoked responses to slMFB-DBS, although only one patient out of four displayed a clear response, replicable over 3 days of measurements. Our measurements also highlight the particular issue of side-effects related with slMFB-DBS (co-activation of oculomotor nerve fibers) which can affect the outcome of the electrophysiology analysis, particularly if these side-effects are too subtle to be noticed by the patient. In the future, DBS-evoked responses could help guiding clinicians in the selection of optimal slMFB-DBS parameters and eventually be a candidate biomarker for a closed-loop DBS setting in MDD.

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Benchmarking one-class Riemannian EEG classifiers to detect wakefulness under general anesthesia

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Introduction: Current brain monitors for detecting Accidental Awareness during General Anesthesia (AAGA) remain debated, as robust evidence supporting their effectiveness in reducing AAGA's incidence is lacking [1]. To address this, we propose a new brain-computer interface based on Median Nerve Stimulation (MNS), a painless stimulation that elicits motor patterns, to monitor depth of anesthesia [2]. Specifically, we train our algorithm with post-MNS EEG patterns recorded while patients are awake, enabling the detection of the return to an arousal state during the surgery under anesthesia. Since the anesthesia data is unavailable pre-surgery for BCI calibration, we focus on One-Class (OC) approaches. In this study, we evaluate three OC Riemannian methods for this task: K-Means (OC-RKM) [3], Minimum Distance to the Mean (OC-RMDM) [5] and Support Vector Machine (OC-RSVM) [4, 6].

Material, Methods and Results: This study includes 12 patients (6 women; 50 ± 14.3 years) undergoing surgery under general anesthesia with propofol as the hypnotic agent, at CHU Brugmann in Belgium [7]. EEG data were collected in two sessions: preoperatively (awake) and intraoperatively (under anesthesia). Each session involves several recordings, each with 150 MNSs delivered at a frequency of 0.25 to 0.33 Hz. Features were extracted as covariance matrices 250 to 1000 ms post-MNS in the 8–30 Hz frequency band. Classification performances of the three OC Riemannian algorithms are summarized in Figure 1. A Student's t-test with Benjamini-Hochberg correction shows OC-RKM and OC-RMDM significantly outperform OC-RSVM ($p < 0.05$).

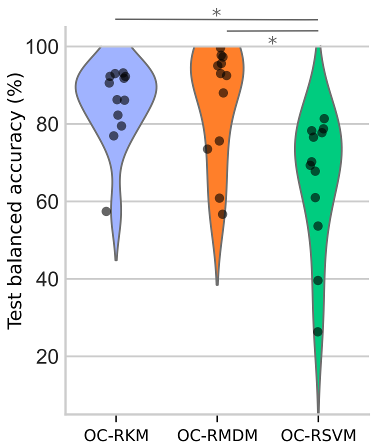

Figure 1: *Test balanced accuracies obtained with 12 patients using OC classifiers trained on data when patients are awake. Best results with OC-RKM are with 2 prototypes, and thresholds of median + 3 × median absolute deviation. For OC-RSVM,* $\nu = 0.5$*. For OC-RMDM parameters, see [5]. *p-value* < 0.05.

Conclusion: Results indicate that both OC-RKM and OC-RMDM effectively delimit an awake state in most subjects, though not all. In contrast, OC-RSVM has a lower performance, possibly due to the use of a Riemannian kernel reference point C_{ref} computed as the mean covariance matrix of the awake class, which may inadequately capture the geometry of both classes. Additionally, ν was not optimized, as its tuning in a one-class context remains challenging. Future work will assess performance regarding the number of electrodes, alternative C_{ref}, and comparisons with other one-class algorithms. An ensemble method will also be considered to improve robustness for depth of anesthesia estimation across subjects, leveraging the strengths of each model.

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Neuromorphic Processing of sEMG Signals for Finger Position Estimation

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Introduction: Neuroprosthetics aim to restore lost motor or sensory function. Upper limb myoelectric prostheses which rely on processing surface electromyography (sEMG) signals from the amputee's residual limb are of the most widely used devices. While traditional control relies on pattern recognition for identifying discrete hand movements, regression-based approaches offer a more intuitive control by modeling hand kinematics with sEMG [1,2]. However, implementing these methods on wearables faces challenges due to resource limitations (memory, power, latency). Neuromorphic computing, with its brain-inspired architecture and energy-efficient spike-based processing, offers a promising solution [3]. While explored in prosthetic control, its application to regression-based approaches remains limited [2]. This paper introduces a neuromorphic regression-based processing method for mapping sEMG signals to finger positions during hand movements, as illustrated in Figure 1.A.

Methods and Results*:* The regression task involved mapping 16 sEMG electrodes to 5 Degrees-of-Actuation (DoAs) corresponding to the position of the 5 fingers. sEMG signals taken from the dataset in [4] were downsampled from 2kHz to 250Hz, rectified, and normalized between 0 and 1. Each channel was then encoded into spike trains by a Leaky Integrate-and-Fire (LIF) neuron (16 total) [3]. These spike trains were fed into a Spiking Neural Network (SNN) with two hidden layers of 256 LIF neurons and a five-neuron output layer. The SNN was trained using a surrogate gradient and the Adam optimizer using the snnTorch library [5]. Regression accuracy was assessed by comparing the output neurons' membrane potentials to the ground truth DoAs using Mean Absolute Error (MAE). Preliminary results showed an MAE of 6.0 ± 3.3 degrees, comparable to results reported in [2] using a similar dataset (see Figure 1.B for an example of the regression).

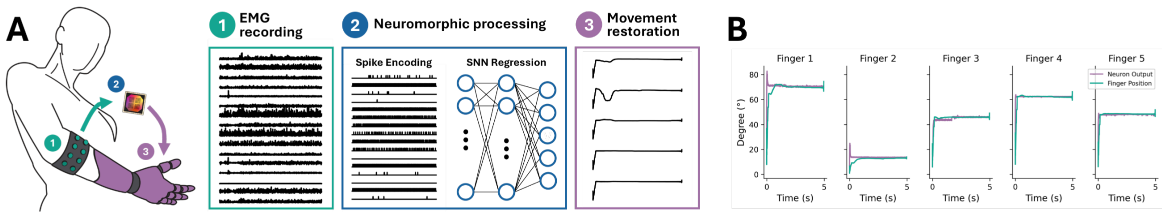

Figure 1: A. Schematic of prosthesis control using the proposed neuromorphic approach, 1: sEMG signal recording, 2: Event-based processing of the sEMG signal composed of spike encoding and SNN regression, 3: Finger movement restoration on prosthesis based on SNN output. B. Finger position (ground truth DoAs represented in green) estimation results for a lateral grasp. Neuron output (in purple) represents the neuron's membrane potential.

Conclusion: Preliminary results using event-based computation demonstrate successful finger position estimation from sEMG signals across six hand gestures, regardless of arm position. This suggests our decoding approach exhibits position invariance. Future work will focus on implementing the model on a 16-core SNN developed by our team [6].

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A Novel Fully Implantable High Data Rate BCI for Speech Restoration.

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Introduction: Brain-computer interfaces (BCIs) have demonstrated their ability to provide functional control of computing devices and to restore lost communication abilities for individuals with profound motor and speech deficits due to neural injury or progressive neuromuscular disease. Recently, these systems have achieved a level of performance high enough to enable restoration of interactive, conversational communication [1]. BCIs operating at these highest levels of performance are enabled by intracortical electrode arrays implanted in motor areas. Although BCIs are poised to address unmet clinical needs, current speech BCI studies utilize research devices with percutaneous components. We present a fully implantable, intracortical BCI system designed for clinical adoption while simultaneously supporting higher electrode counts that could facilitate increased BCI performance.

Figure 1: (Left) Rendering of the fully implanted intracranial BCI. (Right) Photographs of the Cortical Module (top) and Internal Transceiver (bottom).

Materials, Methods, and Results: The system is composed of a cortical module, lead, and an internal transceiver. A single cortical module has 421 intracortical microelectrodes (each 1.5mm in length, 40 µm in diameter) that are amplified and digitized on the module to allow for neural signal transmission over a subcutaneous lead. The internal transceiver form factor and implant procedure follow an approach similar to that of an implantable pulse generator of a deep brain stimulator. The internal transceiver receives power for the system with a wireless inductive link from an external, wearable transceiver. Broadband data are telemetered via a wireless optical communications link and support extraction of spiking, spikeband, and local field potential (LFP) based features. Power delivery and optical communications bandwidth are designed to support up to four cortical modules, or 1684 intracortical microelectrodes. Preclinical testing of the system is underway for safety, biocompatibility, and functionality. In 31 research ovine model procedures, zero serious device or procedure-related events were observed, and signal stability has been observed out to 2 years. Twenty-six week biocompatibility is currently supported in accordance with ISO10993. Chronic implantation of the cortical module in ovine auditory cortex yields both neuronal spiking and LFP features, and demonstrates a high bit rate readout of brain state. Neural features were validated based upon their signal characteristics and their dynamics with respect to auditory stimuli.

Conclusion: This system will be tested in a First-In-Human clinical study, under IDE, to investigate the feasibility of speech restoration in a population suffering from impaired communication due to a progressive neuromuscular disease or a neural injury.

Disclosures: Paradromics, Inc. authors hold company equity. VG holds equity in Neuralink Corp. DMB is an inventor on IP owned by UC Davis, and is an ad-hoc surgical consultant for Paradromics Inc.

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Enhanced SSVEP Classification with Pre-trained Models: The SSVEP-CAT Approach for Calibration-Free BCI

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Introduction: This study addresses the challenge of developing calibration-free Steady-State Visual Evoked Potential (SSVEP) classification models for Brain-Computer Interface (BCI) systems. Inter-user generalization may reduce the user burden of calibration sessions and improve user experience. However, deep learning technique requirements for large datasets hinder practical deployment. To address this limitation, we introduce the SSVEP-CAT (Convolution, Attention, and Transformer) model. We adopted a transfer learning approach that utilizes a pre-trained model including a Convolutional Neural Network (CNN) for feature extraction and a transformer-based classification module, leveraging self-attention to maintain high accuracy. This project aims to evaluate the impact of using a small number of users on SSVEP-CAT classification accuracy.

Material, Methods, and Results: We evaluated the SSVEP-CAT model on two open access datasets to verify if its use reduces data dependence. Dataset I [2] contained 12-class frequency-phase modulated SSVEPs from 10 users, and dataset II [3] included 64-channel EEG data from 35 users. From both datasets, data corresponding to 12 target stimuli and 8 occipital lobe channels were employed for analysis. The data underwent a 4th-order Butterworth band-pass filter, sliding window technique, and complex Fast Fourier Transform (FFT). The model used 2D CNNs for feature extraction, an attention layer for feature recognition, and a transformer encoder for complex temporal representation analysis (Figure 1). When trained on dataset I, SSVEP-CAT achieved an accuracy of 89%, outperforming the CCNN (CNN based on complex features) [1], which reached 81% (Table 1). An advantage of SSVEP-CAT lies in its ability to leverage pre-training on another dataset with a sufficiently large number of users and trials, such as Dataset II. When training was conducted on 3 users without pre-training, the accuracy achieved was 19% (CCNN) and 36% (SSVEP-CAT). However, this accuracy increased to 82% when pre-training was performed prior to fine-tuning on the same 3 users.

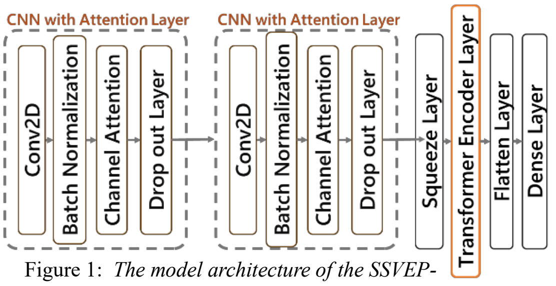

Figure 1: *The model architecture of the SSVEP-CAT model*

Table 1: *Impact of Increasing Number of Users on Model Performance: Mean Accuracy ± Standard Deviation*

	Number of users for training/fine-tuning from Dataset I		
Model	**3**	**5**	**9**
CCNN [1]	19±11	54±17	81±15
SSVEP-CAT without pre-training	36±7	68±9	89±8
SSVEP-CAT with pre-training on Dataset II	82±12	86±10	91±7

Conclusion: The proposed SSVEP-CAT model outperformed the CCNN without pre-training, highlighting its robustness as it generalized better with increasing fine-tuning data. Transfer learning enabled better performance of the SSVEP-CAT model on limited users, but its reliance on large datasets remains a limitation. The SSVEP-CAT improved classification accuracy demonstrating a potential strategy for addressing BCI calibration and improving BCI system user experience.

Acknowledgments and Disclosures: We acknowledge the funding provided by the Glenrose Hospital Foundation, MITACS, and SMART NSERC CREATE grant.

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Challenges in Common Spatial Pattern Reliability for Neurofeedback

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Introduction: Motor imagery (MI)-based neurofeedback requires precise extraction of physiologically significant brain activity from EEG signals. A key challenge is the individualization of targeted activity, as commonly used methods like the Laplacian filter [1] may not capture subject-specific neural dynamics. Common Spatial Patterns (CSPs) [2] provide a personalized approach by extracting spatial filters from individual brain activity. However, CSPs are sensitive to noise and artifacts in EEG data, which can impact their reliability [3]. This study examines CSP reliability and explores the use of Representational Similarity Analysis (RSA) [4] to select neurophysiologically relevant CSPs. Preliminary findings highlight the challenges in isolating MI signatures with CSPs and the need to refine their selection to enhance neurofeedback protocols.

Material, Methods and Results: We used the EEG data from 21 participants (28 active electrodes) recorded during 10 alternating trials of rest and right-hand MI (8 seconds / trial; [1]). A virtual hand displayed clenching movement as visual stimulation during MI. The EEG signals were band-pass filtered between 8 and 30 Hz to focus on motor-related frequencies. CSPs were calculated and, for each subject, the most physiologically relevant CSP among the top six ones was visually selected by the authors (Figure 1a). The result highlighted the inter-individual variability of CSP decomposition, evidenced by the variable rank of the selected CSPs and the frequent presence of ocular artefacts signatures. This variability is further emphasized by Figure 1c, representing the average of the selected CSPs, and Figure 1d, showing the associated standard deviation across subjects, where high variability in temporal regions extending to the motor region can be seen. To evaluate the reliability of CSPs in isolating motor-related activity, CSPs pattern were then compared to the grand average difference topography between MI and rest (MI – Rest) using a leave-one-out RSA approach (Figure 1b). A match between the CSPs selected by the experts and those identified by RSA was observed in 45% of the subjects, with a RSA score of 0.24 ± 0.12 (mean ± SD).

Conclusion: This study underscores the variability and challenges in isolating physiologically relevant motor-related activity using CSPs. Preliminary results reveal that CSPs captured motor imagery patterns in 45% of the cases, emphasizing a lack of reliability. These findings underline the necessity of exploring alternative approaches to improve CSP selection, such as region-specific computations, advanced artifact correction techniques [5], or automated methods to detect and exclude artifact-contaminated CSPs. This also opens opportunities to explore innovative methodologies to address CSP limitations, aiming to improve their reliability and support the implementation of personalized neurofeedback protocols.

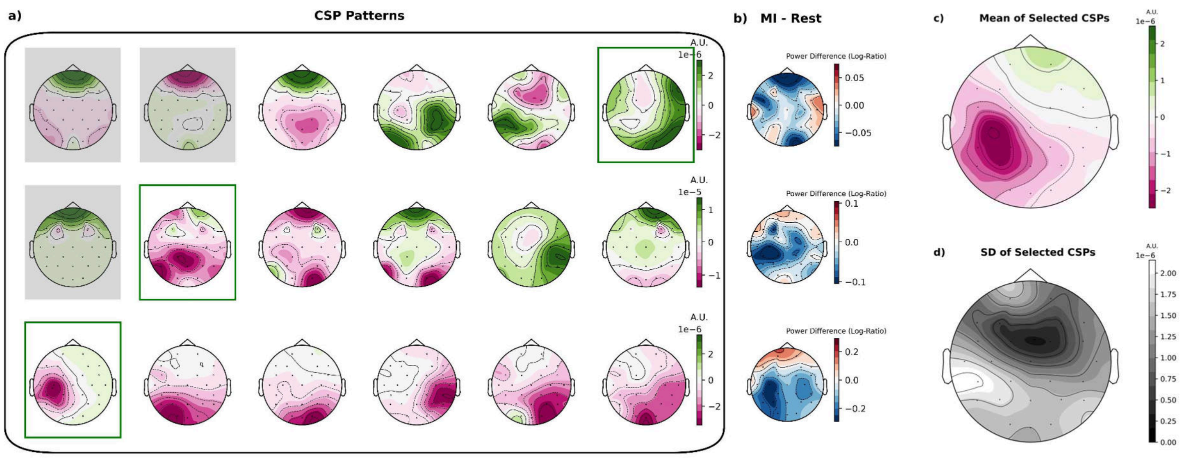

Figure 1: a) CSP patterns for three representative participants. Green boxes highlight the CSPs selected by the experts. Gray-shaded boxes indicate CSPs identified as contaminated by artifacts. b) MI-Rest topographies for the same three participants, illustrating MI-related activity. c) Mean and d) standard deviation of the CSPs selected by the experts across all participants.

Acknowledgments: This work was supported by the French National Research Agency (BETAPARK project, ANR-20-CE37-0012).

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Navigating the clinical trial pathway for implantable brain-computer interfaces: the COMMAND study

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***Introduction**:* Implantable brain-computer interfaces (BCIs) can enable people with paralysis to control digital devices using decoded brain signals. Predominantly, implantable BCIs have required craniotomy to place penetrating or surface electrodes on the brain, with some of these systems depending on transcutaneous ports for connectivity, leaving components visible and outside of the body. The Synchron BCI is a fully implanted system delivered using a minimally invasive endovascular technique. Following a first-in-human study completed in Australia (SWITCH trial[1]; n=4 participants), we present the results of the COMMAND early feasibility study — the first FDA-approved trial of a permanently implanted BCI — along with key insights gained from the clinical trial pathway.

***Material, Methods, and Results**:* The COMMAND study (ClinicalTrials.gov registration: NCT05035823) was a prospective, multi-center, single-arm, open label, early feasibility study (EFS) conducted under an investigational device exemption (G210178). The COMMAND EFS evaluated the safety and feasibility of the Synchron BCI in six participants with chronic severe bilateral upper limb paralysis. The primary endpoint was device related serious adverse events resulting in death or permanent increased disability. Secondary endpoints were device migration and target vessel patency. Additional outcomes explored BCI decoding of neural signals to generate 'digital motor outputs' for digital device control.

All six participants were successfully implanted with the endovascular BCI. Each participant met the primary study endpoint with no device related adverse events resulting in death or permanent increased disability during the one-year post-implant evaluation period. Additionally, there was preserved target vessel patency and no evidence of device migration at 3- and 12-months post-implant. Four out of six participants demonstrated consistent BCI decoding performance, enabling them to successfully perform various digital device control tasks throughout the one-year post-implant evaluation period. Of the remaining two participants: one experienced rapid progression of ALS leading to the withdrawal of life-sustaining care and the other encountered system signal artifacts, both of which impacted their ability to effectively use the BCI.

Conclusion: Endovascular access to brain regions for the placement of BCI sensors is an alternative to procedures requiring open-brain surgery. In addition to the favorable safety profile of endovascular procedures, the prevalence of angiography suites and neurointerventionalists capable of performing these procedures could promote wider and more rapid translation of BCI for people with paralysis. Results from the COMMAND EFS demonstrate early indication of safety and effectiveness of Synchron's endovascular BCI for participants with severe bilateral upper limb paralysis. Results and learnings from this study will contribute to the clinical translation of implantable BCIs via the clinical trial pathway.

Acknowledgements and Disclosures: We thank the participants and their caregivers for their generously volunteered time and dedicated contributions to the clinical trials. TJO holds stock options in Synchron Inc.

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Clinical Evaluation of Communication Brain Computer Interfaces in Amyotrophic Lateral Sclerosis: A Landscape Analysis

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Introduction: Amyotrophic lateral sclerosis (ALS) is a progressive neurodegenerative disease leading to severe paralysis and loss of communication, significantly impacting their quality of life. Communication brain-computer interfaces (cBCIs) offer a potential solution for paralyzed individuals, yet there are no standardized clinical outcome assessments (COAs) for evaluating their efficacy. This study conducts a landscape analysis, reviewing current communication efficacy approaches, COAs, and expert feedback to guide the development of cBCI-specific measures for ALS patients.

Material, Methods and Results: Through a project funded by the FDA's Rare Neurodegenerative Disease Grants Program (established under the Accelerating Access to Critical Therapies (ACT) for ALS act) we conducted a systematic literature review to identify existing measures that may be used or adapted to assess the effectiveness of cBCIs. Using a comprehensive and robust search filter, two independent reviewers screened 13,620 published manuscripts across multiple databases. From those papers, we identified 21 COAs relevant to cBCI in ALS patients (Fig. 1). Concurrent with the literature review, we conducted a series of structured interviews with key opinion leaders (KOLs) (n=15). KOLs confirmed the relevance of many of the COAs previously identified and provided valuable insight on the evaluation of communication in ALS and cBCI assessment. No additional COAs were identified during KOL interviews for inclusion. Finally, we assembled a panel of experts for an extended discussion on selected COAs. The panel reviewed 21 COAs, discussing their relevance, scale types, and applicability. It was concluded that while some metrics are useful, none were comprehensive enough for standalone clinical use, and modifications would be necessary for cBCI evaluation in ALS.

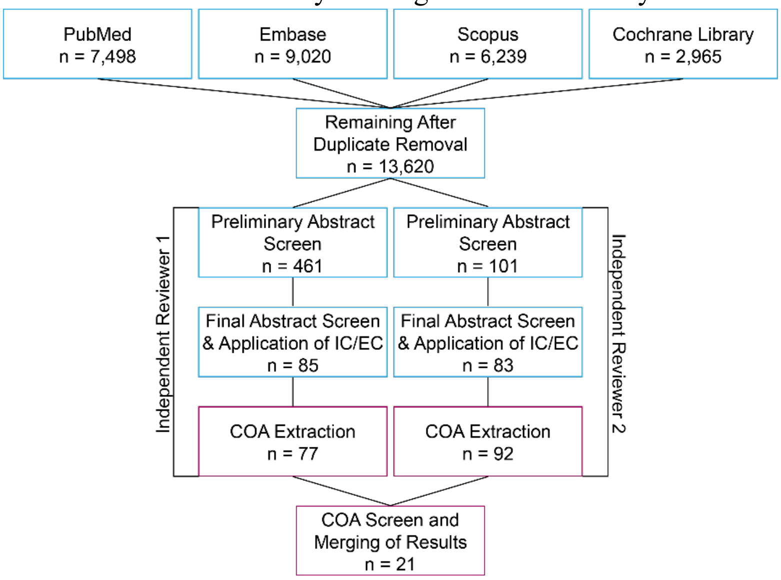

Figure 1: Flow chart of comprehensive literature review processes and results after merging independent review results*. Blue bounding boxes indicate literature review and manuscript identification and screening. Magenta bounding boxes indicate clinical outcome assessment identification and extraction from selected papers.*

Conclusion: This study highlights the need for the development and application of comprehensive COAs for evaluating cBCIs in ALS patients. Through a comprehensive landscape analysis, we conclude that, although several relevant COAs exist in the scientific literature and current clinical practice that may be useful in the assessment of cBCI in ALS, none are suitable for use without some modification nor are any comprehensive enough for standalone use. Moving forward, patient-centered, adaptable evaluation approaches should be the primary focus guiding future development and validation efforts for metrics to assess cBCI efficacy and patient satisfaction.

Acknowledgments and Disclosures: We would like to thank our clinical partners at Johns Hopkins University, Rancho Los Amigos National Rehabilitation Center, and the University of Utah for their ongoing collaboration and contribution to this work. The project described was supported by Grant Number 1UH2FD008137 from FDA's Office of Orphan Products Development. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the FDA nor FDA's Office of Orphan Products Development. The authors do not have any conflicts of interest to report.

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Decoding of Coordinated Hand and Arm Movements

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Introduction: Natural reaching entails the coordinated movements of joints distributed over the entire upper limb – including the arm and hand. Furthermore, individual neurons in motor cortex carry "multiplexed" signals associated with the coordinated control of both hand and arm movements [1]. Despite this, brain-computer interface (BCI) decoders for restoring upper limb movement have been trained with isolated, sequential movements of the arm, wrist, and hand [2]. Decoders trained on isolated movements do not lead to smooth, quick movements seen in native arm use during tasks requiring coordinated movements [2]. Additionally, previous work in non-human primates has demonstrated tuning to movement speed in addition to velocity [3,4]. Here we show that training on a task requiring coordinated movements and including a normalized speed term in the decoder, that accounts for hand, wrist and arm movements, improves BCI control during a coordinated grasp and transport task.

Material, Methods and Results: Data was collected from an individual (C1) with a C4 ASIA D spinal cord injury who was participating in an ongoing clinical trial (NCT01894802) for intracortical BCI control of a robotic prosthetic limb conducted under an FDA Investigational Device Exemption. They completed a 7-degree of freedom (DOF) grasp and transport task in Virtual Reality (VR). The DOFs correspond to hand translation (3D), wrist orientation (3D), and grasp aperture (1D). All DOFs were controlled simultaneously. The task was completed using two motor decoders: a velocity-based (V) decoder as used previously [1] and a new version that added a speed term (V+S). The participant failed the task if any phase of the task timed out (> 10 s) before they achieved the target posture in all DOFs. The decoders were trained and tested in a two-step training protocol used previously [1,2]. The computer assistance is titrated until the user has unassisted control of the VR arm. All results presented are for the unassisted trials.

Over 4 sessions, the participant attempted the simultaneous 7DOF grasp and transport task 180 times with each decoder. They successfully completed the entire task 50 and 80 times for V and V+S decoders, respectively (2-tailed 2-proportion z-test: $p = 9.95e\text{-}4$; Cohen's h: $h = 0.349$). For those successful trials, the task completion time on average was 21.52 s ($\sigma = 4.11$) and 19.24 s ($\sigma = 5.05$), respectively (2-tailed 2-sample t-test: $p = 5.9e\text{-}3$; Cohen's d: $d = 0.482$). Figure 1 shows task completion times for each successful trial, grouped by the decoder used.

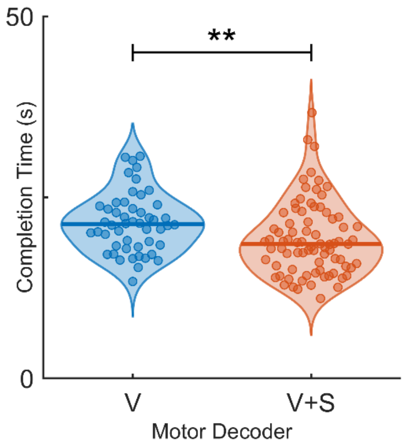

Figure 1: Task completion times for each motor decoder. The dots correspond to the completion times for individual trials. The V+S decoder shows significant improvement in task completion time compared to V ($p < 0.01$ and "medium" effect size).

Conclusion and Discussion: These results are promising evidence for the benefit of adding a speed term to the decoder when completing coordinated tasks. The participant completed more tasks successfully ($p < 0.001$ and "small" effect size) and faster ($p < 0.01$ and "medium" effect size) with the addition of a speed term. This important addition to decoder design promises to improve the smoothness and naturalness of BCI-controlled prosthetic arms for activities of daily living.

Acknowledgments and Disclosures: We thank the study participant for their effort and dedication. This work is supported by the NIH NINDS (1R01NS130302).

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Motor-imagery neurofeedback for beta downregulation in Parkinson's disease

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Introduction: Parkinson's disease (PD) is a neurodegenerative disease associated with motor and non-motor symptoms, with current treatments limited by eligibility criteria and side effects. Since 2002, neurofeedback (NF) has been explored as a complementary therapy, but evidence remains highly inconclusive, showing variability in NF metrics and motor outcomes [1]. One third of these studies have used EEG, often targeting generic neural activities unrelated to the mechanisms underlying PD [2]. Knowledge of PD pathophysiology has improved since, establishing alpha, beta and gamma bands as potential NF targets [1]. Yet, the pathological beta band has been targeted in only two studies [3, 4]. We aim to confirm the feasibility of a non-invasive beta downregulation NF protocol using motor imagery (MI) and explore its motor effects.

Material,Methods and Results: 14 PD patients on dopaminergic treatment performed an EEG-based NF session (64 electrodes). During NF trials, they used right-hand MI to reduce beta power (13-30 Hz) over the left motor cortex. Online feedback (FB) was provided by virtual hand movement amplitude, proportional to beta reduction relative to rest. The experiment included "MI" control trials, where patients performed MI without FB. Each patient completed 3-4 sequences of one MI trial followed by two NF trials. Every trial was immediately followed by a 7s-finger tapping task, measured via EMG and accelerometer.

Beta reduction (ie. NF performance) was greater in the NF condition than MI control for 13 out of 14 patients (Fig 1A). This reduction was associated with bilateral desynchronization, peaking over left central electrodes in the low beta band and on more central electrodes in the high beta band (Fig 1B, bottom row). In contrast, the MI control condition showed less pronounced and more widespread desynchronization, without clear focus on the targeted area (Fig 1B, top row). NF performance progressively increased along trials in the NF condition, while it remained stable in the MI condition. Eleven patients had shorter reaction times following NF than MI trials, and 10 of them showed an increased number of taps.

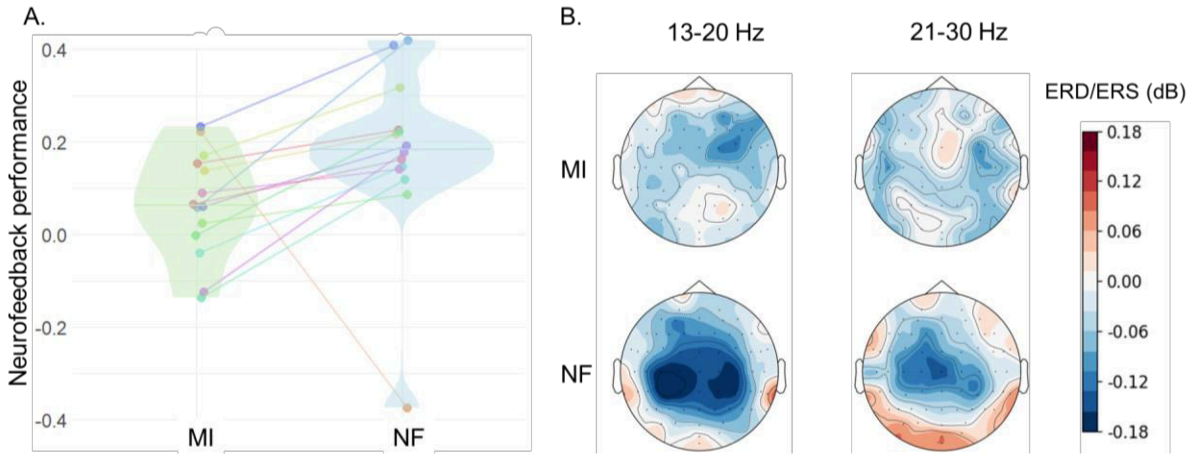

Figure 1: A. Individual neurofeedback performance during MI and NF trials for each subject (colored dots and lines), with the distribution of NF performance across subjects represented as a violin plot for each trial type. B. Grand average topographical maps of ERD/ERS in the low beta (13-20 Hz) and high beta (21-30 Hz) bands across the 14 participants during MI and NF trials.

Conclusion: ON-dopa PD patients can reduce successfully their beta activity in a single NF session. Providing FB induced a greater reduction of beta activity compared to performing MI alone. While the absence of a sham condition limits inferences about the specific impact of NF *per se*, MI was chosen because it is used in PD therapy and has been shown to improve motor function [5]. Our results suggest that enhancing beta desynchronization, here through NF, can be associated with improved motor function in PD, particularly the sequence effect of bradykinesia (i.e rapid decrement in amplitude and speed of repetitive movements). Future analyses will explore links between neurophysiological modulations and motor task performance.

Acknowledgments and Disclosures: This work was supported by the French National Research Agency (BETAPARK project, ANR-20-CE37-0012) and a France Parkinson grant to C. Dussard.

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Consumer grade in-ear EEG for at home pediatric BCI

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Introduction: A primary objective for brain computer interface (BCI) research is to develop technologies that end users can use independently in their regular lives, namely at home. Key barriers for at home use identified by BCI users are headset comfort and ease of set up [1]. When comparing EEG headsets for BCI, end users have indicated preference for simple consumer grade headsets over full head research grade EEGs because of increased comfort and reduced setup time [2] (Figure 1). Furthermore, for individuals with thicker curly hair or diverse hairstyles, full head EEGs often underperform due to interference with the user's hair, thus making traditional scalp-based EEG headsets inequitable [3]. Fortunately, in-ear EEG may provide a solution. In-ear EEGs record a single channel that is comparable to a low-channel scalp EEG system [4]. Due to the low profile of these headsets (similar in size and shape to earbuds), these headsets are easy to set up, feel familiar to caregivers and users, and do not conflict with the user's hair or wheelchair headrest making them far more comfortable for prolonged wear. Thus, these headsets may be a viable solution to reduce barriers to at home BCI use. However, in-ear EEG systems still require additional validation for use in performing various BCI applications. In this study, we compare a consumer grade in-ear EEG to a research grade full head EEG to determine if in-ear EEGs may be sufficient for BCI use at home.

Materials and Methods: An in-ear, commercially available EEG system with audio playing capabilities was selected for this validation study (Headset 1). Typically developing young adult participants simultaneously wore both the in-ear headset and a gold-standard research-grade EEG headset for recordings (Headset 2). We have intentionally obscured the names of these two headsets to ensure fair validation of the systems, but can provide additional information on request. Participants were presented with commonly used BCI paradigms (auditory and visual P300, ASSR, and SSVEP) while EEG data was recorded. The resulting EEG data were then processed and classified offline with identical processing procedures. Across the two headsets, correlations between EEG data and classifier performance were compared to determine performance of the in-ear EEG compared to the gold-standard. Data collection and analysis are currently ongoing.

Figure 1: *For some children, full head EEG headsets conflict with wheelchair headrests requiring additional supports and/or braces.*

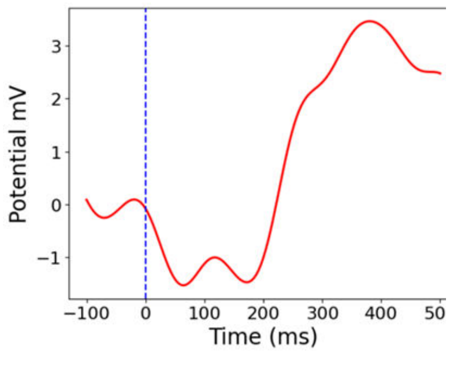

Figure 2: *An averaged auditory P300 response from one participant recorded from Headset 1*

Results and Conclusion: Initial analysis (n=3) of the EEG signal from the in-ear EEG indicates that in-ear EEG appears to be able to detect the large positive inflections indicative of the P300 response (Figure 2). Further investigations into real time classification performance are being conducted to determine if consumer in-ear EEGs may be a viable long-term solution for comfortable, equitable, and easy to use EEG for at home BCI applications for children.

Acknowledgments and Disclosures: We would like to thank Dani Jourdain for assistance with initial piloting of these experiments and the industry partners for providing headsets for evaluation.

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Closed Loop Decoding of Ipsilateral and Contralateral Proximal Movements in an Individual with Tetraplegia

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Introduction: It is widely acknowledged that the output of cortical areas involved in movement generation is mainly focused on the contralateral side of the body. Accordingly, with a few exceptions[1], most BCI research has focused on contralateral control of a single limb. However, numerous studies have shown that each hemisphere of the brain can drive movements of the ipsilateral limb independently[2]. Here, we study ipsilateral and contralateral control about a single proximal joint of a virtual anthropomorphic limb from unilaterally placed microelectrode arrays in an individual with tetraplegia.

Material, Methods and Results: We developed a virtual environment using the Unity software platform to enable control of ipsilateral and contralateral shoulder abduction of an anthropomorphic virtual avatar. Neural activity was recorded using two 96-channel microelectrode arrays placed in the left precentral gyrus of participant T11 in the BrainGate2 clinical trial (NCT00912041). T11 is a 40-year-old male with tetraplegia from a cervical spinal cord injury (C4 AIS-B). T11 completed a posture match task using shoulder abduction imagery to move the virtual arm to a discrete set of target angles presented on the screen. A 1D Kalman filter trained using rapid calibration enabled T11 to control both the ipsilateral and contralateral effector within seconds (without any previous open loop training data). T11 achieved a target accuracy of 86% within the ten second time limit for both the ipsilateral side and contralateral side. For analysis, we examined two types of features per electrode: multi-unit threshold-crossing spike rates and power in the spike band (250-5000 Hz). Using a Kruskal-Wallis test, 90 of the 384 features displayed significantly different values between upwards and downwards movements for both the ipsilateral and contralateral effector. Of those 90 features, 16 also showed significantly different activity between ipsilateral and contralateral movement, thus discriminating between both effectors and direction of movements.

Conclusion: This work demonstrates an early characterization of neural representation of ipsilateral and contralateral upper limb proximal joint kinematics.

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Designs for no-control functionality using dynamic stopping algorithms as gatekeepers in P300 BCIs

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Introduction: The ability to communicate only when intended is vital, but brain-computer interface (BCI) no-control performance is understudied. Dynamic stopping methods designed to improve the speed of event-related potential (ERP) BCI designs can also function as gatekeeper algorithms to enable no-control performance [1]. Conceptually, a dynamic stopping algorithm stops presenting stimuli when it finds the available information sufficient for an accurate decision. However, it may still produce an output, even if of questionable accuracy, when the pre-determined maximum sequences of stimuli are complete. Asynchronous BCIs may use separate control-state algorithms to decide if the user is attempting BCI use. Such control-state algorithms act as gatekeepers to determine whether the BCI types. However, there are several designs that enable the dynamic stopping algorithm to also function as a gatekeeper and produce asynchronous BCI function for P300 BCI designs.

Methods and Results: A P300 BCI speller is designed around classifying the brain response to each presented stimulus as indicating a target or non-target. A **sequence** contains one presentation of each stimulus. Stimuli are usually groups of keys (originally rows and columns). In the original design [2], the key at the intersection of the row and column with the highest average classification scores was selected after a fixed number of sequences. We define additional concepts: The **Decision Window** is the group of sequences used to make a selection, which can have a ***fixed*** duration (original P300 BCI) or a ***variable*** duration (dynamic stopping) with minimum and maximum numbers of sequences. If the duration is variable, a **Gatekeeper** algorithm is needed with **Gatekeeper Criteria** that must be met for a selection to be made. The **Decision Type** governs what happens at the end of the decision window. A ***forced*** decision type selects the key with the highest score, regardless of whether it met the gatekeeper criteria. A ***forced-abstention*** decision type produces an ***explicit abstention*** output if no key passes the gatekeeper criteria. After a forced or forced-abstention decision, a new decision window is started. However, a ***sliding*** decision type discards the oldest sequence in the decision window and appends a new sequence without pausing the stimulus presentations (an ***implicit abstention***).

Decision window width, decision type, and gatekeeper criteria affect performance (Fig. 1). Forced decisions produce more errors but are less sensitive to optimal gatekeeper criteria than forced-abstention decisions, which can frustrate users by repeated failures to select a key. Sliding windows can appear to get stuck and make no selections if gatekeeper criteria are too stringent. However, sliding windows can also be both responsive during intended typing and robust during no-control. During intended typing, the decision window restarts after each selection, supporting rapid typing. But once the decision window is filled with no-control sequences, no-control performance is relatively robust.

Conclusion: Dynamic stopping algorithms used as gatekeepers can provide both rapid selections and robust no-control performance. On-line testing will quantify benefits and optimize gatekeeper criteria.

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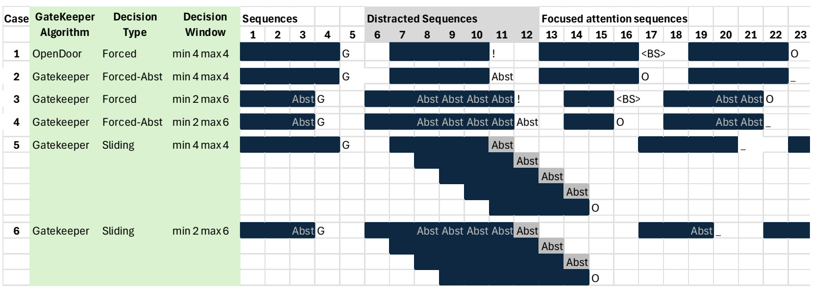

*Figure 1: Six examples of the effects of different combinations **of gatekeeper algorithm, decision type,** and **decision window** duration. Explicit (Abst) and implicit abstentions (Abst or Abst) enable no-control performance instead of errors during distractions (sequences 6-12).*

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Phoneme Sequence Encoding in Ventral Motor Cortex

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Introduction: Understanding the neural mechanisms of speech production is fundamental for advancing brain-computer interface (BCI) technologies and neuroscience. Intracortical speech BCIs not only achieve high-accuracy decoding[1,2] but also provide a unique window into how the ventral precentral gyrus (vPCG) encodes continuous speech. Here, we demonstrate that vPCG encodes the entire sequence of phonemes within a word during overt speech production, revealing limitations in traditional models of phoneme sequence representation, such as the competitive queue (CQ)[3] and slot-based models[4].

Material, Methods and Results: Neural spiking activities were recorded from two BrainGate2 clinical trial participants, T12 and T15, while they attempted to speak English sentences. Both participants have amyotrophic lateral sclerosis (ALS), leaving us no reliable phoneme timing information. Additionally, each sentence spoken is unique, making it impossible to eliminate trial-to-trial variability in neural spiking activity by averaging multiple repetitions of the same condition. To address these challenges, we developed a recurrent neural network (RNN) encoding model capable of predicting neural firing rates and phoneme timings for any phoneme sequence. The model leveraged data from multiple sessions (14.1 hours for T12, 12.8 hours for T15) to model how vPCG represents sequences of phonemes, allowing us to investigate the neural mechanisms underlying speech production by interrogating the model.

The RNN model accurately predicted neural activity for novel English sentences (Pearson r: 0.80 for T12, 0.85 for T15). Analyses of model-generated neural activity revealed that vPCG simultaneously encodes up to eight phonemes within a word, with stronger encoding of future phonemes than the past. Using linear regression, we identified that subspaces encoding nearby phonemes were highly correlated, distinct from the orthogonal encoding subspaces observed for encoding actions in a motor sequence in the macaque prefrontal cortex[5]. The encoding magnitude for each phoneme followed a gradient-like pattern similar to the CQ model but showed a gradual decay after articulation. Phoneme representations transitioned dynamically through subspaces, moving from future encoding to output and finally to past subspaces, similar to a slot-based model.

Conclusion: Our findings show that vPCG simultaneously encodes multiple phonemes in correlated subspaces and dynamically transitions these representations through time. The serial order is encoded in both the magnitude and the order-specific subspaces. We believe these findings will advance our understanding of the neural coding of phoneme sequences in the ventral motor cortex.

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A pilot study towards synthesizing speech during intraoperative recordings using the Layer 7 cortical interface

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Introduction: Implantable Brain-Computer Interfaces (BCIs) have shown promising results in establishing alternative communication means for people living with a neurodegenerative disease. Previous studies on electrocorticographic (ECoG) signals have shown that increasing the number of contacts and their density can improve speech decoding [1] and synthesis [2] applications. Here, we present a pilot study to test the feasibility of synthesizing speech using the Layer 7 cortical interface (Precision Neuroscience) during an awake craniotomy for glioma resection in the left frontal lobe. Equipped with a total of 1024 contacts placed over ~1.5 cm^2 of face motor cortex, we conducted an experiment in which the patient spoke single words aloud from a list of four after hearing them audibly through a loudspeaker in the operating room. Both neural and acoustic data were simultaneously recorded.

Material and Methods: We developed a BCI system consisting of three components to (1) receive neural and acoustic data in real time and compute time-aligned high-gamma and acoustic features, (2) continuously train a transformer model on those incoming and accumulated features over time, and (3) decode the incoming signals using a continuously updating model. The transformer model maps high-gamma activity into linear predictive coding (LPC) coefficients and utilizes LPCNet to generate the acoustic waveform [3] which is directly written into the soundcard buffer for low-latency playback.

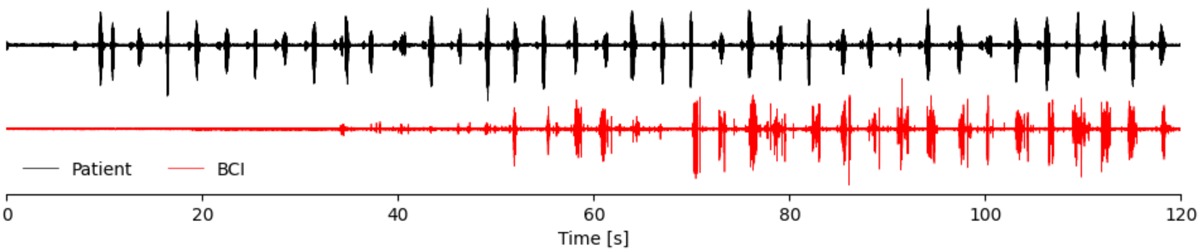

Figure 1. Patient and synthesized speech from the first two minutes in the operating room.

Results: Over time and with accumulating training data, the neural network started to output synthesized speech, at first very quietly, then more audibly. Figure 1 shows a snippet of the actual and reconstructed speech from the first experiment run, indicating that once enough trials have been seen during training, the model is capable of producing speech output at the time when the patient is speaking. Given the short period of time, both for training and data collection, all synthesized samples were not intelligible.

Significance: These preliminary results demonstrate the feasibility of intraoperative speech synthesis, which could be used to verify an effective anatomical placement of the Layer 7 cortical interface in future applications as a fully implantable speech BCI.

Disclosures: KB, JD, JM, EH, and BR have a financial interest in Precision Neuroscience.

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Intraoperative detection and classification of speech neural signals using the Layer 7 Cortical Interface

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Introduction: Brain-computer interfaces (BCIs) based on electrocorticography (ECoG) have seen broadening usage in clinical trials to augment and restore communication and control abilities for severely paralyzed individuals [1, 2]. Previous studies have shown that increased density of the electrodes can contribute to higher decoding accuracy from intraoperative data [3]. For these high-density grids, locating the ideal implantation site can be crucial for obtaining relevant information for decoding. It is therefore important to develop methods that can help assess implantation success and guide grid repositioning if necessary. This requires training and testing neural decoding models in real time during implantation surgery. However, it is not yet known whether detecting and classifying speech is possible in real time during awake surgery using high-density µECoG grids.

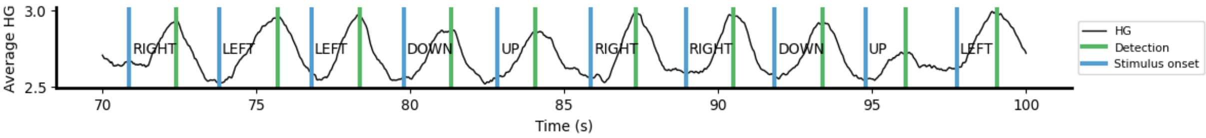

Figure 1. Example of real-time speech detection results. Black trace is the average high gamma (HG) energy across all channels. Blue vertical lines represent stimulus onset, Green vertical lines represent detection.

Material, Methods, and Results: The 1024-channel Layer 7 Cortical Interface (Precision Neuroscience, NY, [4]) was temporarily placed on ~1.5 cm^2 of the face motor area of a participant with no speech impairments during an awake craniotomy for tumor resection. The participant performed a word repetition task where they spoke one of four words out loud. An online speech detection model was designed to identify energy increases in the high-gamma band (70-170 Hz). A real-time classification pipeline was developed to segment the trials, train a neural network model with the growing dataset online, and make classification decisions with the best available model at that time.

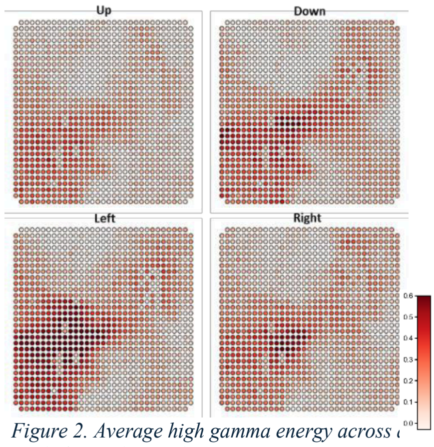

Figure 2. Average high gamma energy across (trials for each stimulus.

Conclusion: Real-time speech detection and classification is feasible using the Layer 7 cortical interface in a data-limited setting such as awake neurosurgical procedures.

Acknowledgments and Disclosures: We would like to thank the study participants who volunteered their time for this study. KB, JD, JM, EH, and BR have a financial interest in Precision Neuroscience.

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Towards Calibration-Free ECoG-Based Brain-Computer Interfaces: A Dual-Alignment Incremental Approach

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Introduction: Autonomous usage of ECoG-based brain-computer interfaces (BCIs) is still hindered by the burden of frequent calibrations, which require extensive data collection, leading to potential user fatigue and signal degradation. Therefore, a rising interest in addressing inter-session variability and long-term signal drift emerges. Domain Adaptation (DA) strategies, adapted to online unsupervised scenarios, may offer a pathway to stabilize models' performances. Recent approaches typically rely on batch normalization either alone or paired with Euclidean or Riemannian alignments [1], requiring large storage of feature-space transformations. This work introduces a novel approach that incrementally aligns incoming data - target - to resemble what was previously seen by the model - source.

Material, Methods and Results: The developed method integrates a dual alignment strategy: (1) geometric, where the target's data structure is mapped to the source's one; and (2) distributional, to harmonize the target's statistical properties. Additionally, it leverages a compact latent space, reducing computational overhead and storage, opposing to literature's most recent studies attempting real-time data alignment. Pseudo-online results, obtained with three states classification data from the "STIMO-BSI" (NCT04632290) clinical trial [2], acquired using WIMAGINE technology [3], demonstrate significant improvements (F1-Score) in model performance across sessions over five months (Fig. 1).

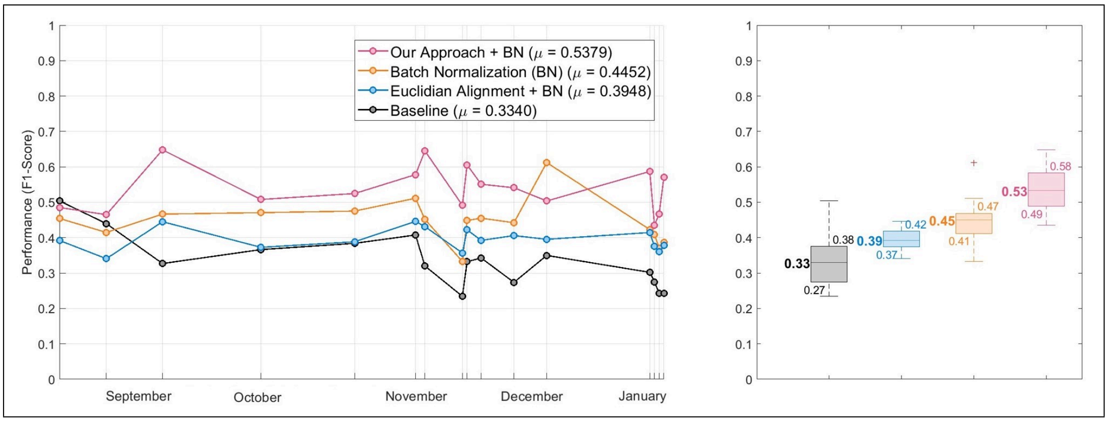

Figure 1: *Models' baseline performance compared with above-mentioned strategies and our approach, outperforming the others. The initial point represents the training day, while subsequent points correspond to the other existing sessions.*

Conclusion: This real-time incremental strategy surpasses recent methods in unsupervised online DA, advancing calibration-free ECoG-based BCIs and enabling more reliable use in home settings. Future work includes testing on additional datasets (e.g., more classes, upper limbs) and in online experiments.

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Recent Improvements of the Wireless Link of the CorTec Brain Interchange Implanted BCI

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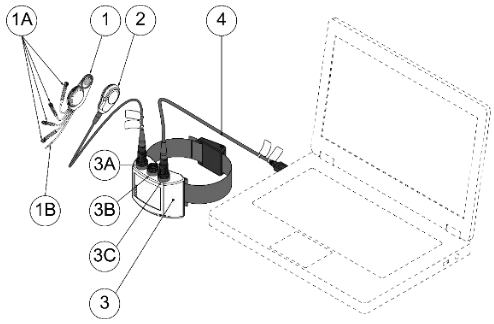
Introduction: The CorTec Brain Interchange is a brain-computer interface system consisting of a head-implanted electronic unit (IEU) and body-external components. The IEU is implanted behind the ear and wirelessly powered by a magnetically suspended headpiece placed on the skin, similar to that used in cochlear implant systems. The IEU communicate via a radio-frequency link with the body-external components. The location of the antenna outside the body is known to be critical. Here, we investigate potential improvements of the robustness of the wireless data link by moving the antenna from the traditional location at the upper arm to the headpiece.

Material, Methods and Results: Two szenarios (see Figure 1) are compared with respect to their wireless data link robustness: RF communication between the implant and the antenna located (A) in the communication unit, 30cm away from the implant and (B) in the headpiece, opposite to the implant. The data link performance is quantified as data packets lost in percent. Moving the antenna to the headpiece reduced packet loss as shown in Table 1, in the scenarios investigated here.



1: Implanted Electronic Unit (IEU)
1A - Electrode Connectors
1B - Ground Electrode

2: Headpiece

3: Communication Unit
3A - Headpiece Cable Connector
3B - Trigger Input Connector
3C - USB Cable Connector

4: USB Cable

Figure 2: *Components of the Brain Interchange System. The two locations for the data-transmission antenna outside the body are: Inside the communication unit (3) and inside the headpiece (2).*

Conclusion: Change of antenna position from communication unit to headpiece improved the wireless link quality. Note: as shown in [1], a reduced wireless communication packaet loss results in a lower noise level of the signals received by the computer.

Table 1: *Packets lost in two scenarios (Communication Unit 1 and 2 refer to the same szenario but two different systems)*

Metric	*Communication Direction*	*Antenna in Com-Unit 1*	*Antenna in Com-Unit 2*	*Antenna in Headpiece*
Packets Lost	*External to Implant*	*0.07%*	*0.02%*	*0.0%*
	Implant to External	*8.08%*	*4.43%*	*0.9%*

Acknowledgments and Disclosures: This work was funded by the European Innovation Council (EIC) in the call HORIZON-EIC-2022-ACCELERATOR-01, Proj. No 190118958, “BIC ONE”.

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Improving validation of BCI-based CV assessment

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Objective: Our laboratory develops non-invasive brain-computer interfaces (BCIs) for assessing color vision (CV) and identifying CV deficiencies. These systems use steady-state visual evoked potentials (SSVEPs) to identify *metamers*—light sources with different spectral distributions that are the same color [1]—and are based on the theory that light sources that are metamers do not elicit SSVEPs. To validate CV assessments, experiments use the same visual stimulator to compare BCI- and behaviorally-identified metamers.

We compared the accuracy of two methods for behaviorally-identifying metamers. The first [2], *fixed luminance*, reduced the search space to a single dimension by limiting settings to those with equal luminance. The second, *variable luminance*, introduced a novel approach allowing participants independently adjust the stimulator settings in two dimensions. We hypothesized the variable luminance method would enable the identification of light sources that were closer to being metamers, and thus, elicit smaller SSVEPs.

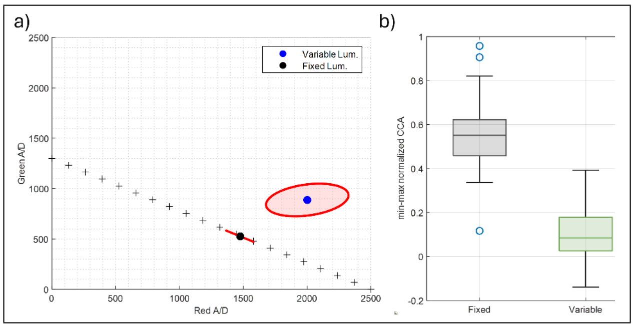

Figure 1: *Experimental results. a) Behavioral results . b) Comparison of min-max normalized SSVEPs for the two methods.*

Methods: 14 participants (6F) without CV deficiencies (FM-100 test [3] (mean $\pm$ SD: 40.6 $\pm$ 24.3)) participated (approved by the Stratton VA IRB) in behavioral experiments, 3 returned for BCI-based experiments (1F). The stimulator alternated between a monochromatic (590 nm) *amber* light source and a dichromatic (525 and 625 nm) *green* and *red* light source at 10 Hz. The luminance of the monochromatic light source was always fixed at 2400 D/A units.

Fixed luminance method – 20 stimulator settings (5 s/setting, 2 s ISI) were presented to participants in two orders (10 runs each). Order 1 – the dichromatic source initially emitted only green light (with equal luminance to the monochromatic light source), then gradually reduced green and increased red luminance, while maintaining constant overall luminance. Order 2 – reversed the sequence. Participants pressed a button to indicate the metamer; the final metamer was the median of the runs.

Variable luminance method – Participants controlled green and red luminances using 2 knobs and pressed a button when they identified the metamer; the final metamer was the median of 10 runs.

BCI-based experiments – 32 channels of EEG were recorded (g.tec; Brain Vision actiCAP). Four stimulator settings were presented (20 runs/setting): (1) Fixed luminance metamer, (2) Variable luminance metamer, (3) dichromatic source turned off (i.e., max SSVEP), and (4) constant amber (i.e., min SSVEP). SSVEPs were quantified using canonical correlation analysis (CCA) and min-max normalized.

Results: Metamers identified using the fixed luminance method (red: 1476, green: 526 A/D) elicited larger SSVEPs ($p < 0.001$) than the variable luminance method (red: 2001, green: 887 A/D) (Fig. 1).

Conclusion: The fixed luminance method for behaviorally-identifying metamers elicited smaller SSVEPs, suggesting these settings of the visual stimulator were more similar in color. An improved method for behaviorally-identifying metamers will enhance the development of BCI-based CV assessment systems.

Acknowledgments and Disclosures: This work was supported by the NIBIB of the NIH (Grants R21EB036221 (JJSN) and P41EB018783 (JRW)) and resources from the Stratton VAMC.

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Enhancing Online Learning through Neuroadaptive Interfaces: The Role of Motivation and Task Load Adaptation

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Introduction: Online learning has emerged as a transformative medium, with 21.8% of Canadians engaging in formal online training in 2022 [1]. However, ensuring optimal learning outcomes in such settings remains challenging. An important aspect to effective learning is the Zone of Proximal Development (ZPD), which delineates the range of tasks learners can achieve with scaffolding [2]. In brain-computer interfaces (BCIs), neuroadaptive systems (NS) provide a promising method to adapt cognitive states, such as cognitive load and task load (TL), in real time to maintain learners within their ZPD [3,4]. Unlike cognitive load, which is influenced by many factors, TL focuses on the mental effort explicitly required to complete a computer-based task. This study examines motivation in an online learning task, comparing the effects of extrinsic motivation (EM) and neuroadaptive countermeasures on learning outcomes.

Material, Methods and Results: Fifty-one participants (M = 26.6 years) were assigned to one of three groups: control (C), reward-only (R), and neuroadaptive (N). A real-time NS was developed, which used EEG to calculate TL as the ratio of frontal alpha and parietal theta band powers from eight electrodes. Task load was classified as high or low based on 1st and 3rd quartile average theta-alpha ratios from the group C data, triggering changes in stimulus presentation speed. The task involved learning 32 constellations in four training blocks, with countermeasures for Group N and performance-based incentives for Group R. All groups demonstrated improved performance over time. Group R outperformed Group C and Group N in later blocks, reflecting the motivational benefits of rewards. Despite Group N achieving comparable results to Group C, EEG-based topographic maps revealed group-specific neural patterns, with Group N exhibiting more effective associative decoding than Group C providing evidence for TL's role in optimizing performance.

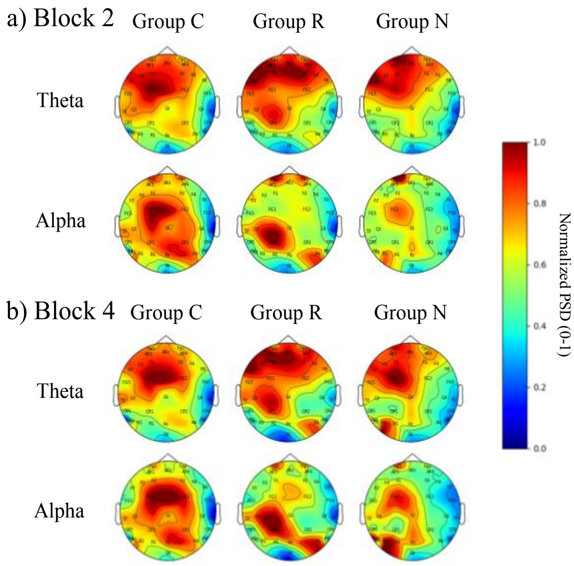

Figure 1: *EEG-based topographic maps displaying alpha and theta activity by group in the encoding phase of Block 2 (a) and Block 4 (b).*

Conclusion: This study advances understanding of TL's role in NS, highlighting its potential to enhance learning by using real-time interventions. By objectively measuring TL using EEG, this study provides a robust framework for future research and practical applications in education and beyond. Future research should focus on refinement and explore broader applications of a NS.

Acknowledgements: This work was supported by SSHRC through the Canada Graduate Scholarships - Master's program, ALLRP 565704 – 2, and RGPIN-2020-06048.

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Intracortical voice synthesis neuroprosthesis to restore expressive speech to an individual with ALS

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Introduction: Brain-computer interfaces (BCIs) have enabled people with speech loss due to neurological disease to communicate by decoding their neural activity into text[1-3]. However, text-based communication falls short of restoring crucial aspects of human speech such as prosody, intonation and voice feedback. In this study, we present a "brain-to-voice" neuroprosthesis that instantaneously synthesizes voice with continuous closed-loop audio feedback by decoding intracortical neural signals of a man with ALS. We also decode paralinguistic features of speech from neural activity, enabling the participant to modulate intonation and pitch of his BCI-synthesized voice.

Materials and Methods: A 45-year-old man 'T15' with ALS and severe dysarthria (unable to speak intelligibly) participated in the BrainGate2 clinical trial. Four microelectrode (Utah) arrays with a total of 256 electrodes placed in the precentral gyrus recorded intracortical signals as T15 attempted to speak. The absence of ground truth speech from T15 posed a major challenge for building an instantaneous voice neuroprosthesis. We overcame this hurdle by generating target speech time-aligned with neural activity as a proxy to T15's intended speech[4]. We developed a real-time causal neural decoding pipeline with a Transformer-based brain-to-voice model to predict spectral and pitch speech features from neural activity. A vocoder synthesized voice every 10 ms and played it aloud (**Fig.1a**). Separate paralinguistic decoders ran simultaneously to detect changes in intonation and pitch. We then modulated the synthesized voice in closed-loop, allowing T15 to ask a question, emphasize words, and "sing" melodies.

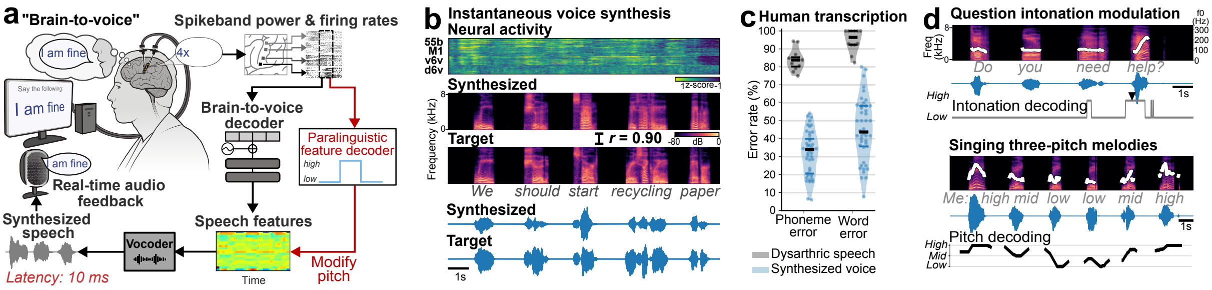

Fig. 1: ***Closed-loop expressive voice synthesis BCI. (a)*** *Brain-to-voice decoder pipeline for instantaneous voice synthesis.* ***(b)*** *An example of causally synthesized speech from neural activity, which matches the target speech with high fidelity.* ***(c)*** *Intelligibility of synthesized speech- median phoneme and word error rates obtained via open transcription by human listeners.* ***(d)*** *Example trials of closed-loop modulation of paralinguistic speech features- question intonation modulation (top) and three-pitch melody (bottom). White trace shows synthesized pitch.*

Results: The brain-to-voice BCI causally synthesized voice nearly-instantaneously with high accuracy (Pearson r=0.89±0.04 with target speech across 40 Mel-frequencies) (**Fig.1b**). Human listeners performed an open transcription of the synthesized voice with a median phoneme error rate of 34.0% and word error rate of 43.8% (in contrast to 96.4% word error rate for T15's residual speech) (**Fig.1c**). Thus, the brain-to-voice BCI vastly improved T15's intelligibility. T15 used this BCI to produce flexible unrestricted vocalizations (including with a neural decoder that approximated his own voice). He could expressively modulate his BCI-voice to ask a question (accuracy: 90.5%), emphasize words (accuracy: 95.7%), and sing short melodies with three different pitch levels (**Fig.1d**).

Conclusion and Significance: These results demonstrate an unprecedented quality of expressive brain-to-voice synthesis, advancing the potential of BCIs to fully restore naturalistic speech.

Acknowledgments and Disclosures: We thank T15 and his family for their invaluable contribution. M. W., D.M.B., S.D.S.: Inventors on IP owned by UC Davis; L.R.H: Consultant to Neuralink, Synchron, Axoft, Precision Neuro, Reach Neuro; D.M.B: Surgical consultant to Paradromics; S.D.S: Inventor on IP owned by Stanford University licensed to Blackrock Neurotech and Neuralink, advisor to Sonera.

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Simultaneous independent control of two cursors on the first day of intracortical BCI use by a participant with microelectrode arrays in bilateral precentral gyri.

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Introduction: Although independent bimanual movements are ubiquitous in daily living, restoring this functionality for people with tetraplegia using intracortical brain-computer interface (iBCI) technology has received little attention. Electrophysiological studies in monkeys and humans have shown that neuronal ensemble activity in the unilateral motor cortex reflects both contralateral and ipsilateral movement[1,2], which can be harnessed to control two cursors simultaneously[3,4]. However, neurons can be tuned differently to uni- and bilateral arm movements[2,5], requiring non-linear decoders trained on multiple days of data order to gain bimanual cursor control[4]. Here, we demonstrate independent control of two cursors on the first session of closed-loop iBCI control by a BCI-naive participant using microelectrode arrays in bilateral motor cortices. A rapid calibration paradigm[6] enabled our participant to gain control of both cursors within minutes without the need for any prior training data.

Material, methods and results: We recorded data from a single human participant (T18) enrolled in the ongoing BrainGate pilot clinical trial (www.ClinicalTrials.gov; Identifier: NCT00912041). T18 is a 48 y/o male with tetraplegia from a cervical spinal cord injury (C4 ASIA A). T18 has six 64-channel intracortical microelectrode arrays placed in bilateral hand knob areas, of which four are in the left motor cortex and two in the right motor cortex. He was asked to perform a bimanual grid task, by moving two cursors simultaneously to their corresponding targets and holding both in place for 300ms. Once acquired, the next set of targets were immediately presented. T18 moved each cursor by attempting to control an imaginary joystick with the corresponding hand. A single Kalman filter was used to decode 2D directional vectors for both cursors simultaneously for a total of four control dimensions. A rapid calibration paradigm, where the decoder parameters were recomputed every 3 seconds, enabled T18 to gain control of the two cursors within minutes of the block on the first day of closed-loop iBCI sessions.

Conclusion: This work demonstrated that neuronal ensemble activity from bilateral precentral gyri enables a iBCI user to rapidly gain independent control of two independent effectors simultaneously operating in four dimensions, without the need for any open loop calibration block.

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CAUTION: Investigational Device. Limited by Federal Law to Investigational Use LRH: The MGH Translational Research Center has a clinical research support agreement (CRSA) with Axoft, Neuralink, Neurobionics, Paradromics, Precision Neuro, Synchron, and Reach Neuro, for which LRH provides consultative input. LRH is a non-compensated member of the Board of Directors of a nonprofit assistive communication device technology foundation (Speak Your Mind Foundation). Mass General Brigham (MGB) is convening the Implantable Brain-Computer Interface Collaborative Community (iBCI-CC); charitable gift agreements to MGB, including those received to date from Paradromics, Synchron, Precision Neuro, Neuralink, and Blackrock Neurotech, support the iBCI-CC, for which LRH provides effort. All other authors have no competing interests.

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A Wearable BCI Mediated Generative AI System for Conversational Interactions

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Introduction: There are many existing speech generation systems that utilize BCI for individuals with severe motor impairments such as ALS [1][2][3]. This work presents a novel SSVEP based BCI system that is realized in a fully mobile and wearable form factor incorporating EEG sensing and an augmented reality heads up display. The system also incorporates a novel conversational copilot system that uses generative AI technologies to personalize conversational interactions. The system was evaluated with a cohort of ALS users in both acute and chronic use.

Material, Methods and Results: The generative AI system was developed using the Axon-R system from Cognixion. This system includes an optical see through augmented reality display, Android 13 based wearable computer and an 8 channel EEG wet sensor array. A novel interaction framework was developed in Unity to enable lower accuracy SSVEP based BCI stimulus-response classification user selection. The heads-up display interface is shown in Figure 1. The system incorporates a set of personalized generative AI conversation and word completion models to enable users to engage in near real-time communication with others using speech or a chat style interface. The system was evaluated and refined in a usability study in preparation for a longitudinal study, which is ongoing. Metrics captured included information transfer rate (ITR), system usability scale (SUS) [4] and clinical quality of life measures. Results indicate that the refined interface, once users become proficient, provides a compelling conversational system for users that have no current technological options.

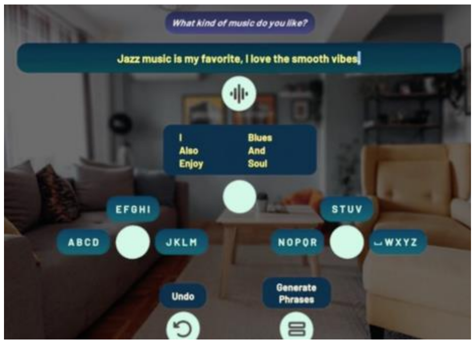

Figure 1: Heads up generative AI driven conversational user interface.

Conclusion: These results demonstrate that a near real-time conversational pace is possible for BCI interfaces augmented with generative AI capabilities.

Acknowledgments and Disclosures: The research team would like to thank the persons with ALS that participated in this study. This work would not have been possible without a generous grant from the Aleph Institute.

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Using a Long Short-Term Memory Neural Network for Generation of Control Signals from μECoG Data

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Introduction: Neural decoding studies highlight significant advancements in brain-computer interfaces (BCIs) for predicting motor intentions and controlling assistive technologies. Studies have demonstrated the robustness of using field potentials recorded from intraparenchymal BCIs as control signals for communication and motor prostheses [1, 2, 3]. We have similarly demonstrated that local field potentials recorded from epicortical micro-electrocorticography (µECoG) BCIs can be decoded using Machine Learning (ML) algorithms, and serve as control signals for speech and motor prostheses [4,5]. µECoG offers a good balance between invasiveness, signal quality, and longevity, making it a viable choice for real-time neural control systems. Artificial Intelligence (AI) algorithms are currently being utilized for decoding behavioral states from cortical activity [6]. Despite its potential, challenges remain in translating µECoG data into accurate control signals suitable for real-world applications. This work investigates these challenges by implementing AI algorithms, specifically Long Short-Term Memory (LSTM) networks, on µECoG neural signals recorded during motor tasks. LSTM networks were selected due to their ability to model temporal dependencies in time-series data. The study aims to evaluate the AI model's ability to generalize and preserve temporal dependencies, which are critical for practical deployment in assistive technologies.

Material, Methods and Results: The µECoG signals were recorded from a patient performing reaching movements toward multiple targets, with 16-channel grids implanted over the hand and arm regions of the primary motor cortex [5]. Common Average Referencing (CAR), comb filters, and low-pass filters were applied to clean the data, remove noise and artifacts, prior to extracting the features from the data for training the model. Model evaluation included scenarios where the X,Y positions of the mouse were predicted using interpolated data i.e., where temporal relationships are not maintained; and extrapolated data i.e., temporal relationships are maintained, in order to understand the temporal dependencies in the algorithm and its ability to provide a generalized solution.

Initial results demonstrated an accuracy of over 90% in predicting movement trajectories and classifying motor intentions within a single experimental session using interpolated data. This high accuracy was based on shuffled data, which does not accurately model real-world conditions. Subsequent investigations compared interpolated data (LSTM with shuffled data) and extrapolated data (LSTM with unshuffled data separated in time) to better assess generalization. Preliminary findings indicated that while the LSTM model performs well with interpolated data, the performance was reduced to approximately 70% accuracy when handling extrapolated data, highlighting challenges in capturing temporal dependencies effectively and utilizing AI models in real-time applications.

Conclusion: Our findings show that LSTM networks perform well with interpolated data but struggle to generalize when temporal relationships are preserved i.e., with extrapolated data. This highlights a critical limitation for real-world applications and aligns with existing research emphasizing the need for models that handle sequential neural data effectively.

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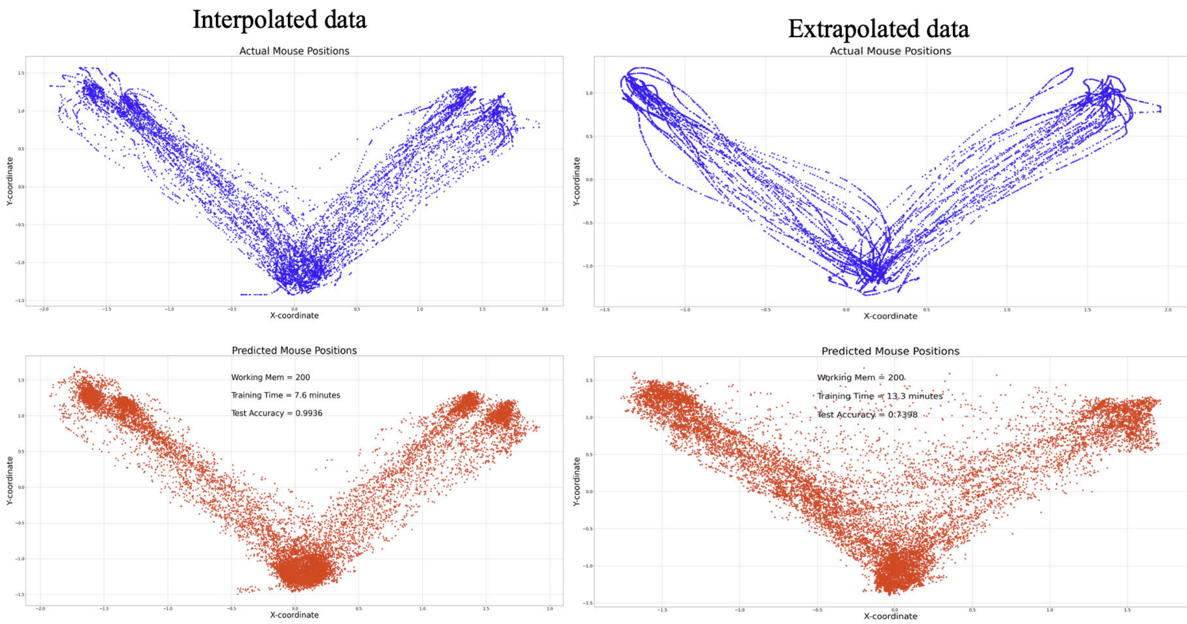

Figure 1: A comparison plot in which the first one shows the predicted vs actual mouse positions of the interpolated data and the second one shows the same for extrapolated data.

Acknowledgments and Disclosures: Tyler Davis MD/PhD, Sara Hanrahan PhD, Paul House MD, and Spencer Kellis PhD conducted the experiments and collected the data used in this study. The authors have no COI to disclose. Support from DARPA Revolutionizing Prosthetics 2009 contract N66001-06-C-8005.

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Decoding gestures from intracortical neural activity in ventral precentral gyrus

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Introduction: Intracortical brain-computer interfaces (iBCIs) can restore communication for individuals with paralysis by decoding their motor intent from neural signals and performing computer actions. Recently, we showed that precentral gyrus encodes a broad range of body movements/gestures and speech in a widely distributed manner [1,2]. Following this observation, in this study we integrated gesture decoding with computer cursor control driven by electrodes in ventral (speech) motor cortex with the goal of introducing discrete assistive computer actions, such as mouse right-click, scroll, copy/paste, etc. into an existing multimodal cursor and speech neuroprosthesis framework.

Material, Methods and Results: One participant with ALS was implanted with 4 Utah arrays in precentral gyrus (areas 4, 6v and 55b) [3,4]. We first collected a dataset examining the neural representation of 60 broadly sampled body movements, with a specific focus on hand and face (**Figure 1a**). Neural responses exhibited distinguishable signatures for most attempted body movements (**Figure 1b**), and these movements could be reliably decoded from the neural data (**Figure 1c**). Next, we selected a set of 2, 3, or 4 movements and asked the participant to perform a multi-gesture cursor and click task, in which the participant moved a cursor towards a target and then attempted a cued gesture to select it (**Figure 1d**). We observed significant neural modulation to both cursor direction and attempted gesture. Signals from all arrays contributed significantly to gesture decoding (**Figure 1e**). Cursor movement and gestures were decoded in real time as described in [3], and the participant achieved closed-loop decoding accuracy of **91**%, **89**% and **80**% for 2, 3 and 4 gestures, respectively.

Conclusion and future work: We showed that gestures can be decoded from neural activity in cortical areas 6v, 4 and 55b in a closed-loop task. Next, we will integrate gesture decoding into personal computer use to allow flexible and intuitive mapping between attempted gesture and computer actions.

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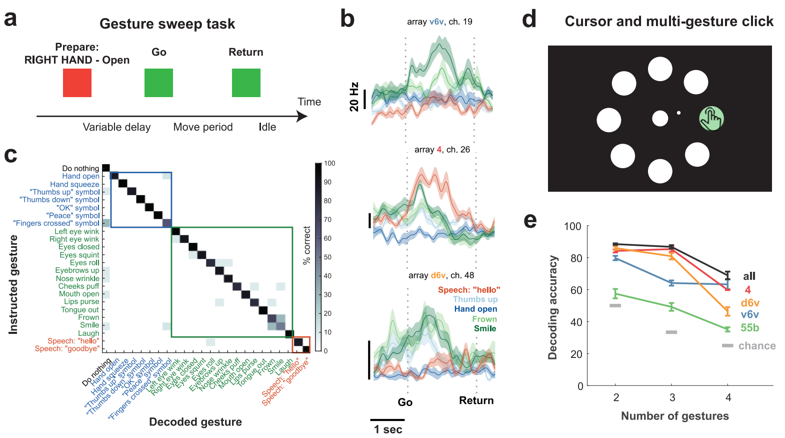

*Figure 1. **a)** Instructed delay task to evaluate neural tuning to 60 attempted movements. A cued movement was displayed on the screen above a red rectangle in the center of the screen. After a variable delay, the rectangle turned green (go cue), prompting the participant to execute the movement until a return cue was displayed. **b)** Trial-averaged firing rates (mean±s.e.) for five example conditions recorded from three example electrodes from different arrays, aligned to the go cue and color-coded by condition. **c)** Confusion matrix for gesture classification of a subset of gestures from the hand (blue), face (green), and speech (orange) was performed using Linear Discriminant Analysis (LDA). Colored squares group gestures by their corresponding modality. **d)** Example cursor and gesture task. The participant was instructed to move the cursor to the green target and, once the target was reached, execute the prompted action. **e)** Offline decoding accuracy (LDA) of 2, 3 and 4 gestures with signals split by array. Grey bars indicate chance classification accuracy.*

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TALES – Tech, Analysis, Legal, Ethics, Social: A Comprehensive Impact Assessment Framework for Responsible Neurotech Innovation

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Introduction: Neurotech is a rapidly growing sector with extraordinary potential for improving human health and wellbeing, providing novel tools for basic research, and generating commercial and economic benefits. However, the development and application of neurotech also raises important legal, ethical, and social considerations. Recently, international organizations (e.g. OECD, UNESCO) have published consensus reports highlighting recommendations for responsible innovation in neurotech [1] and the risks and challenges of neurotech for human rights [2]. Health Canada has convened a Working Group on Responsible Innovation in Neurotech to develop an appropriate implementation of these strategies in Canada [3]. Furthermore, neurotech is increasingly utilizing methods from machine learning and artificial intelligence, which raise additional legal, ethical, and social considerations [4]. An emerging strategy aligned with these ethics recommendations is the development and usage of impact assessment frameworks throughout the innovation process, which serve to identify and assess benefits, concerns, and risks of emerging technology and provide guidance about risk prevention and mitigation [5,6,7].

Material, Methods and Results: We present the TALES neurotech impact assessment tool, which facilitates the evaluation of tech specifications, analysis methods, and legal, ethical, and social considerations related to the development and application of a neurotech device. We developed TALES for an educational context – as an integral part of the 'Ethical Considerations for Neurotech' course within the Queen's University Neurotech Microcredential Program. The course consists of four modules and a final project. In the first module, learners are (re-)introduced to foundational neuroscience and ethics concepts and explore a variety of types of neurotech devices (neuroimaging, neuromodulation, and brain-computer interfaces). In subsequent modules, learners explore various use-case sectors (medical, consumer, organizational) with practical case-studies and learn to use the TALES impact assessment framework. In the final project, learners apply TALES to analyze a new case-study of their choice.

Figure 1: *Queen's University Neurotech Microcredential Program. Coming soon (2025): Ethical Considerations in Neurotech course.*

Conclusion: The TALES neurotech impact assessment tool is a novel educational resource for learners in the 'Ethical Considerations in Neurotechnology' Microcredential course. In the future, adaptations of TALES could have further potential applications across industry and the public sector to guide, promote, recognize and set standards for responsible neurotech innovation.

Acknowledgments and Disclosures: Funded by the Microcredential Challenge Fund (Province of Ontario) and the Connected Minds Program (Canada First Research Excellence Fund, Grant #CFREF-2022-00010). Financial compensation was received for curriculum development and teaching.

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Comparative Analysis of the NeuroExo™, the Stentrode™, and the N1™ BCI devices

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Introduction: Technology has revolutionized how we interact with others and view the world, with advancements in neural engineering enabling communication for users previously unable to do so. This technology, known as brain computer interfaces (BCI) translate brain activity into commands for virtual or physical machines to restore or rehabilitate motor, sensory or speech functions [1]. However, the recent convergence of BCIs and IoT can enable direct brain communication with appliances, vehicles, and even people [2]. This fosters advancements in communication for a diverse range of individuals, enhancing connectivity and interaction for all. Three BCI systems that stand out in creating devices that converge BCI and IoT are the NeuroExo from the BRAIN Center at University of Houston, the Stentrode from Synchron™, and the N1 implant from Neuralink™. This study aims to compare these three BCI devices in terms of their usability, device specifications, and trade-offs.

Material, Methods and Results: Data were sourced from peer-reviewed studies, patents, and company documentation. The product and engineering specifications of the BCIs were assessed based on the following categories: invasiveness, signal modality and processing, machine learning and tasks performed. NeuroExo is entirely non-invasive, using an external electroencephalography (EEG) headset with self-positioning dry comb electrodes, while Stentrode requires minimally invasive surgery as it is placed into the superior sagittal sinus via the jugular vein, and N1 involves major intracranial surgery to place an implant directly on the motor cortex. Resolution also varies with invasiveness: NeuroExo has 8 channels with a sampling frequency (SF) of 500 Hz, Stentrode features 16 channels and has a SF of 2 kHz, and N1 offers 1,024 channels at a SF of 19.3 kHz. Signal modalities reflect similar trends. NeuroExo measures EEG and electrooculography (EOG) up to 131 Hz, suitable for movement related cortical potentials. Stentrode detects vascular electrocorticography (vECOG) up to 250 Hz, while N1 measures LFP and action potentials (AP) for the most granular neural data up to 3-27 kHz. All three BCI devices have analog signal conditioning (e.g., Bandpass filtering), but only the NeuroExo includes digital adaptive noise canceling necessary for artifact identification and removal. Classification algorithms include support vector machine (SVM) and linear discriminant analysis for NeuroExo and SVM for Stentrode, with N1 employing a custom spike detection system. IoT compatibility highlights distinctions, with NeuroExo seamlessly integrating BT and Wi-Fi. Stentrode relies on RF, while N1 claims BT support. The three BCI systems differ in the scope of tasks performed. Stentrode trials include communication tasks such as unsupervised typing at home, while NeuroExo focuses primarily on upper-limb stroke neurorehabilitation at both the clinic and at home. As per company social media posts, N1 has reported gaming applications, such as chess. Standardized and transparent testing protocols, as well as user, clinical and engineering outcome metrics are needed to allow quantitative comparison of these BCI systems.

Conclusion: The devices differ in invasiveness: NeuroExo is non-surgical, while Stentrode and N1 require surgical implantation. Stentrode and N1 have received an IDE from the FDA, while there is an FDA approved BCI predicate to NeuroExo. Despite differences, all three systems enable IoT integration, advancing connectivity and user interaction. This study underscores the importance of balancing risk, functionality, and user preferences to guide device selection in an increasingly IoT-connected world.

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Multimodal Sensor Fusion for EEG-Based BCI Typing Systems

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Introduction: For people with severe speech and physical impairments (SSPI), a robust communication interface is often a necessity to improve quality of life. Non-implantable electroencephalography (EEG)-based BCI typing systems are one option in the field to restore communication. In an EEG-based typing interface, a sequence of symbols are presented consecutively on a screen, and the intended symbol is probabilistically inferred by the resulting event-related potentials (ERPs) [1]. Selecting the intended symbol often takes multiple attempts due to a subset of all symbols being presented in each sequence, and a decision cannot be made if the EEG evidence does not strongly support the intended symbol.

Material, Methods and Results: Here we describe a multimodal fusion algorithm combining EEG and gaze tracking (i.e., fixation and trajectory) for control of an ERP-based BCI. This work focuses on a specific BCI paradigm called single-character-presentation (SCP) based visual presentation, which consists of symbols presented in matrix form and individually highlighted in randomized order. We develop and compare probabilistic Bayesian fusion algorithms of increasing complexity to observe the effect of probabilistic assumption sets on the multimodal BCI performance. We propose a method assuming positional and temporal dependence in gaze evidence. We collected calibration data from control participants (n=21, mean age 23.6±3.1 years) in a quiet lab room and participants with SSPI (n=8, mean age 62.6±15.7 years) in their homes. EEG data were collected using a DSI-24 cap (Wearable Sensing) at a sampling rate of 300 Hz, and the gaze data were collected using a portable eye tracker (Tobii Pro Nano) at a sampling rate of 60 Hz. The SCP matrix paradigm and the data acquisition modules are developed in BciPy [2], which is a standalone application for experimental data collection.

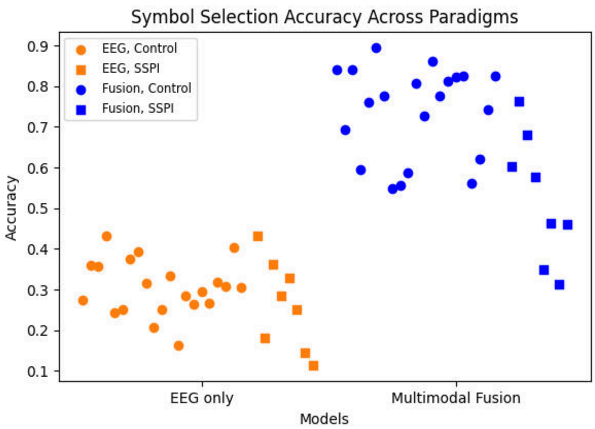

Figure 1: *Performance analysis of EEG only (orange) and Multimodal Fusion (blue) models for 21 control (circle) and 8 SSPI (square) participants. The sequential data is bootstrap sampled (N=100) and split into train-test subsets for typing performance analyses.*

Conclusion: Experiments with both control participants and people with SSPI show that the proposed multimodal Bayesian fusion method significantly improves performance in symbol selection (M=0.73, SD=0.11 for control; M=0.53, SD=0.15 for SSPI) compared to EEG-only BCI typing systems (M=0.30, SD=0.06 for control; M=0.26, SD=0.09 for SSPI) (see Fig. 1).

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A Family-centered Brain-Computer Interface Clinical Research Program for Children with Severe Disabilities

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Introduction: Cerebral palsy is the largest contributor to the global burden of severe neurological impairment. Brain-computer interfaces (BCIs) are a potential solution, but pediatric populations have been neglected from research and progress [1]. We established a family-centered pediatric BCI clinical research program (BCI4kids) to enable children with severe motor impairments to realize new participation in life.

Materials, Methods and Results: Children and their families were identified within a population-based, tertiary-care children's hospital. Criteria included: 1) age 4-18 years, 2) severe physical disability (non-ambulatory, minimal hand use, nonverbal), and 3) estimated grade 1 cognitive capacity. After initial screening for BCI competency, participants attended regular sessions, attempting commercially available and customized non-invasive BCI systems to operate a suite of applications (e.g., gaming, device control, art, communication). Outcome measures included personalized goal achievement (COPM), family engagement and experience (MPOC-20, PRIME-P), and technology efficacy and usability. Over 5 years, we have enrolled 34 participants (median 12.4 years, range 3-18, 53% male, 24 distinct etiologies). BCI systems and training were well tolerated with no serious adverse events. All but one participant demonstrated the ability to perform BCI tasks. More than 940 hours of participation have occurred across >820 sessions. Mental imagery-based tasks were the most successful, while other paradigms (P300, SSVEP) had lower efficacy and tolerability. Popular applications included painting, cooking, environment control, internet access, and video games. Six children chose and accomplished power mobility goals (Figure 1). Successful translation of BCI systems into home environments was demonstrated with 11 families, totaling >460 sessions. Families reported a major positive impact and their high engagement informed program development. The program has been implemented in the provincial healthcare system, with increasing referrals and waitlists.

Figure 1: An 11-year-old uses BCI to drive his wheelchair using a power trainer.

Conclusions: Family-centered clinical BCI programs can allow children with severe disabilities to achieve novel, personal goals that they previously considered impossible. Future directions include expansion to other hospital sites in Canada and additional resources to support home and community-based participation.

Acknowledgements and Disclosures: We are grateful to all the families who have participated in the BCI4kids program. We also wish to acknowledge the efforts and innovations of our partners in Edmonton and Toronto. Authors Kelly, Floreani, Kinney-Lang and Kirton are co-founders of Possibility Neurotechnologies, a pre-revenue BCI start-up company. No products are promoted in this program.

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BCI-FIT: Effects of cBCI customization on performance

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Introduction: The BCI Functional Implementation Toolkit (BCI-FIT) is a customization protocol for EEG-based communication BCI (cBCI) systems that provides a set of system configuration options which might improve performance for individuals with severe disabilities [1]. We describe a single-case research design experiment investigating the effects of customization on typing performance.

Material, Methods and Results: BciPy software [2] was configured with options for: 1) event-related potential (ERP) typing interface (matrix or rapid serial visual presentation [RSVP]), 2) interface appearance (e.g. font or matrix size), 3) stimulus presentation (e.g. flash rate or number of characters flashed), 4) signal processing (e.g. trial window), and 5) cap (DSI-Flex or DSI-24, Wearable Sensing).

Using an alternating-treatments single-case research design, we compare typing performance with a customized BCI-FIT configuration to a non-customized single-character paradigm matrix speller. Up to 5 people with amyotrophic lateral sclerosis (ALS) and speech and/or physical impairments are participating in weekly data-collection home visits. First visits include informed consent, clinical screening, initial calibration of the matrix and RSVP interfaces, and discussions about customization options. For each participant, the study team determines an initial BCI-FIT configuration based on clinical screening results, system performance, and user preferences. In subsequent visits, the participant completes system calibration and a typing task (copying four 5-letter words) for both the customized and non-customized conditions. After each typing task, participants provide feedback, including any requested changes to their customized configuration. Dependent variables (DV) include percent of target characters copied (primary typing performance DV), targets copied per minute, and participant-reported workload ratings. Ongoing formative assessment includes discussion of potential changes to the customized configuration based on typing performance, participant preferences, clinical observations, ERP characteristics, and simulations. Data collection continues until 1) sufficient differentiation is observed between the two conditions for percent of targets copied or targets copied per minute (e.g., five demonstrations), 2) percent of targets copied is below 90% in five visits and the study team agrees there are no more system modifications that might improve performance; or 3) 20 visits have been completed.

Figure 1 shows data from two participants, whose customized parameters included interface type, trial window, flash rate, number of characters flashed, and matrix size. P1 consistently copied 95-100% of target characters for both conditions starting in visit 2, so for him BCI-FIT was optimized for targets copied per minute. The final BCI-FIT configuration for P1 outperformed the standard condition with three demonstrations of effect. Typing performance for P2 was variable for both conditions and never reached 90% of targets copied. Although neither condition showed superior levels of performance for P2, outcome data were instrumental in understanding and refining customization for specific participant variables.

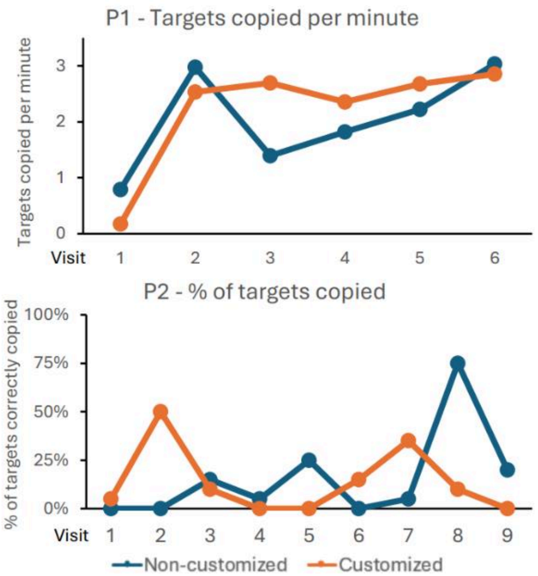

Figure 1: Data from 2 participants comparing performance with non-customized and customized versions of the cBCI across multiple visits.

Conclusion: Customization may improve cBCI typing performance or user experience for some individuals with disabilities. Additional control signals (e.g. code visual evoked potential) and other options could support successful typing for a wider range of users.

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Neural Dynamics of Cognitive Tasks in Human Prefrontal and Parietal Cortex

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Introduction: Many neurological conditions are associated with deficits in cognitive or executive function, including existing populations for implanted brain-computer interfaces (iBCIs) e.g. spinal cord injury, motor neurone disease, and beyond e.g. dementia, mood disorders. Human iBCIs with electrodes in higher order cortical areas offer the potential to further elucidate the neural mechanisms of cognitive function, with the potential of restoring cognitive deficit similarly to the restoration of sensorimotor deficit to date. Here we focus on intracortical electrode arrays implanted in dorsolateral prefrontal cortex (dlPFC) and supramarginal gyrus of parietal cortex (SMG) in one human participant. We use the Stroop task to identify and decode the neural dynamics of an aspect of cognitive control – response inhibition and interference control.

Methods and Results: Neural recordings were made using Utah Arrays (Blackrock Neurotech, UT, USA) implanted in human prefrontal, parietal and sensorimotor cortices. The participant completed a Stroop task, in which presented text and text color differ, e.g. 'RED' shown in red or 'RED' shown in blue. Participants either reported the text (dominant response), or color (non-dominant) in congruent conditions, when the text and color match and incongruent, when they do not. We identified significant single-unit neurophysiological responses to the different color, text, congruent and incongruent conditions. In higher order cortical areas, the evoked neurophysiology for the dominant text response was indistinguishable between congruent and incongruent conditions. However, there were significant differences in the dynamics of the non-dominant color response, both compared to text response and within congruent and incongruent color response. Exemplary individual electrodes are shown in Figure 1A, B. To assess the whole neural population in each cortical area we used a linear discriminant analysis (LDA) to classify congruent and incongruent trials, for text and color responses, Figure 1C, D. There was no significant classification compared to a shuffle distribution during the dominant text response, but a significant classification for the non-dominant color response. No significant classification was found for any condition in primary sensorimotor areas.

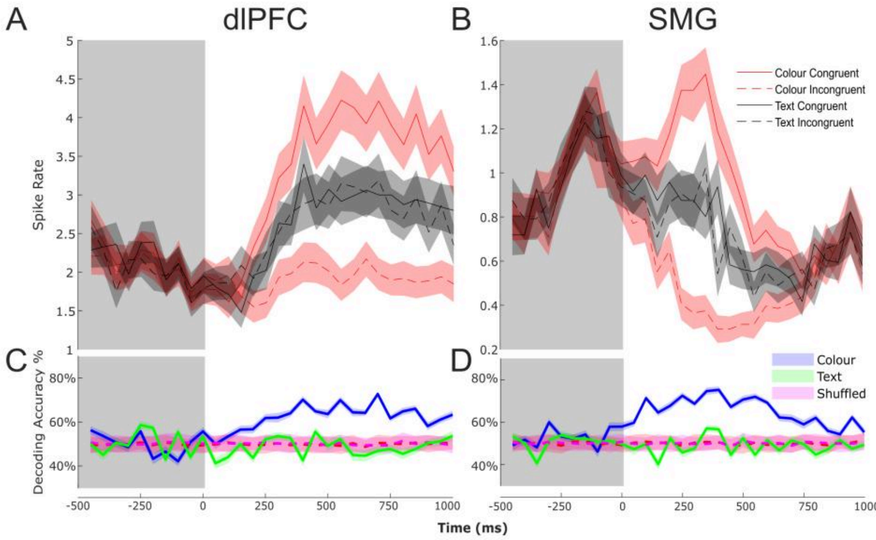

Figure 1: A-B Multi-unit activity of a single electrode in A) dlPFC and B) SMG to different confitions. C-D The LDA classification accuracy of congruent/incongruent from the population response in C) dlPFC and D) SMG.

Conclusion: These results demonstrate circuit level dynamics for response inhibition and interference control. Future work seeks to explore additional cognitive functions and assess the effects of closed-loop stimulation targeting these dynamics to alter performance in cognitive tasks.

Acknowledgments and Disclosures: This work was performed as part of an ongoing clinical trial (NCT01964261). The authors have nothing to disclose relating to this work. The authors wish to thank the participant for their involvement in the study.

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Neural activity during persistent sensations caused by intracortical microstimulation

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Introduction: Intracortical microstimulation (ICMS) in the somatosensory cortex (S1) can be used in closed-loop brain computer interfaces (BCIs) to provide artificial somatosensory feedback and can improve motor BCI performance [1]. When a tactile sensation is elicited using ICMS, it is expected to last exactly as long as the stimulation. However, on very rare occasions (41 cases in over 260,000 trials), some participants in our studies report sensations that outlast the stimulation period, typically by several seconds. The cause and underlying neurophysiological mechanisms of these persistent sensations are unknown.

Material, Methods and Results: Three people were implanted with microelectrode arrays in tactile regions of S1 as part of a clinical trial of an intracortical sensorimotor BCI (NCT01894802). The Neuroport System (Blackrock Neurotech) allowed us to simultaneously stimulate and record from these microelectrode arrays. Two participants reported percepts that outlasted stimulation at least once throughout their participation. In some of these cases, we observed a large amplitude signal resembling self-limiting after discharges [2] observed in electrical cortical mapping studies and that disappear spontaneously (Fig. 1A). Apart from the extended percept duration, the only other effects the participants reported were infrequent and slight changes in the quality of the sensation. The sensations remained localized to the location where stimulation initially evoked a percept. The neural activity during these events occurred across all channels on the array containing the stimulation electrode, with the maximum amplitude (1.58 ± 0.23 mV, Fig. 1B) centered on or near the stimulated electrode (see Fig. 1C). The activity did not occur on any other array in the motor cortex or S1, demonstrating highly localized activity. In all cases, the activity vanished within 20 seconds after stimulation ended (12 ± 4.3s).

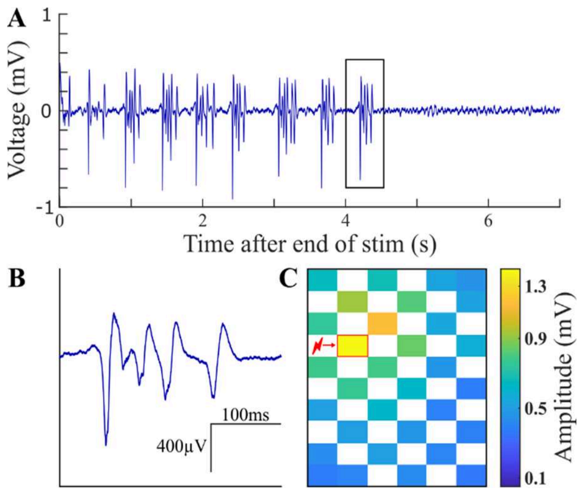

Figure 1: (A) Rhythmic neural activity during a persistent sensation. (B) Zoomed-in view of one burst. (C) Signal strength across the array.

Conclusion: These results indicate that in some study participants large amplitude rhythmic neural activity can occur in S1 after ICMS, and that this activity is sometimes associated with sensory percepts. This activity is spatially and temporally self-limiting. Whether this also occurs spontaneously is unknown. Apart from these infrequent persistent sensations, ICMS has not been associated with any significant clinical findings regardless of whether synchronous neural activity is observed or not. As this rhythmic neural activity is often associated with persistent sensations, which are undesirable, this activity may allow us to more rapidly identify and avoid these stimulus parameters.

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Long-term stability and performance of stimulation and recording in a human participant over 2,800 days

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Introduction: The long-term stability of recording and stimulation performance of implanted electrodes is a fundamental requirement for the viability of brain computer interfaces (BCI) as clinical and assistive devices. Chronically implanted devices have documented lifetimes up to 4 years in human participants [1]; however, the timeline of device material failure [2] and stability of the underlying neural population [3] are unknown for the duration of a multi-decade participant lifetime. In this work, we show the longest reported performance data (both stimulation and recording) from four micro-electrode arrays implanted in a human participant over 0.8 decades.

Material & Methods: Over the implant duration until present time, quantitative measurements were obtained at regular intervals for each electrode individually: RMS noise, 1 kHz impedance, and SNR. We used spatiotemporal patterns of intra-cortical micro-stimulation (ICMS) to elicit naturalistic somatosensory percepts. For each electrode, we quantified participant reported descriptions (Figure 1B) and projected fields (the somatotopic location of each percept, Figure 1A).

Results: Our data shows a stable electrical interface is possible for nearly a decade of chronic implantation. For the duration of study: electrodes on 4 (of 4) arrays were still able to record single neuron waveforms (Figure 1C) and the participant was able to volitionally modulate those measured neurons via mental imagery. Nearly every electrode on 1 (of 2) stimulation arrays (SIROF) continued to elicit somatosensory percepts via ICMS (Figure 1D). Finally, not only did projected fields significantly overlap across the measured time points (suggesting robust, longitudinal stability), but the projected field also expanded with time (Figure 1A).

Conclusion: This work demonstrates current technology has the ability to effectively both record and stimulate for nearly twice as long as previously reported in the literature. These significant advances validate long term performance over multi-year BCI clinical trials.

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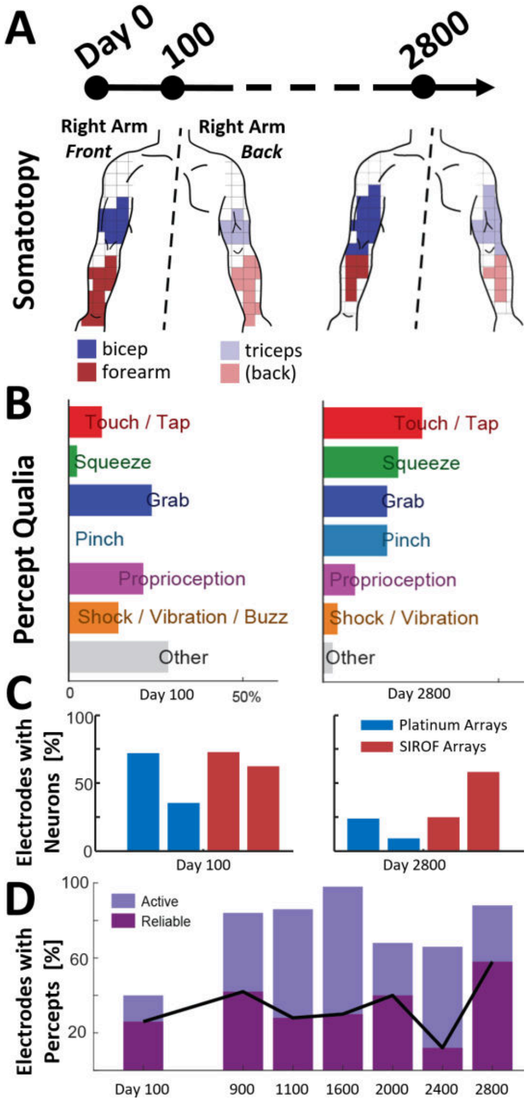

Figure 1: **(A)** *The projected fields of ICMS evoked somatosensations during the first and last timepoints. Each grid space on the body (color-coded by category) was reported from at least one electrical stimulation pattern during a survey of all implanted electrodes in sensory cortex.* ***(B)*** *Reported descriptions of evoked sensation across all electrodes, as a percentage of all reported descriptions.* ***(C)*** *Percentage of electrodes on each array which recorded single neuron activity for the first and last timepoint.* ***(D)*** *One SIROF array maintained nearly 100% of electrodes able to elicit a percept. Reliable had >67% percept rate.*

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Motor imagery and execution activate similar finger representations that are spatially consistent over time

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Introduction: Sensorimotor representations can be activated through top-down processes in the absence of somatosensory input or motor output, e.g., through attempted or imagined movements. Such top-down tasks can even reveal fine-grained sensorimotor representations of individual fingers. These top-down activated representations are increasingly used to plan implantation of and control brain-computer interfaces (BCIs) in individuals with impaired sensorimotor function. While executed finger movements activate representations in the primary sensorimotor cortex that are spatially consistent over time within participants, the stability of top-down activated finger representations remains largely unexplored. Here, we investigated the spatial consistency, and thereby reliability, of top-down activated finger representations in the primary somatosensory (S1) and primary motor cortex (M1) during a motor imagery task over time. Additionally, we tested the neural similarity of fine-grained finger representations activated trough motor imagery and motor execution.

Material, Methods and Results: Sixteen able-bodied participants imagined and executed individual finger movements (thumb, index, or little finger) in two 3T fMRI sessions that were ~2 weeks apart. We observed both highly overlapping finger-selective activity clusters (Fig. 1) and highly reproducible finger-specific activity patterns across sessions in S1 and M1 within participants (Fig. 2a) in the motor imagery and motor execution task. Further, we found that activity patterns elicited by motor imagery and execution share mutual information (Fig. 2b).

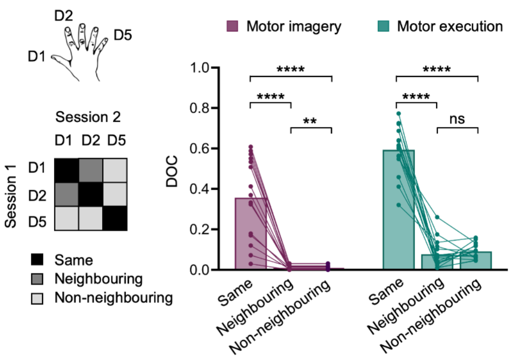

Figure 1: *Spatial overlap* (i.e., *dice overlap coefficient; DOC) between univariate S1 activity clusters of same, neighbouring, and non-neighbouring fingers across sessions. Higher DOC for same compared to other finger representations shows consistent somatotopy across sessions. Similar results were obtained for M1. Dots depict data of individual participants. D1 (digit 1) = thumb; D2 = index; D5 = little.*

Conclusion: Our results show that motor imagery activates neural activity patterns in S1 and M1 that are highly consistent across sessions. We further demonstrate neural similarity between finger representations activated through motor imagery and execution. These findings validate the use of top-down tasks, such as motor imagery, to reliably target finger representations in the context of BCIs.

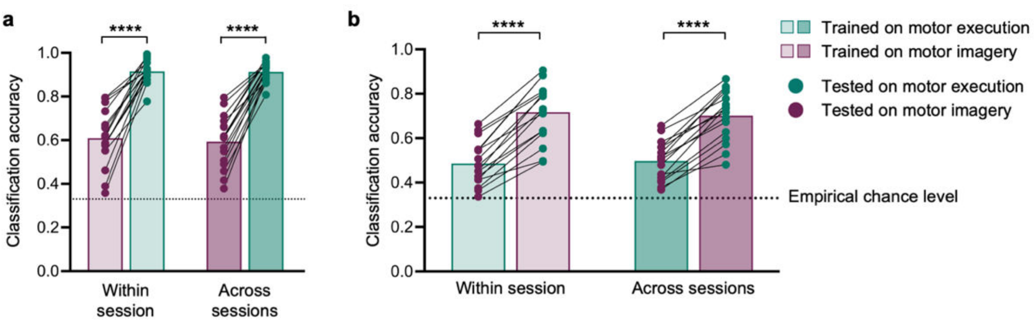

Figure 2: *Classification accuracy of individual fingers in the S1 hand area based on multivariate voxel-wise activity patterns. a) A classifier trained on activity patterns of one session successfully decoded individual fingers of the other session, demonstrating highly consistent activity patterns associated with individual fingers across sessions. b) A classifier trained on activity patterns elicited by motor execution successfully decoded imagined finger movements (and vice versa), indicating similar activity patterns between the two tasks. Similar results were obtained for the M1 hand area. Dots depict data of individual participants.*

Disclosures: The authors declare no competing interest.

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Riemannian Tangent Alignment Enhances BCI Decoding Across Subjects, Sessions, and Modalities

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Introduction: Brain–computer interfaces (BCIs) face challenges in generalizability due to variability in neural representations across sessions, modes, and subjects [1]. This study tests the hypothesis that neural activity resides in a latent space [2], comparable across data sources via tangential Riemannian processing, to improve decoding accuracy [3].

Material, Methods and Results: We analyzed data from 16 subjects in the Multimodal Signal Dataset for 11 Intuitive Movement Tasks [4], focusing on motor imagery tasks for cylindrical, spherical, and lumbrical grasping. EEG signals were preprocessed (ICA, 8–40 Hz bandpass, downsampling to 250 Hz), and event-related windows (0.5–4 s post-event) were extracted from central and parietal channels. Covariance matrices were projected into the Riemannian tangent space, aligned via Procrustes Analysis, and reduced using the first three PCA components. The chance level for this dataset is 33%. Cross-session validation showed alignment improved accuracy from 33% to 45% ($p < 0.05$). In cross-mode validation, where models were trained on motor execution and tested on imagery, alignment reduced variability (t = -4.68, $p < 0.001$). Cross-subject validation, aligning one subject as reference and others as targets, yielded significant gains (t = -13.90, $p < 0.001$). To better understand alignment, each subject was used as the reference, aligning the remaining subjects to them. PCA plots showed improved clustering post-alignment, indicating enhanced representation consistency. Models trained on aligned data achieved 51% accuracy on the remaining subjects, compared to 34% without alignment ($p < 0.001$).

Conclusion: This study demonstrates that it is possible to align neural data in a low-dimensional representation, improving BCI decoding across sessions, modes, and subjects. However, the optimal dimensionality for alignment remains untested, and the interpretability of this representation requires further investigation. These findings pave the way for future studies to explore optimal dimensionality and the underlying structure of aligned neural representations.

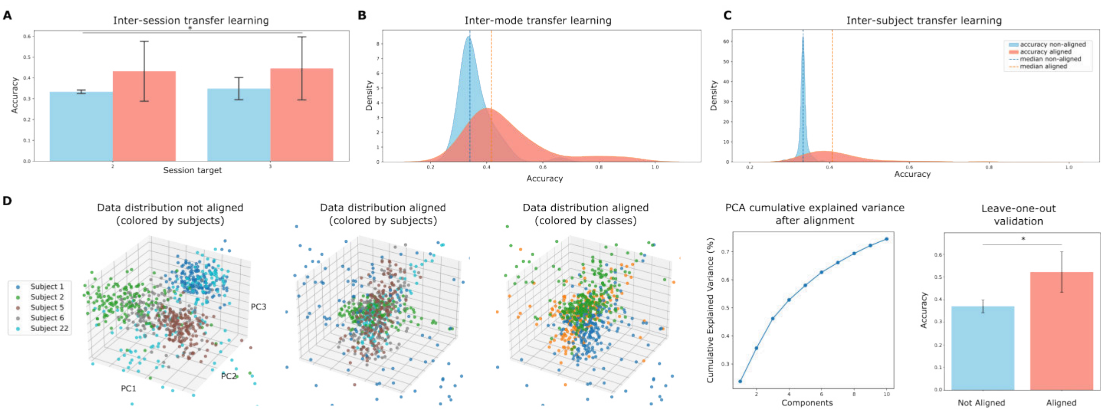

Figure 1: *Visualization of results: (A) Cross-session (B) Cross-mode and (C) Cross-subject alignment. (D) Final validation includes PCA-based visualization of mental class clustering before and after alignment, the cumulative explained variance by PCA components, and leave-one-out accuracy comparison pre- and post-alignment.*

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Decoding Text Embeddings From Functional MRI Data Using Deep Learning

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Introduction: This study explores the relationship between brain activity (measured via fMRI from eight participants [5]) and the internal representations of language models like USE [1] and MPNet [4]. A deep neural network decoded text embeddings from fMRI voxel representations, leveraging a reading-out-loud task for alignment.

Materials, Methods, and Results: We analyzed the publicly available fMRI dataset [5], where nine right-handed adults read Chapter 9 of *Harry Potter and the Sorcerer's Stone* [3], one word at a time (0.5 s/word). Imaging volumes were acquired every 2 s using a 3T scanner, yielding voxel-wise time series of approximately 25,000–31,000 voxels per participant. The final data encompassed 1211 time samples per subject. Two pre-trained embedding models were considered: paraphrase-MiniLM-L6-v2 (USE) [1], which produces 384-dimensional embeddings, and all-mpnet-base-v2 (MPNet) [4], which produces 768-dimensional embeddings. Each embedding was synchronized with the fMRI time series by grouping four consecutive words into one embedding per 2 s interval, introducing a lag of eight words to account for delayed hemodynamic response [2]. Longer sequences (eight or twelve words) were also examined to assess the effect of additional context. A DNN mapped voxel intensities to text embeddings, and performance was evaluated via the cosine similarity index between predicted and actual embeddings using 5-fold cross-validation. USE and MPNet embeddings were decoded at the above-chance levels for all participants and at word-sequence lengths. USE consistently outperformed MPNet ($F(2, 70)=132.75$, $p<10^{-17}$), and longer sequence lengths improved decoding accuracy ($F(4, 70)=281.78$, $p<10^{-39}$), though there was no interaction between model type and sequence length ($F(4, 70)=0.07$, $p>0.9$).

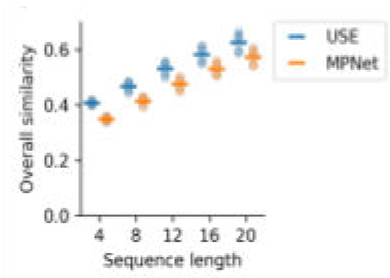

Figure 1. Overall similarity scores across subjects as a function of the embedding model and sequence length.

Conclusion: This study validates the ability to decode text embeddings from fMRI data, providing a significant step toward mapping the internal representations of large language models (LLMs) to human cortical activity. Both USE and MPNet embeddings were successfully decoded, with the former showing more substantial alignment with brain representations. These findings underscore the potential for integrating human neural data with LLMs, advancing our understanding of AI-human cognitive alignment and paving the way for future cross-disciplinary research to refine and interpret these models.

Acknowledgments and Disclosures: The authors express gratitude to colleagues who provided feedback. No conflicts of interest are declared.

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Impact of local Laplacian Spatial Filters on C-VEP-Based BCI Performance

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Introduction: Brain-Computer Interfaces (BCIs) enable direct communication between the brain and external devices, offering potential for assistive communication [3]. It can be possible only if the brain responses can be reliably decoded over time. Code-Modulated Visual Evoked Potentials (C-VEPs) stand out for their high ITRs and minimal training requirements, leveraging m-sequences to elicit distinct neural responses [1]. However, real-time decoding faces challenges due to the non-stationarity properties of the EEG signal and its low spatial resolution [2]. We compare different Laplacian spatial filters, including weight calculation methods such as $1/d$, $1/d^2$, $1/\log(d)$, and $1/\sqrt{d}$ where d is the orthodromic distance between two sensors, for enhanced signal quality and robust classification techniques, achieving improved accuracy and advancing the potential of non-invasive BCIs [2].

Material, Methods and Results: The study utilized a C-VEP paradigm with stimuli based on 63-symbol m-sequences [1]. EEG data was collected from eight sensors (O_1, O_2, P_z, P_3, P_4, PO_7, PO_8, and O_z) with 13 participants focusing on visual stimuli across five sessions [3]. Preprocessing incorporated Laplacian spatial filtering, enhancing spatial resolution by emphasizing local neural activity [2]. Classifiers (LDA, BLDA, MLP, SVM, and k-nn) were compared using correlation-based features [4]. Testing different Laplacian methods, the $1/d$ weighting approach and a radius of 1 yielded the highest accuracy [2], and SVM showed consistently higher accuracy compared to other classifiers, demonstrating superior signal enhancement and classification performance [4]. These findings underline the critical role of advanced preprocessing and classifier selection in achieving reliable and high-speed BCI's.

Conclusion: This study highlights the effectiveness of Laplacian spatial filtering, achieving an accuracy of 76.0% ± 18.9 with the $1/d$ weighting method and an SVM classifier, compared to a baseline of 59.7% ± 17.3 without Laplacian filtering. The approach shows how the preprocessing steps substantially impact accuracy compared to the type of classifier used.

Acknowledgments and Disclosures: This work has been supported by the NIH-R15 NS118581 project.

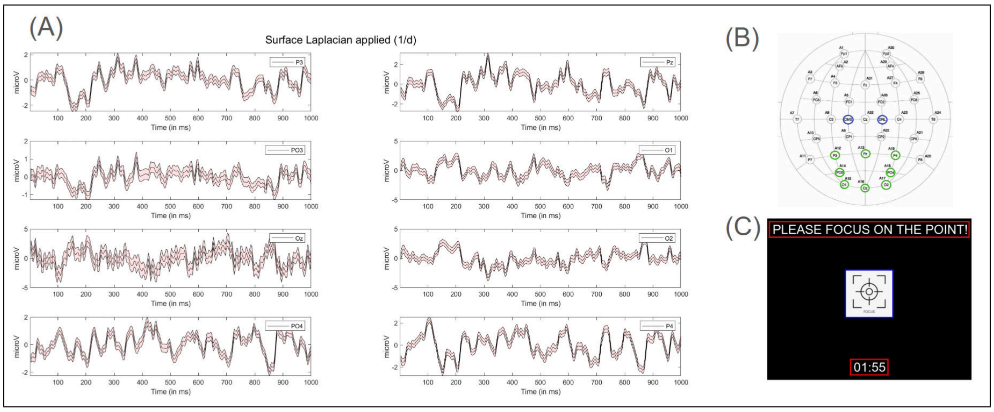

Figure 1: *(A) Time-domain EEG plots showing mean signals with variability bounds, highlighting consistency in neural responses for template-based feature extraction. (B) EEG cap layout highlighting VEP electrodes (green) and ground (blue). (C) Experimental paradigm.*

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Clinical Brain Computer Interface for adaptive neuromodulation in Parkinson's disease as regular clinical care: a protocol

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Background: In Parkinson's disease (PD), spectral power of beta oscillations (13-30 Hz) in the subthalamic nucleus (STN) local field potentials (LFPs) are linked to motor symptom severity. Beta power typically decreases after levodopa intake or deep brain stimulation (DBS) and can guide adaptive DBS (aDBS), which adjusts stimulation in real-time using closed-loop control. Furthermore, 7 Tesla MRI connectivity analysis ensures precise brain-electrode placement in the STN motor subdivision for optimal beta signal localization. aDBS may alleviate adverse effects associated with continuous DBS (cDBS) or combined medical treatment ("ON-related adverse effects") and address insufficient efficacy while medication is wearing off ("OFF episodes"). The Medtronic BrainSense™ technology in the Percept™ DBS neurostimulator supports aDBS implementation as a clinical brain-computer interface (BCI).

Methods: Starting January 2025, Amsterdam UMC will evaluate aDBS in regular clinical care through a single-blinded, n-of-1 trial design to establish its efficacy for individual PD patients. Inclusion criteria include daily OFF periods (>2 hours), ON-related adverse effects (>2 hours), or inadequate symptom control during the ON state due to stimulation-induced adverse effects. Stimulation adverse effects, often affecting speech or gait, are assessed via the Unified Parkinson's Disease Rating Scale (UPDRS). For each patient, 7T MRI connectivity (T2-weighted imaging and DWI probabilistic tractography) confirms electrode placement relative to the STN motor subdivision. Electrode contacts within this subdivision are used for LFP analysis and the aDBS algorithm. Eligible patients implanted with the Medtronic Percept™ system (~300) will be screened, with aDBS initiated for approximately 1 patient weekly. Beta power frequencies for the aDBS algorithm will be identified using cluster-based permutation tests and Cohen's d analysis of LFP spectral densities recorded during OFF- and ON-levodopa states. Participants will undergo 1-week periods of aDBS and cDBS in a blinded, randomized order over a 2-month evaluation phase. The primary outcome is the change in duration (hours/day) and intensity (VAS) of primary symptoms and adverse effects. Secondary measures include UPDRS, PDQ-39, BDI, SAS, and ISI scores. Therapy preference will be assessed via satisfaction VAS scales.

Discussion: This accumulated, n-of-1 study will provide important clinical evidence for and experience with the use of STN beta power-based commercial BCI technology in the management of advanced PD.

Disclosures: The authors do not have any conflicts of interest to disclose.

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Reporting checklist for observational implanted and non-implanted neural interface studies: protocol for a Delphi process

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Introduction

Standardization of reporting in neuroscience and electrophysiology literature has been a long-standing topic of interest. With the rise of neural interfaces (NIs), such as the brain-computer interface, electrophysiology has made its way into real-time clinical applications. Due to the complexity of these systems, the biomarkers they depend on and their recording and their various applications, reporting of this type of research is challenging. The IEEE Standards Working Group (SWG) P2794 aims to reduce heterogeneity in reporting and improve findability, interpretability and reproducibility (FAIR principles) of NI research by drafting and publishing a reporting checklist.

Objective

Identify and describe a consensus-based set of reporting criteria for implanted and non-implanted observational and interventional neural interface studies.

Methods

Executive committee. From 2019 till 2025 the IEEE SWG P2794 has held numerous meetings to design and draft a reporting standard for neural interface research. Currently, the working group is conducting a multi-step approach to validate a reporting checklist by literature search, expert review and dissemination to the wider scientific community. **Systematic review.** Reporting guidelines that may include items relevant to observational and interventional neural interface studies and related research fields will be analyzed and compared with items that were found relevant by the IEEE SWG P2794, resulting in a finalized draft reporting checklist. We will search the following electronic databases from inception: EMBASE, Cochrane Library, PubMed, Web of Science, EQUATOR network. **Expert review.** From November 2024 till June 2025 a series of meetings are being held to review this reporting checklist for both observational and interventional neural interface research with selected subject matter experts (SMEs). **Consensus process.** During the BCI society meeting in June 2025, a Delphi procedure will be held as a workshop to finalize the checklist. A follow-up online meeting will be organized with the attendants. The Guidance on Conducting and REporting DElphi Studies (CREDES) will be used for the design, implementation and reporting of this study. **Guideline validation.** Expert reviews to the checklist will be analyzed qualitatively using semi-structured feedback and interviews, while the consensus process will utilize anonymous quantitative feedback and semi-structured qualitative feedback for adjusting and optimizing the checklist. Consensus will be defined as an anonymous agreement of >70% on each checklist item by workshop attendees. The final checklist will contain items that reached consensus and submitted to a peer-reviewed scientific journal by August 2025.

Conclusion

The finalized checklist is expected to reduce heterogeneity in the reporting of various non-implanted and implanted brain-computer interface studies by integrating feedback from literature, SMEs and the wider scientific community.

Acknowledgments and Disclosures: This work would not have been possible without the support of the IEEE SWG P2794 members. The authors don't have any conflicts of interest to disclose.

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Multi-gesture BCI control of a communication board

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Introduction: Amyotrophic lateral sclerosis (ALS) can lead to severe paralysis with impaired communication. Eye-trackers are commonly used for controlling assistive devices but can become unreliable due to eye-movement deterioration [1]. Alternatively, brain computer interfaces (BCIs) can be used to control assistive devices by translating neural signals during attempted movements into device-specific outputs. Despite previous studies demonstrating the potential for online decoding of upper-limb and facial gestures [2-5], multi-gesture decoding has not been applied for controlling assistive devices. Here we show that a clinical trial participant with ALS can control an assistive device by attempting six upper-limb and facial gestures. The BCI operated by translating electrocorticographic (ECoG) signals from a high-density 128-electrode grid over sensorimotor cortex (Figure 1) into directional control of a communication board (Figure 2).

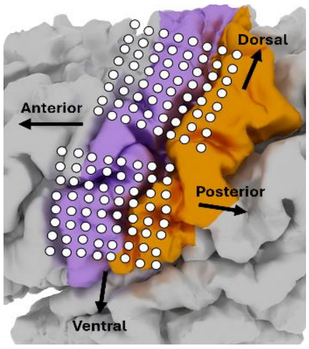

Figure 1: ECoG grid over right sensory (orange) and motor cortex (purple) of speech and upper-limb representations.

Materials, Methods, and Results: We selected a set of six gestures for communication board control by first sampling multi-band frequency features from repeated trials of 16 gestures (200 trials/gesture). We then down-selected a set of six gestures that showed the highest performance in simulations. Specifically, we calculated a performance score for each gesture, which accounted for the sensitivity, accuracy, precision, and false positive frequency, and used the six gestures with the highest performance scores (control gestures). The control gestures were each mapped to one of six communication board commands (up, down, left, right, enter, back). A gesture classification occurred when the probability of the rest class fell beneath a specified threshold. The control gesture class with the highest probability was classified. We determined our six control gestures and tested our model in real-time with the communication board (Figure 2) by verbally instructing the participant to attempt one of the six gestures.

Figure 2. Communication board where it is possible to navigate to, select, and de-select an n icon using BCI control.

Conclusion: Multi-gesture classification is a feasible BCI control strategy for a participant with ALS implanted with high-density ECoG electrodes.

Acknowledgments and Disclosures: We would like to thank the clinical trial participant for offering his time for this research.

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Design of a Sensor System for a Semi-Autonomous BCI Controlled Mobility Device

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Introduction: Independent movement is one of the most highly requested Brain-Computer Interface (BCI) applications by families of children with complex physical needs. Key to supporting these children are Power Mobility Training Devices (PMTDs), which allow children to become comfortable using mobility devices. However, to advance PMTDs by implementing autonomous and long distance driving, a sensor system is needed. NeuroMove is a framework designed to allow PMTDs to implement autonomous and long distance driving via mixed-range sensors.

Material, Methods and Results: To perform the spatial mapping and collision avoidance critical to the PMTD's ability to navigate semi-autonomously, a multilevel sensor array was created. It includes a 3-dimensional LiDAR, ultrasonic sensors and force sensing resistors (FSRs). A Unitree 4D LiDAR RM sensor is mounted inverted above the head of the user [1]. It performs spatial mapping, capturing the layout of an area within a 30m radius of the LiDAR. An array of eight MaxBotix LV-MaxSonar-EZ MB1000 ultrasonic sensors are placed around the NeuroMove PMTD for local object detection. Three of the ultrasonic sensors are arranged across the front to completely cover an area in front of the trainer with a working range of 0.2m-6m. The other five sensors cover the sides and back of NeuroMove to detect objects while turning or reversing. The combination of LiDAR and ultrasonic sensors ensure that the system can detect objects that are near infrared absorbing, transparent, or sound absorbing that would be missed by a single sensor type. The Interlink Electronics FSR 408-500 is secured to a flexible "bumper" at the front of the trainer as a safety feature to detect if a collision occurs.

The ultrasonic sensors and FSRs are connected to an Arduino Uno to process and synthesize sensor data before sending it to the Raspberry Pi 5 (RPi). The RPi functions as NeuroMove's controller and is directly connected to the LiDAR for maximum data baud rate. The Unitree 4D LiDAR outputs a series of 4-dimensional tensors to the RPi, where each tensor contains the x, y, z, and sample time of a point in space. The RPi will convert these tensors into a 2-dimensional occupancy grid specifying where the PMTD is and isn't able to navigate to via a subtractive algorithm and downsampling. When a user desires to autonomously navigate to a destination, a modified jump point search algorithm is run on the occupancy grid to find the optimal path to said desired destination. While in motion, a software interrupt from the Arduino Uno due to the FSRs or ultrasonic sensors detecting a close object can halt NeuroMove. The RPi will utilize shared memory for all data transfer and low computational complexity algorithms where possible for maximum software efficiency.

Conclusion: The NeuroMove framework will allow for greater freedom of mobility for children with complex mobility needs by introducing more advanced driving operations. Combining different sensor types allows for full spatial visualization, and pathfinding gives users the option for easier navigation. By putting the NeuroMove framework on top of existing PMTDs, pediatric patients with complex physical needs will have an easier journey towards improved independent movement.

Acknowledgments and Disclosures: A-MEDICO for providing the funding allowing this research to take place. The support of the BCI4Kids laboratory, Danette Rowley, and patient partners is deeply appreciated.

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Observed Changes in the Visual Oddball Event-Related Potential in a 10-Session, Longitudinal Study

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Introduction: The visual oddball paradigm is used in psychophysiological research [1] and brain-computer interface paradigms [2] to elicit the P3b event-related potential (ERP). Generally, test-retest reliability of the P3b is thought to be high over repeated sessions [3-5]. However, there are few studies that have observed the elicitation of the P3b over many repeated sessions over several months. In this study, we elicited the P3b using a standard visual oddball paradigm [6] in 10 sessions over approximately 3-4 months and observed changes in both P3b morphology as well as ERP features (i.e.. amplitude, latency) commonly derived from the P3b morphology over sessions.

Material, Methods and Results: 30 participants completed 400 trials of the visual oddball task, with a 4:1 oddball to standard stimulus ratio, in each of 10 sessions, held on the same day and at the same time each week, over approximately 3-4 months. Electroencephalography (EEG) data were collection using the BioSemi ActiveTwo (BioSemi, Amsterdam, The Netherlands) using a 2048 Hz sampling rate at 64 channels locations. In addition to group-averaged oddball, standard, and difference-wave ERPs, amplitude (as positive mean amplitude; Fig. 1) and latency (as 50% positive area latency; not shown) [7] of the P3b were calculated at the group level for each of the ten sessions, or days (D01 through D10), at Pz.

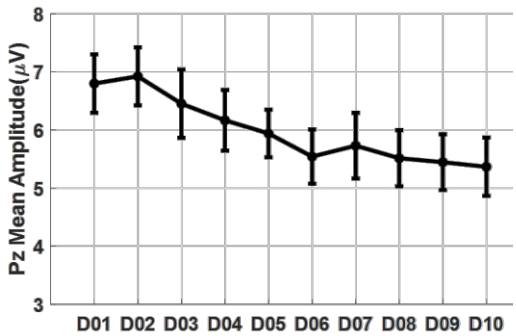

Figure 1: *P3b amplitude at Pz, averaged at the group-level (N = 30), for each of the ten sessions, or days (D01 through D10). Error bars are ±1 standard error of the mean (SEM).*

Conclusion: Test-retest reliability of the P3b should not be assumed in all situations given the clear, nearly monotonic changes over sessions observed in this longitudinal study (e.g., amplitude, Fig. 1). Although the factors leading to these changes need to be investigated in subsequent studies, and these data were collected open-loop, these results may have an impact on BCI decoder accuracy in long-term, daily use.

Acknowledgments and Disclosures: The authors would like to acknowledge Teresa L. Garrett for efforts coordinating participant compensation. This research was funded by the Air Force Office of Scientific Research Laboratory Research Initiation Request 20RHCOR049 and the United States Department of Defense as part of the congressional appropriation of the 6.2 (Applied Research) Research, Development, Test, and Engineering (RDT&E) budget category. The authors declare no conflicts of interest.

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From Research to Reality: Advancing Pediatric BCI Innovations into Clinical Practice

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Introduction: Many children with moderate to severe quadriplegia are highly capable but may be unable to walk, use their hands, or speak. They face significant obstacles to their fundamental human right to interact with the world and to participate in life. Brain-computer interfaces (BCI) are a potential solution that removes the requirement of voluntary movement. Individuals can learn BCI by training their mental intent, similar to learning a new motor skill, and performance using a BCI system improves with training [1]. In July 2023, the Alberta Children's Hospital (ACH) implemented an Occupational Therapy (OT) led BCI clinical service in partnership with the BCI4Kids research program to provide novel interventions using BCI technology for these children.

Methods: The BCI@ACH clinical service was designed to provide non-invasive BCI options to allow children with moderate to severe motor impairments to achieve personalized goals (i.e., playing music/videos, baking, creative art, adapted gaming). The patient population included children ages 4 to 18 years old; the majority with quadriplegia (non-ambulatory with minimal hand function) and varying degrees of vision, hearing, and communication (Fig. 1). Patients either did not yet have an access method using commercial assistive technology (AT) or used BCI technology to augment their existing access method. A personalized approach aimed to teach children how to train their own BCI mental commands included the use of self-regulation tools, videos, photos, symbolic visuals and/or auditory prompts (Fig.2). Sessions included patient-motivating, goal-oriented activities to optimize repeated BCI practice. Room lighting, screen size and location, and visual software settings were adjusted based on patient needs. The use of both research and commercial BCI technologies allowed the OT to integrate with existing AT software. Customized social stories were created for the child/family to reinforce how they use BCI technology. Families also had the opportunity to receive training so their child could practice using BCI at home.

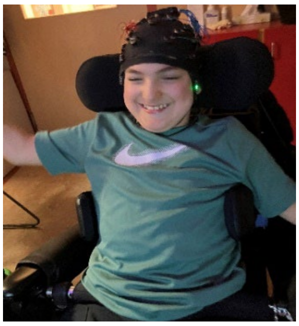

Figure 1: 14-year-old boy with spastic quadriplegia, cochlear implants, and CVI using BCI to turn pages in his favourite books.

Figure 2: 4-year-old boy training calm state with self-reg. stuffy puppy paired with photo.

Results: Over 18 months, 33 children and families received at least one BCI session. Two patients declined, and one waited for equipment. A total of 327 BCI sessions were provided at ACH. Fifteen patients learned one mental command, 14 learned two, and one is on the verge of three. Presently, seven patients are learning to use their mental command(s) in conjunction with scanning access, whereby items in a selection set are highlighted, and the mental command selects the item. Three are using BCI to supplement an existing access method in a hybrid manner, such as a chin-joystick with BCI. Common challenges include headset fit and design (i.e., wires losing connection to electrodes). Most families express satisfaction with the BCI clinical intervention. One parent's feedback, "He definitely has more success with BCI than switches, yes, he gets tired but not frustrated; he never got this far with switches."

Conclusion: A clinical service using simple BCI solutions can be implemented into a public health care system to allow children with complex physical needs to achieve personalized goals.

Acknowledgments and Disclosures: We are grateful to all the families who have participated in the BCI@ACH clinical service. We also wish to acknowledge the efforts and innovations of the BCI4Kids research program and the collaboration with our clinical partners in Edmonton and Toronto. No conflicts of interest exist.

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Representation of syntax in intracortical inferior frontal gyrus signals

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Introduction: Brain-computer interfaces (BCIs) that decode speech have largely decoded phonemes and relied on large language models to form those into words and sentences. Forming words and sentences requires proper grammar, including syntax, both on word (tense, grammatical number, person) and sentence (subject/object/verb order) levels. Despite the critical role of syntax in natural language processing, electrophysiological evidence for its representation in the brain remains limited. Evoked responses in the inferior frontal gyrus (IFG), particularly in pars triangularis, showed some modulation with tense processing[1]. Imaging and lesion studies link IFG damage to deficits in syntax comprehension and agrammatism. However, the precise role of the IFG, especially pars opercularis, in syntactic processing remains unclear, including the specific type of processing involved and the extent of syntactic information represented at the neuronal scale. Decoding syntax directly from brain signals in the IFG could potentially improve BCIs by enabling more fluent and contextually appropriate sentence generation for individuals with impaired speech.

Materials, Methods, and Results: We recorded intracortical activity from a human participant as part of the Reconnecting the Hand and Arm to the Brain clinical trial. We recorded broadband (30 kHz sampling rate) signals with a 64-channel Utah array placed in caudal IFG (caudal border of pars opercularis). The participant silently read phrases, with missing verbs, displayed on a monitor at the start of each trial (phrase onset). After 2~2.5 s, the root verb was displayed on the screen (verb onset), and the participant determined how to conjugate the verb in agreement with the context of the phrase. After a go cue, the participant spoke the conjugated verb aloud. The task was designed to evaluate multiple types of syntax: different tense (present/past), person (first/second/third), number (singular/plural), and mood (imperative/indicative).

We analyzed a total of 1460 trials over 7 sessions. We extracted spike band power (300 Hz–1 kHz) and binned it at 100 ms. We observed that ~40% of the electrodes modulated prior to voice onset, while up to 20% modulated after voice onset. To decode each type of syntax, we built support vector machine decoders with a radial basis function kernel at multiple offsets between neural and task times. We used 10 causal bins of history as neural features, resulting in 520 features. We then computed principal components (PCs) of these features and used the first 25 PCs as inputs to the SVM decoder. We held out 30% of trials as a test set. We repeated the decoding procedure 30 times and compared the mean accuracy to the empirically shuffled (chance) accuracy distribution. We observed significantly above-chance decoding accuracy (~60%; $p<0.05$, permutation test) between verb and voice onset for tense decoding, and accuracy of 65% ($p<0.05$, permutation test) about 400 ms after phrase onset for person/mood (second imperative vs. third singular indicative) decoding.

Conclusion: These results suggest that caudal IFG may play a role in processing syntax for speech production. This information appears to occur at different times relative to the processing of the phrase context and to verb conjugation, depending on the aspect of syntax. This suggests that this area may be involved in multiple aspects of speech production. This could ultimately provide a useful input for a speech BCI.

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Changes in globus pallidus internus local field potentials during freezing-of-gait in Parkinson's disease

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Introduction: Freezing-of-gait (FoG) is a common phenomenon in Parkinson's disease and is characterized by the inability to step. This can occur in a variety of scenarios including gait initiation, tight spaces, or distracting environments. FoG's impact on quality of life can range in severity from annoyance to life-threatening due to the increased risk of falls it carries. Deep brain stimulation (DBS), an effective and widely used treatment for Parkinson's disease, is currently delivered in a continuous, unchanging manner. The field is pushing toward an adaptable approach where stimulation parameters are adjusted based on changes in the local field potentials they stimulate. If a neural signature associated with FoG could be identified, this could allow for tailored stimulation or external perturbation to shorten the freezing episode or eliminate it all together. Previous studies, limited to the subthalamic nucleus, showed that FoG was associated with beta bursts, more prolonged beta just prior to freezing, and excessive synchronization in the 18Hz beta band.

Materials, Methods and Results: This study evaluates the LFPs of the output nucleus of the globus pallidus internus (Gpi) in a real world setting with a sensing-enabled DBS device (Medtronic's Percept), and simultaneous ankle accelerometer data. Five individuals with Parkinson's-related FoG and a Percept DBS system were evaluated on medication and off stimulation. The participants walked an obstacle course of five FoG-triggering scenarios while simultaneous LFPs and ankle accelerometer data were collected. LFPs were analyzed during periods of freezing, standing, and walking. The modulation index, derived from the Kullback-Leibler divergence between the theta phase and various amplitude bands was computed as a measure of phase-amplitude coupling. Preliminary results show that phase-amplitude coupling during freezing followed the trend standing < freezing < walking for the alpha, beta, and gamma amplitude bands. The effect was the most pronounced for theta-gamma coupling.

Conclusion: These results suggest that changes in phase-amplitude coupling could be used to identify periods of freezing-of-gait directly from Gpi LFPs.

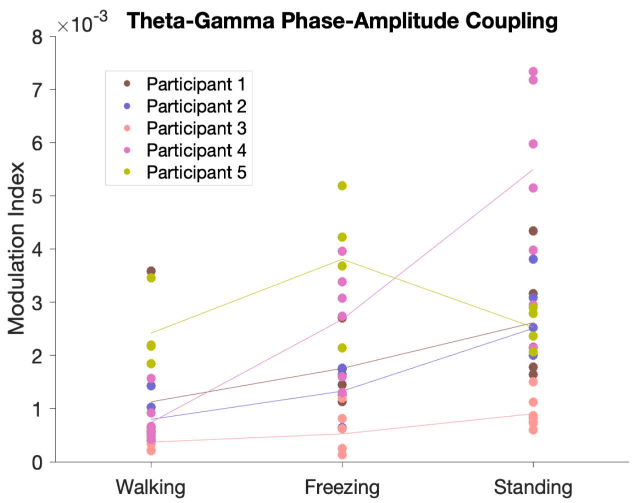

Figure 1: coupling between the theta phase and gamma amplitude during freezing tends to lay between that seen during walking and standing.

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Evaluation of spatial and frequency features for improving the classification of motor imagery

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Introduction: The classification of Motor Imagery (MI) is an essential component in the development of Brain-Computer Interfaces (BCI), given its potential in clinical applications such as rehabilitation of impaired motor functions. However, current systems face significant challenges to achieve optimal performance due to the complexity and volume of the features involved [1, 2]. In this context, EEGNet model has emerged as an efficient alternative, enabling classification even directly from raw EEG signals. This study addresses two key questions: first, we examine whether EEGNet performance can be improved implementing two additional stages, a scheme of filters based on MI-related rhythms followed by a feature extraction stage in two domains (spatial and frequency); and second, we evaluate whether the proposed additional stages for EEGNet outperform two commonly used classification models such as Support Vector Machine (SVM) and Linear Discriminant Analysis (LDA).

Material, Methods and, Results: The present proposal focused on characterizing EEG signals from the sub-bands associated with MI, by extracting features to subsequently generate a feature vector, the dimensionality of which was reduced using the Relief-F algorithm before proceeding with performance evaluation. The evaluations were carried out using frequency-based features through Discrete Wavelet Transform (DWT) for the first evaluation, and spatial features using Common Spatial Pattern (CSP) for the second evaluation. The overall framework of the study can be seen in Fig.1a). For model evaluations, the IVa dataset from the III BCI Competition[3] was used, which includes the 118-channel EEG recordings from 5 subjects performing imagined movement tasks (right and left hand). The evaluations were performed using 5-fold cross-validation, obtaining the results shown in Fig.1 b). These show that the EEGNET+DWT model outperforms others, achieving an average of 71.13% (see Fig. 1 c)).

Conclusion: The results suggest that the combination of EEGNet with features extracted in the frequency domain (EEG+DWT) can be effective for binary classification of motor imagery tasks. In subject *aw*, the EEGNet+DWT model did not outperform traditional classifiers. However, no significant differences in performance were observed. Furthermore, spatial features did not contribute to enhancing EEGNet's performance (EEG+CSP). As future work, we will analyze if the fusion of both temporal and spectral features is relevant for this task, complemented by inter-subject regularization techniques, in order to improve the model's ability to generalize to new subjects. Last, an automatic channel selection method will assessed to discard redundant or non-relevant channels.

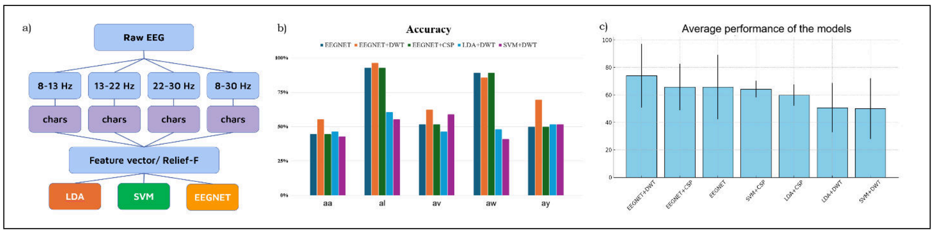

Figure 1: *a) Model evaluation framework, b) Comparison of models and features, c) Average performance.*

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Population Transformer: Learning Population-level Representations of Neural Activity

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Introduction: We present a self-supervised framework that learns population-level codes for arbitrary ensembles of neural recordings such as intracranial electroencephalography (iEEG) at scale. We address key challenges in scaling models with neural time-series data, namely, sparse and variable electrode distribution across subjects and datasets. The Population Transformer (PopT) [1] stacks on top of pretrained representations of temporal activity (e.g. BrainBERT [2]) and enhances downstream decoding by learned aggregation of data channels. The pretrained PopT lowers the amount of data required for downstream decoding experiments, while increasing accuracy, even on held-out subjects and tasks. Beyond decoding, we visualize the learned attention weights to show how they can be used to extract neuroscience insights from large amounts of data. Full paper, code, and weights available at [1].

Material, Methods and Results: **Data**. iEEG data was collected from 10 subjects (total 1,688 electrodes, with a mean of 167 electrodes per subject) who watched 26 movies (19 for pretraining, 7 for downstream decoding) [3]. The downstream decoding tasks were auditory-linguistic features extracted from the movie audio and transcripts. **Model**. PopT consists of a transformer encoder stack, where the input tokens are a [CLS] token and temporal embeddings (E) from an ensemble of channels at time t. The 3D coordinates of each channel are added to each temporal embedding. **Pretraining**. Our self-supervised learning task has two discriminative components: (1) ensemble-wise – the model determines if activities from two channel ensembles occurred consecutively, and (2) channel-wise – the model identifies outlier channels that have been swapped with a different timepoint's activity. **Decoding**. We fine-tune and decode with the intermediate [CLS] embedding attached to a new single linear layer for the specific decoding task. **Results**. We find that fine-tuning and decoding with a pretrained PopT outperforms all baselines of aggregating individual channel embeddings across channel ensemble sizes (Fig 1a). Inspecting the attention weights on our model fine-tuned on decoding periods of Speech vs Non-speech reveals highly responsive language areas such as Wernicke's area (Fig 1b). We further show that pretraining allows one to reach similar performance levels as other models with far fewer samples and compute steps (Fig 1cd).

Conclusion: Our work reveals how beneficial self-supervised pretraining on large datasets can be for downstream decoding, neuroscience discovery, while being sample and compute efficient.

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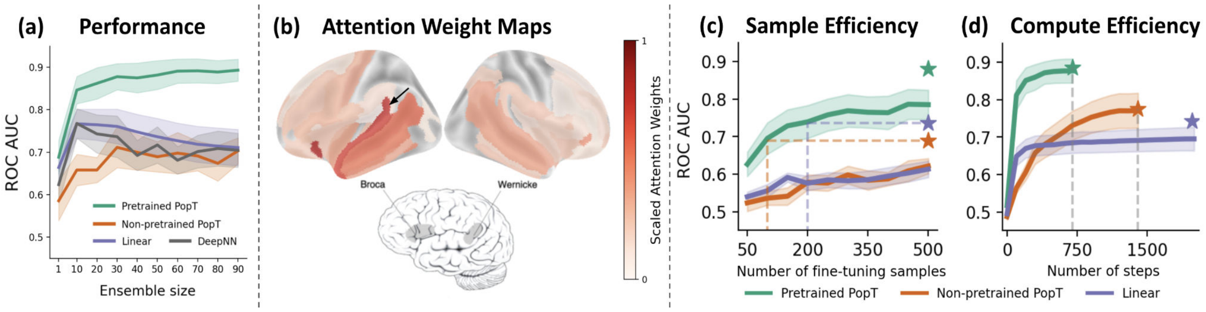

Figure 1: Results on the Speech vs Non-speech decoding task. (a) Downstream decoding performance vs ensemble size, (b) attention weight maps from the [CLS] token after fine-tuning, (c,d) sample & compute efficiency of fine-tuning using pretrained vs non-pretrained models.

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Exploring the Potential of Motor Imagery-Based BCIs for Targeted Motor Function Recovery

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Introduction: Motor imagery (MI)-based brain-computer interfaces (BCIs) activate motor-related brain regions and, through neurofeedback, foster neuroplasticity, offering significant potential for neurorehabilitation [1]. While MI-BCIs have shown success in restoring hand function after stroke, their use in mitigating upper-limb impairments in multiple sclerosis (MS)—a chronic neurodegenerative disorder characterized by impaired motor control and coordination—remains underexplored [2]. This study presents a preliminary investigation into the feasibility of using MI-BCI for targeted therapy of two specific motor function deficits. Using two representative hand tasks—one requiring coordination and the other control (see Figure 1A-B)—the objectives were: 1) to examine whether MI of these tasks alters corticospinal excitability (CSE), indicating the potential for fostering neuroplasticity and improving hand function, and 2) to determine if distinct task-specific neural activation patterns can be detected via electroencephalography (EEG), suggesting they may be targeted with BCI-based neurofeedback training.

Material, Methods and Results: Data from twenty-one healthy participants (8 males; mean age: 41.35 ± 8.36 years) were analyzed for this study. Transcranial magnetic stimulation (TMS) was used to assess changes in CSE due to MI of the coordination and control tasks. A single TMS pulse was delivered during intervals of MI and rest and resulting motor-evoked potentials (MEPs) were measured from the first dorsal interosseous (FDI) muscle (Figure 1C). For the control task, MI significantly increased MEP amplitudes (Δ=37.43 µV, $p = .005$), and decreased MEP latencies (Δ=−0.38 ms, $p = .003$), compared to rest. For the coordination task, MI significantly decreased MEP latencies compared to rest (Δ=−0.25 ms, $p = .008$), but MEP amplitudes were not significantly different (Δ=29.69 µV, $p = .19$). CSE was also assessed during actual execution of the tasks (ME), and changes in both MEP amplitudes and latencies were significantly different from rest for both tasks (control: Δ=508.94 µV, $p < .001$; Δ=−1.94 ms, $p < .001$; coordination: Δ=528.23 µV, $p < .001$; Δ=−1.71 ms, $p < .001$).

In a separate session, 64-channel EEG was recorded as participants performed 60 intervals each of MI and ME of the two tasks, as well as rest. Data were analyzed using the Filter Bank Common Spatial Patterns (FBCSP) algorithm (using delta, theta, alpha, beta, gamma frequency bands) and Linear Discriminant Analysis (LDA) (see Figure 1D). The control and coordination tasks could be distinguished from rest with average accuracies of 76.3% and 70.2% for MI, and 83.3% and 87.2% for ME. While the average classification accuracies for control vs. coordination were just 61.3% (MI) and 63.6% (ME), accuracies for 9 participants for MI, and 6 for ME, exceeded 70%. The statistical threshold for chance for all accuracies is 58.3% (for n=120 trials, α=0.05, based on binomial distribution).

Conclusion: Increased MEP amplitudes and decreased latencies indicate that CSE increased during the MI tasks, suggesting the potential of these tasks to foster neuroplasticity. On average, the distinct neural patterns differentiating motor control and coordination were detected with accuracy greater than chance, and for some participants with very high accuracy. The results suggest the potential for targeted BCI-based therapy for improving motor control and coordination, though further work is needed to more reliably and specifically identify the neural activation patterns associated with these functions.

Acknowledgments and Disclosures: The authors are grateful for the funding support of the MS Society of Canada and the School of Graduate Studies, Memorial University. We declare no conflict of interest.

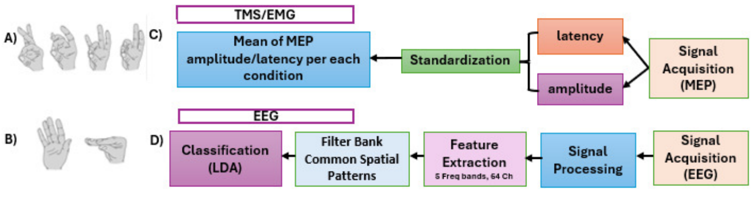

Figure 1: (A) Motor Coordination: Touch each finger to the thumb sequentially, and repeat throughout interval.
(B) Motor Control: Extend the hand fully, then bring the four fingers and thumb together, and repeat throughout interval.
(C) TMS/EMG Workflow: Key steps for processing MEP amplitude and latency.
(D) EEG Workflow: Signal acquisition, processing, feature extraction, and classification using LDA to identify neural patterns.

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NAVSync: A Real-Time Neural Audiovisual Synchronization Platform for Silent Speech Research

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Introduction: NAVSync (Neural Audiovisual Synchronization) is a real-time platform developed for silent speech research, aiming to accommodate individuals who cannot produce overt vocal output. By aligning neural signals—such as electrocorticography, microelectrode arrays or neuromuscular recordings—with audiovisual and behavioral data, NAVSync facilitates the study of internal speech production and neural intent, without relying on users' own audio recordings. The system emphasizes ultra-low-latency synchronization, critical for silent speech investigations and interactive training scenarios.

Material, Methods and Results: NAVSync integrates multimodal data streams, including target audio playback and dynamic visual cues, to guide users' silent speech attempts. Through a time-synchronized slider interface, participants can align their speech efforts with predefined targets, allowing for user-driven refinement and neural decoding model supervision. The platform achieves packet-level synchronization at the 1-ms scale and system updates in as little as 5 ms, ensuring robust timing consistency across all streams. This versatility positions NAVSync as a useful framework for exploring a wide range of silent speech behaviors and neural decoding strategies, while remaining adaptable to various modalities and experimental contexts.

Conclusion: Conference attendees will experience a live, interactive demonstration of NAVSync's synchronization and feedback capabilities, underscoring its broader potential to enhance silent speech studies. By providing precise, real-time alignment of silently produced speech attempts with audiovisual cues, NAVSync can further our understanding of internal speech and help inform future approaches to communication restoration and neural interface design.

Acknowledgments and Disclosures: NAVSync was originally developed during Qinwan Rabbani's doctoral work in the Crone and Moro-Velazquez Labs at Johns Hopkins University, supported by the National Institute of Neurological Disorders and Stroke (NINDS) Grant UH3NS114439. Qinwan Rabbani served as the primary developer. Foundational components of the web interface were contributed by Samyak Shah, with additional technical assistance and support from Rohit Ganji. System design guidance was provided by Dr. Nathan E. Crone, Dr. Laureano Moro-Velazquez and Dr. Matthew S. Fifer.

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The History and Future of (Re) Defining BCIs

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Introduction: The term "brain-computer interface" and acronym "BCI" have become hot commodities. As BCIs and similar systems become more prominent and powerful, more companies, labs, and other groups will want to expand the definition of "BCI" to include systems that they sell, research, or otherwise promote. In science, engineering, and medicine, definitions are crucial for many reasons. Indeed, several efforts have been made to define BCIs, including clarifying key elements like sending information directly from a brain to a computer, providing feedback to the user, and (near) real-time operation [e.g., 1, 2]. However, other efforts have tried to redefine BCIs. Here, we address these efforts, introduce categories of redefinition approaches, and review why this issue matters.

Material, Methods and Results: We reviewed dozens of peer-reviewed articles and other materials that present or discuss the definition of a BCI. The term and acronym were introduced in the first peer-reviewed paper that described a working BCI [3], but this article did not focus on the definition. The first two reviews of BCIs did address the BCI definition [4,5], including key elements such as sending messages directly from the brain to an external device. Soon thereafter, the EU funded two major projects devoted partly to defining BCIs and associated terms [6,7]. IEEE developed a definition a few years ago [8]. The BCI Society devoted a major effort to the BCI definition in 2024, resulting in a definition similar to canon that represents the views of its 445 members at the time of voting [9]. Nonetheless, efforts to broaden the BCI definition continue, most recently and notoriously through [10].

We identify consistent approaches to (re)defining BCI and problems with them. Unsurprisingly, these efforts always try to expand the definition to add the non-BCI systems that its proponents use. Approaches may be nominal, focusing on the term itself. This approach ignores the well-known underlying problems with this term; if we go by the name alone, a keyboard or mouse provides an interface from a brain to a computer. We prefer a canonical approach that considers which systems have been presented as BCIs in conferences, papers, talks, and other mechanisms as well as established definitions. Other approaches include fatalistic, arguing that efforts to define BCI will inevitably be misconstrued by journalists and the public, or financial, which posits that a broader definition would encourage more funding (without mentioning that it would also increase the number of people seeking funding). Arguments have also been made that definitions should be inclusive to avoid hurt feelings.

Conclusion: Efforts to redefine BCIs will continue and elicit growing controversy. These redefinition efforts will rarely succeed in establishing a new definition that meets the expectations of its proponents. However, they will succeed in: fomenting and conveying fragmentation; necessitating discussions and replies; and confusing important groups including funding agencies, regulators, journalists, companies, researchers, medical and BCI practitioners, patients, students, instructors, and the public at large.

Acknowledgments and Disclosures: The authors declare no conflicts of interest.

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Versatile Modular Research Platform for Brain-Wide Neuroscience in Navigating Non-Human Primates

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Introduction: Simultaneous high-throughput neural recordings across multiple brain areas significantly enhance our understanding of the neural basis underlying complex animal behaviors. In this study, we developed a versatile, modular research platform for brain-wide recording and modulation in non-human primates engaged in navigation tasks and validated its high performance.

Material, Methods and Results: We developed a highly customizable and modular research platform (Fig.1a) that integrates cranial implants with electrode protection, a low-cost wearable eye-tracking and scene-capturing system, a behavioral event alignment system, 3D-printable monkey chairs, and tailored hardware and software solutions. This platform enables ultra-high-throughput electrophysiology, supporting the simultaneous recording of over 10,000 channels in non-human primates. Additionally, it integrates with Automated Guided Vehicle (AGV) carts, allowing animals to navigate in two-dimensional spaces. Using a macaque driving-foraging paradigm, we validated the system's efficiency and reliability for systems neuroscience studies (Fig.1b). Furthermore, an electrically stimulated blindfolded driving-foraging paradigm demonstrated the platform's potential for visual prosthetics research.

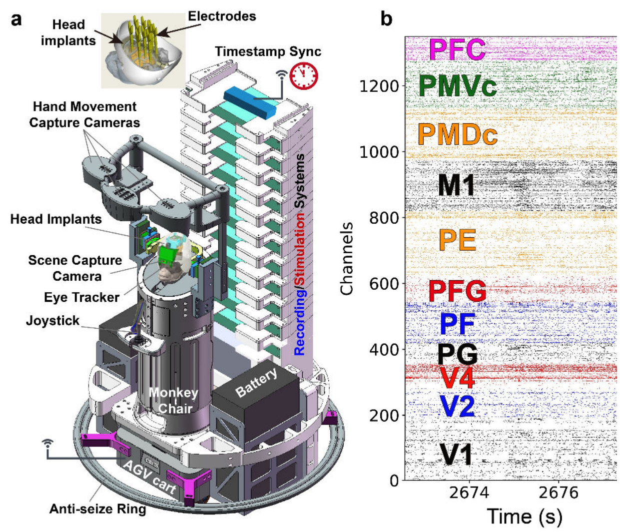

Figure 1: *(a) Main part of the research platform. This platform employs a monkey driving-foraging task as the experimental paradigm and integrates multiple application modules for neuroscience research: 1. Behavioural monitoring of non-human primates, including eye tracking, hand movement monitoring, cart tracing, and joystick force recording. 2. Brain-wide systems neuroscience research, encompassing the design and surgical solutions for whole-brain cranial implants based on CT/fMRI, as well as ultra-high-throughput electrophysiological recording and data analysis solutions. 3. Visual prosthetics research: capturing external visual scenes with a scene capture camera, converting them into multi-channel electrical stimulation signals on line, and transmitting these signals to the monkey's cortex to induce phosphenes or shape perception. (b) Raster plot of spike signals recorded simultaneously from over 1,300 channels across more than 10 brain areas, when the monkey is performing a foraging task.*

Conclusion: Our approach not only enhances the efficiency and accessibility of brain-wide systems neuroscience research but also supports BCI studies based on high-density ultra-flexible electrodes.

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An Assessment of the Impact of Feature Preprocessing on Deep Learning Models for P300 Classification

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Introduction: Feature preprocessing is a standard step when using traditional machine learning (ML) models for brain-computer interface (BCI) applications. In contrast, the full channel set and minimally processed data are typically used for deep learning models that automatically learn feature representations from the raw data. The high feature dimensionality of electroencephalography (EEG) signals has implications on BCI classifier performance given the typical amounts of available user-specific training data relative to the number of trainable parameters of a classifier model. The number of parameters is typically in the order of 10^2 for traditional ML models vs. 10^3 to $10^6$for deep learning models, while the amount of user-specific data ranges from 1×10^3 to 6×10^3observations to train a P300 classifier. We investigate the impact of various feature preprocessing techniques on deep learning models for P300 classification.

Material, Methods and Results: We analysed data from the bigP3BCI dataset, which has data from online P300 speller studies with participants with and without amyotrophic lateral sclerosis (ALS) [1]. Participants without ALS in the bigP3BCI dataset have a broader range of online spelling accuracies when compared to participants with ALS in the dataset. Feature extraction techniques applied include channel subset, downsampling and xDAWN filtering [2]. Classifier models include linear discriminant analysis, convolutional neural network and long short-term memory (CNN-LSTM) network [3] and EEGNet [4]. User-specific P300 classifiers were trained on data from the calibration phase and data from the test phase were used to evaluate the performance of the trained classifiers.

Results grouped by participants with and without ALS are shown in Figure 1. The effect conferred by a combination of preprocessing techniques was classifier model and population dependent: all interaction effects of feature preprocessing were statistically significant ($p < 0.05$), except for CNN-LSTM with a downsampling decimation factor (DF) of 8 and xDAWN filtering.

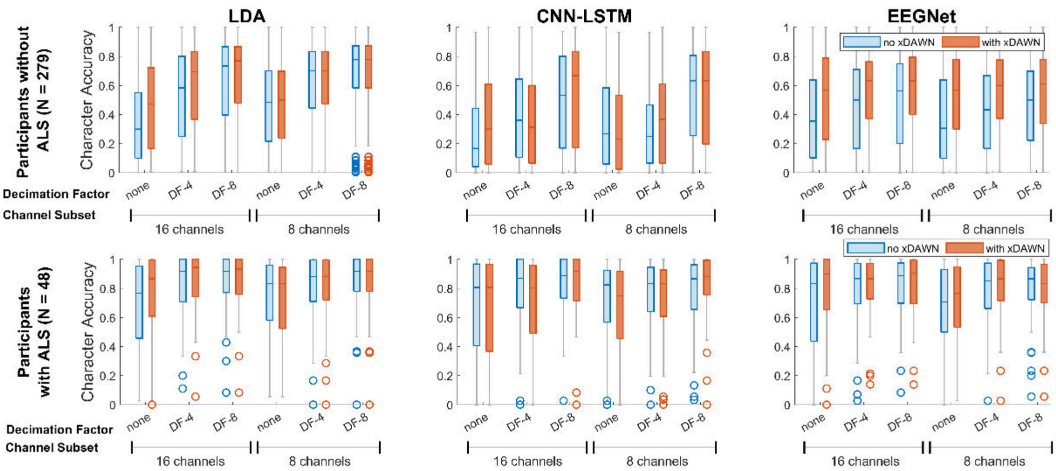

Figure 1: Box plots of P300 speller character accuracy with various signal preprocessing methods and classifier models (linear discriminant analysis (LDA); convolutional neural network long short-term memory (CNN-LSTM) network; and EEGNet).

Conclusion: Overall, deep learning models for P300 classification can derive benefit from feature preprocessing over minimally processed features.

Acknowledgments: This work was funded by the National Institutes of Health (R21DC018347-02S1).

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Fine-Tuning a Foundation Model for Motor Imagery Pediatric Brain-Computer Interfaces (BCIs)

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Introduction: Previous research has shown that BCI classification accuracy heavily relies on the availability of sufficient training EEG data for each participant. However, limited EEG recording durations—especially in pediatric populations—pose significant challenges. Furthermore, variations in brain responses between users and across multiple BCI sessions hinder the generalizability of models, often necessitating lengthy calibration sessions [1]. Recent advancements in foundation models and self-supervised learning offer potential solutions to these challenges. Foundation models are large-scale, pre-trained neural networks designed to generalize across multiple tasks by learning from extensive, unlabelled datasets. They can be fine-tuned for specific downstream classification tasks using minimal labelled data. These models have achieved groundbreaking results in fields like natural language processing, setting new performance benchmarks. This research is the first to explore the application of foundation models in pediatric BCIs, addressing the critical issue of limited training data in this population.

Material, Methods: This study utilized a dataset comprising left/right hand Motor Imagery (MI) EEG data from 32 typically developing pediatric participants (ages 5–17). The dataset included 19 EEG channels following the standard 10-20 electrode placement system. We employed a pre-trained foundation model, EEGPT [2], which outperformed alternative models due to its pre-training on a large, multi-task adult EEG dataset. After preprocessing the pediatric dataset for compatibility with EEGPT, we developed a pipeline to fine-tune the model for the downstream classification task using a linear probing approach. Classification accuracies for the training and test sets were calculated for all participants and compared to those achieved by a Convolutional Neural Network (CNN) trained from scratch.

Results: Fig. 1 presents the classification accuracy for the 32 pediatric participants using the fine-tuned foundation model (58%±3.7) compared to a CNN classifier trained from scratch (48%±5.8). Early results demonstrate that the foundation model pre-trained on adult data and fine-tuned for pediatric data classification yields acceptable performance and outperforms the CNN model.

Conclusion: This study highlights the potential of foundation models in pediatric BCI systems, representing a significant step toward practical, high-performance pediatric BCI applications.

Acknowledgments: We thank the Alberta Graduate Excellence Scholarship for funding this research.

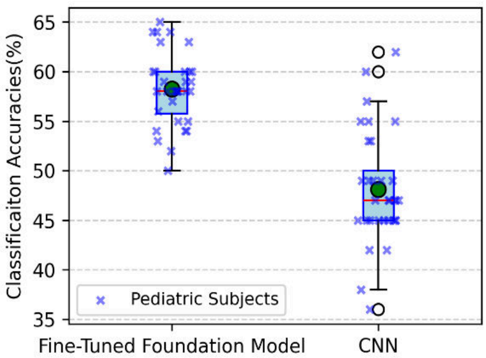

Figure 1. Box plot with scatter points showing classification accuracies for the Motor Imagery task across 32 pediatric subjects.

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Considerations for Utilizing the mindBEAGLE's Hybrid BCI-Based Paradigms in Bilingual Patients with Decompressive Hemicraniectomy and Hydrocephalus: A Case Study

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Introduction: Brain-computer interfaces (BCIs) like the mindBEAGLE offer promising avenues for assessing cognition and facilitating communication in patients with disorders of consciousness (DoC).[1] However, applying this technology to bilingual patients with complex neurological conditions, such as those who have undergone decompressive hemicraniectomy (DHC) and have hydrocephalus, presents unique challenges. This case study investigates considerations and potential adaptations when using mindBEAGLE in this patient population.

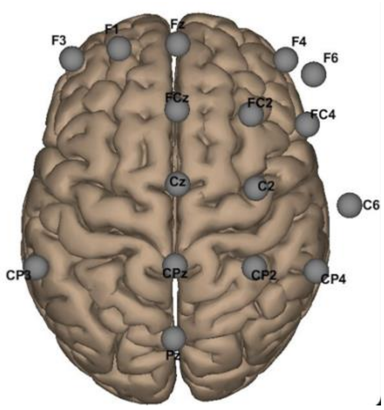

Figure 1 3D Brain Montage of EEG Electrodes

Materials and Methods: This case study examines a 64-year-old bilingual female patient who underwent decompressive hemicraniectomy (DHC) following a ruptured arteriovenous malformation. The mindBEAGLE system was utilized to assess cognition and communication potential, with task instructions tailored to the patient's native language and cultural background.[2] Consideration was given to the effects of altered brain geometry and biomechanics due to DHC and hydrocephalus on EEG signal quality and reliability.[3-5] Data analysis is ongoing using g.tec's g.BSanalyze software. EEG recordings will be analyzed considering the disrupted skull integrity and potential changes in signal propagation. The presentation will include these results with an evaluation of biosignal quality, the significance of evoked potentials, and the electrode configurations required for successful paradigm completion.

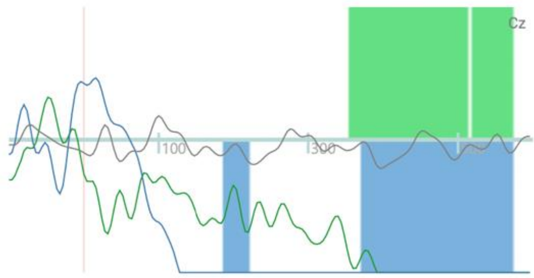

Figure 2 VT7 Assessment Output: Average Evoked Related Potential (ERP) of Channel Cz

Conclusion: This case study provides valuable insights into the challenges of applying BCI technology in patients with complex neurological conditions. Our findings highlight the obstacles encountered and accommodations used to address the unique needs of this patient's altered brain biomechanics and bilingual background.

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ezmsg: An Enhanced Open-Source Framework for High-Performance Brain-Computer Interface Development

C Boulay[1,2], G Milsap[3], P Peranich[3], S Aswegan[2], J Ramos da Cruz[1], J Dunant[1], D Ibanez[1], S Kellis[2], R Franklin[2]

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We present significant updates to *ezmsg* ("easy message") – a high-performance execution engine and multiprocessing backend implemented in pure Python – to enhance its capability as a robust, flexible software framework for real-time signal processing in BCI development. Originally created at Johns Hopkins' Applied Physics Lab, and introduced publicly at Society for Neuroscience 2024 [1], *ezmsg* has been successfully deployed in multiple clinical BCI studies [2, 3], and in ongoing efforts at Blackrock Neurotech and the Wyss Center's INTRECOM and W-ICONS studies utilizing ABILITY implant technology.

This work introduces major enhancements to the *ezmsg* ecosystem that expand its utility for BCI research and development. Core improvements include state persistence and rehydration in *ezmsg-sigproc*, enabling module reuse on scalable cloud platforms. New modules provide essential functionality: *ezmsg-tools* for graph introspection and profiling, *ezmsg-learn* for machine learning inference and online adaptation, and *ezmsg-event* for processing sparse neural events such as action potentials and physiological signals. All components are available as open-source software under permissive licensing [4].

To demonstrate real-world performance, we implemented a representative BCI pipeline that processes 256-channel ECoG data for speech decoding, approximating the methodology described in Metzger et al., 2023 [5]. This implementation achieves processing latencies of 2.75 ms per data chunk on consumer hardware, extracting both high-gamma and low-frequency features and performing phoneme classification via PyTorch.

ezmsg's combination of flexibility, modularity, and performance makes it well-suited for both rapid prototyping of online BCI systems and offline analysis for medical device validation. With continued industrial support, we are committed to expanding the *ezmsg*'s capabilities and optimizing its performance for the evolving needs of the BCI community.

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Gathering Clinicians' Perspectives for an Initial Design for Hybrid BCI Wheelchair Control

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Introduction: Brain-computer interfaces (BCIs) offer a potential solution for children with significant motor disabilities who experience limitations using powered wheelchairs with conventional control methods. Hybrid-BCI (hBCIs) offer enhanced control options compared to single-input BCI [1], yet their optimal design for pediatric users remains unexplored. This poster presents the pilot testing of an online asynchronous codevelopment method to build a clinically-informed initial design of an hBCI for wheelchair control before doing user-centred design and usability testing with children with motor disabilities and their families [2].

Material, Methods and Results: Using usability design approaches, we conducted sequential remote think-out-loud sessions with two occupational therapists (OTs) via Zoom™. OTs interacted with a low-fidelity prototype [3] of a switch and motor imagery-based hBCI, while controlling a simulated wheelchair with direct and indirect control methods (Fig. 1). The prototype included simulated input buttons, a wheelchair image that responded to directional commands, and targets in three predefined positions. OTs thought-out-loud about the function and design of the system while moving the wheelchair and their comments were recorded. GUI modifications based on clinician issues and feedback were implemented during sessions. Qualitative data was collected through structured interviews (recorded, transcribed) addressing system functionality, graphics, accessibility, and usability. Recommended changes were made to the design and then used as the starting interface for the next OT. The two clinicians identified 14 design suggestions. Key modifications identified included using colour for engagement, enhanced contrast and interface element sizing for accessibility, and integration of audio for users with visual impairment (Fig 1).

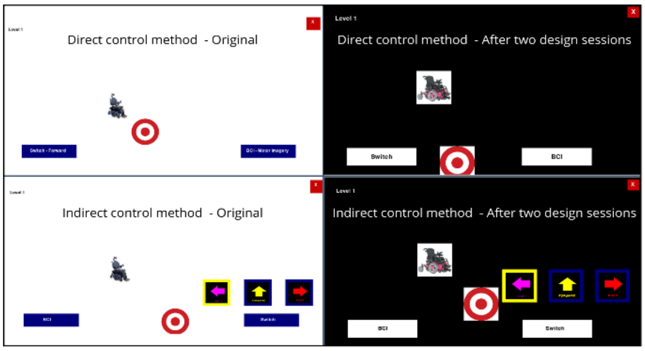

Figure 1: Prototype representing GUI before (left) and after (right) both sessions. Direct control is on the top (switch controls forward and BCI controls right turn) and indirect control is on the bottom (switch scans direction options and BCI selects the option).

Conclusion: This pilot study involved clinicians in the early stages of hBCI design for wheelchair control. The iterative, clinician-informed design process advanced an initial prototype incorporating essential clinical considerations. This process and initial prototype will be used in a future study to gather user and system requirements with more clinicians. This clinician-driven approach will potentially lead to a more effective and user-friendly hBCI system for use in subsequent usability testing with children with motor disabilities to control powered mobility.

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Bimanual BCI: Combining a Brain-Controlled Hand Exoskeleton with the Functional Limb

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Introduction: Brain-controlled robotic systems have demonstrated promise as personalized assistive tools [1]. Yet current BCIs largely focus on unilateral exoskeletons for basic functions [2], offering limited utility in real-world tasks demanding bilateral coordination. This is critical for individuals with unilateral motor impairments, who could combine a BCI-controlled exoskeleton for the affected limb with overt motor actions of the healthy limb. Although the motor cortex supports simultaneous movements, non-invasive electroencephalogram (EEG)-based BCIs remain understudied in this context [3]. Here we show that a BCI decoder trained on a unimanual task can be reliably transferred to more complex bimanual tasks without requiring bimanual-specific calibration.

Material, Methods, and Results: The study involved 7 subjects completing 6 sessions, beginning with a calibration session to build a motor imagery (MI) BCI for right-hand flexion versus rest that controls a hand exoskeleton [4]. In the first two online sessions, subjects performed unimanual MI tasks (rest vs right-hand flexion imagery) with closed-loop feedback, while in the last three sessions, they performed bimanual tasks combining MI-BCI of the right hand with functional tasks of the left hand. Bimanual trials included combinations of left-hand rest/force application in a prespecified range and right-hand rest/exoskeleton control. We used a Riemannian approach [5] to cope with non-stationarities in feature distributions for robust decoder transfer across tasks and over multiple sessions. Figure 1(a) shows subject-level BCI decoding performance, with a significant improvement from U1 (0.301 ± 0.199) to U2 (0.440 ± 0.232, $p < 0.01$), a decline from U2 to B1 ($p = 0.0185$), and subsequent improvement from B1 (0.217 ± 0.157) to B3 (0.368 ± 0.201, $p < 0.01$). Figures 1(b) and 1(c) reveal that this improvement is guided with increased feature separability, as quantified by the Riemannian distinctiveness metric, improving from U1 (0.125 ± 0.046) to U2 (0.168 ± 0.084, $p = 0.039$) and from B1 (0.104 ± 0.041) to B3 (0.150 ± 0.069, $p < 0.01$).

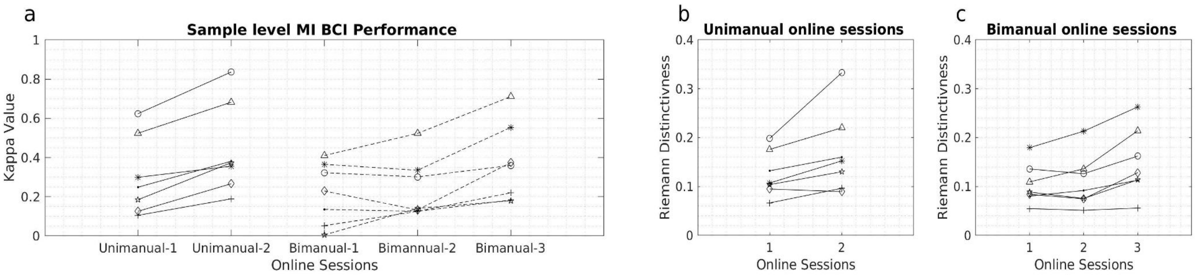

***Figure 1. Bimanual BCI control** a) Kappa value of BCI performance for unimanual (U) and bimanual (B) online sessions. b, c) Riemann Distinctiveness for unimanual and bimanual online sessions, respectively. Each marker represents an individual participant's data point, with lines connecting values across unimanual sessions U1, U2 and bimanual sessions B1, B2, B3.*

Conclusion: Our findings demonstrate that unimanual-trained BCIs can successfully transfer to bimanual tasks, with participants achieving better feature distinctiveness and decoding performance through multi-day training, despite initial performance drops during the unimanual-to-bimanual transition. Our analysis highlights the importance of longitudinal training for robust bimanual BCI control. Our study highlights the viability of transferring unimanual BCI decoders to bimanual tasks, paving the way for more natural and efficient assistive control that enhances real-world functional independence for individuals with motor impairments.

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Brain-Computer Interface Operation in Virtual Reality for Children with Complex Mobility Needs

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Introduction: Brain-Computer Interfaces (BCIs) are an interaction method that presents an abundance of opportunity for people with low or limited mobility which rely on power mobility devices (PMDs) such as power wheelchairs. Combining these technologies open the doors for independence of movement through BCI control of a power wheelchair. Testing such an apparatus in physical space presents many challenges and hazards, such as walls, ledges, and free standing physical obstacles. These challenges may be avoided by testing an analogous system in a virtual environment using immersive Virtual Reality (VR). By practicing in VR, skills develop that should allow for increased performance of an analogous physical system without the hazards that operating such an apparatus with no prior experience would provide [1], [2]. Additionally, the novelty and potential gamification of the system may increase the appeal to juvenile populations and resultantly improve performance on an analogous physical system. This work aims to establish a Virtual Reality Digital Twin of these systems to enable children with complex mobility needs to practice independent movement in comfortable and safe spaces.

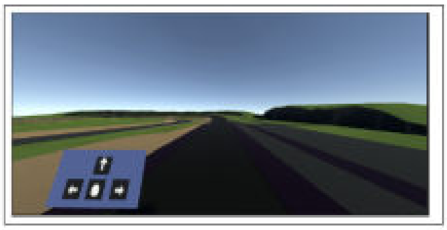

Figure 1: *Image of the preliminary setup in VR exemplifying how a user would interact with the system.*

Material, Methods and Results: An immersive simulation was designed in the Unity3D game engine in which users utilize a P300 paradigm to make selections to move throughout a simulated space (see Fig 1). This environment contains a road with multiple turns and straightaways for a user to engage with steering in more than one direction for varying durations.

Through testing of the system, it is expected that confidence in performance of both the individual and the physical system will increase, leading to increased independence of movement for juvenile populations in which this is lacking. Testing of the system involves a user donning both a DSI-7 (Wearable Sensing) dry-electrode BCI headset with 7 channels, placed underneath an immersive Meta Quest 2 VR headset. Participants are then instructed to attempt to complete one lap of the circuitous road in the simulation through P300 control. The time this takes for completion is recorded, along with the number of intended and unintended selections made by the user. After completing the single lap, participants are asked to complete a multi-question questionnaire to assess considerations about their mental workload, user experience, user interface, and overall satisfaction with the combined BCI+VR system.

Conclusion: This is ongoing work, and our early results are based on first prototypes tested with able bodied adults. This work enables operation of a power wheelchair through a BCI+VR system that can improve quality of life for many children. The potential to practice operating such a system safely in a virtual environment that mimics a real-world device, the Neuromove, is very promising; this eliminates many of the hazards present in the physical world and can make the application of relevant skills in the physical world much easier and more accessible, particularly for children.

Acknowledgments and Disclosures: Thank you to the BCI4Kids and iLab laboratories at the University of Calgary, as well as the teaching team of CPSC502.07.

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Brain-Computer Gaming Control through Imagined Speech Commands in Single-player

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Introduction: Brain-Computer Interface (BCI) controls are traditionally managed by motor imagery, acting as a proxy for directional commands. Using imagined speech (IS), the user's intent directly conveys directions which makes the experience more engaging while closely mirroring real-life situations [1]. In this study, we developed two modes of a BCI controlled, calibration and singleplayer. We evaluated the user's subjective experience and examined whether these two modes shared similarities through a learning model. This approach integrates strategy, dynamic lighting, and immersive sounds, effectively mimicking the environments where a BCI would typically be utilized.

Material, Methods, and Results: Twenty-six healthy volunteers (19 males, 7 females, aged 20.1 ± 1.09, range 18–24) participated in the experiment. All were right-handed native Spanish speakers from Mexico with no speech or language production issues and no clinically diagnosed attention deficit disorders or physical impairments. EEG data was collected using an 8-channel EEG Unicorn Hybrid Black headset (250Hz sampling rate) with electrodes placed at FC3, C3, F5, FC5, C5, F7, FT7, and T7.

Participants completed demographic questionnaires. They then engaged with a non-invasive, endogenous, synchronous, active, and discrete BCI in the form of a maze-like video game. Post-game, they answered a Flow State Questionnaire (FSQ) and Sense of Agency Scale (SoAS). The calibration mode followed automatic movements to train a classifier, used in the singleplayer mode to predict their imagined speech commands in real time. Misclassifications provided additional samples for the classifier, which biased the data set in one direction, see Fig. 1.

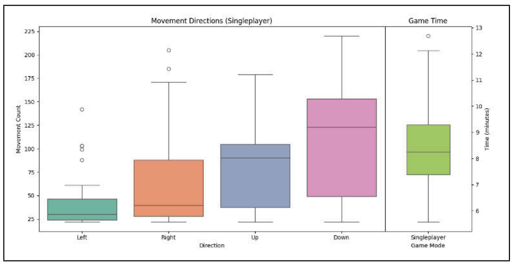

Figure 1: *"Boxplot displaying the total commands per direction in singleplayer mode and the time taken to execute them. There were more trials for directions where the classifier had the highest error rates.*

The FSQ presented a score greater than 3 on a scale of 1 to 5. The lowest Sense of Positive Agency was 50% and the highest Sense of Negative Agency was 67%.

Regarding the EEG data, classifying the directions was underwhelming, with accuracies no better than chance level (25%). However, classification between the two game modes using EEGconformer [2] achieved an accuracy of 84%, a minimum accuracy of 48%, and a maximum accuracy of 100%.

Conclusion: Despite the biased real-time classifier, the overall public response showed a positive Sense of Agency and Flow State. Interestingly, even though the calibration and single-player EEG recordings were conducted within the same hour-long session, the classifier could distinguish them. This observation suggests that a dedicated calibration section might not be reliable for the game, as it may not capture the challenge of actual gameplay. Therefore, a dynamic approach where the game learns and adapts in real-time is recommended. Last, an additional contribution of this work is an IS-based dataset recorded during the two game modes.

Acknowledgments and Disclosures: This work was supported by Secihti, Tecnológico de Monterrey and the NeuroTechs research group. The authors declare no competing interests.

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EEG Data Segmentation Inducing Performance Overestimation

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Introduction: We contend that methodological flaws can lead to overestimations in accuracy for affective state estimation using EEG. One significant methodological flaw is segmentation of EEG data. To explore how EEG data segmentation affects performance, we conducted binary classification experiments using two EEG-based emotion datasets and one additional EEG dataset collected from a watermelon.

Material, Methods and Results: One of the datasets, collected at Kansas State, includes three published stimuli sets. Each stimulus was presented for 15 seconds, and participants rated it on valence, arousal, and dominance using a 5-point Self-Assessment Manikin. Thirty participants experienced 240 stimuli in total. EEG data were recorded using a 64-channel Cognionics system sampling at 500 Hz. The second dataset, collected at Virginia Commonwealth University, consists of EEG signals from 30 participants who viewed 12 one-minute video clips [1]. The third dataset, inspired by [2] was also collected at Kansas State and consists of EEG data recorded from a watermelon over a one-hour session using the same experimental setup as the first dataset. We created forty 60-second trials with a 30-second interval between consecutive trials and assigned binary random ratings for each trial.

Each trial in the first dataset originally lasted 15 seconds. To increase the sample size, we segmented each trial into n-second intervals. For example, by segmenting into 1-second trials, the total number of trials increased to 3600 (240 trials × 15 seconds). By varying n (i.e., using different trial durations), we assessed the impact of segmentation on all three datasets. The power spectral density (PSD) was averaged across four frequency bands: theta, alpha, beta, and gamma band. A binary classification with kNN was applied using the mean valence ratings as a threshold, followed by 4-fold cross-validation to calculate accuracy.

Fig 1. shows the mean classification accuracy of all participants on the valence axis for the emotion datasets and accuracy for the watermelon EEG data. The blue line represents the original accuracy, and the orange line represents accuracy by applying leave-one-trial out. From the figure, it is observed that increasing the number of trials enhances classification performance in subject-dependent analyses. Nearly 93% accuracy can be achieved with the segmentation of watermelon EEG data. However, accuracy drops to chance levels when leave-one-trial out is performed.

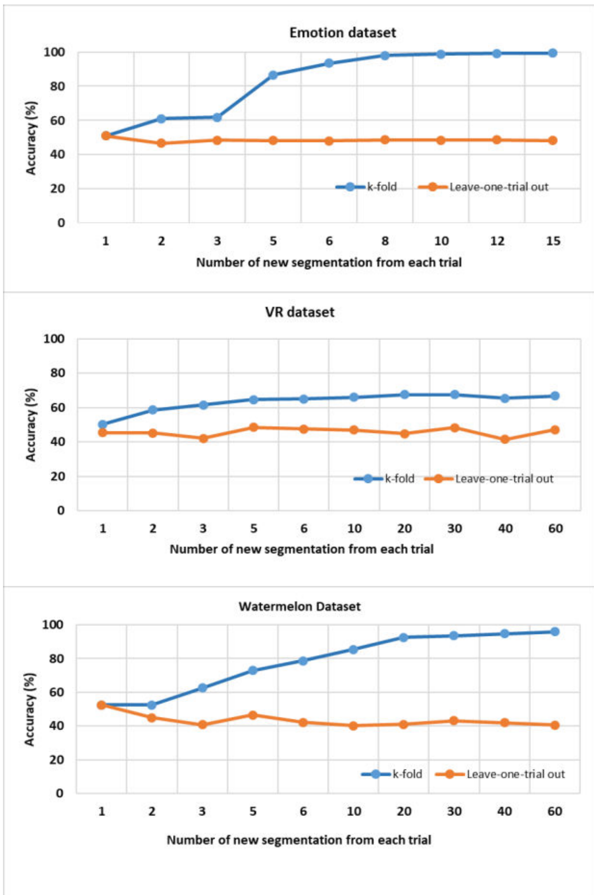

Figure 1: *Mean accuracy of all participants using different segmentation durations for three datasets (Top: Emotion dataset, Middle: VR dataset, Bottom: Watermelon dataset)*

Discussion: This study offers a preliminary analysis of EEG data segmentation's impact on affective state estimation. High classification accuracy from EEG signals of a watermelon can be achieved by simply segmenting trials, despite the absence of genuine neural responses. The overestimated accuracy across all three datasets suggests that it may be due to inherent temporal autocorrelations in EEG signals.

Acknowledgments and Disclosures: This study was supported by NSF under award #1910526. Findings and opinions within this work do not necessarily reflect the positions of the National Science Foundation.

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Robotic Exploratory Control Via Subcortical Oscillations

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Introduction: Navigation through real-world environments remains a difficult task in intelligent robotics, due to a constantly changing landscape of potential hazards and new information. To address this, roboticists and neuroscientists have turned to the brains and behaviors of rodents — some of nature's most successful explorers — to inspire optimal solutions. [1-2] Most approaches model patterns of activation in the hippocampus and associated circuitry, leveraging rodents' exceptional memory of spatiotemporal sequences for navigation. None, however, have utilized the coupled activity of multiple subcortical regions that balance navigation with regulation (e.g., grooming, immobility), a key optimization that animals use in real-world scenarios. Indeed, activity in the amygdala, olfactory bulb, hippocampus, along with their functional couplings, have been shown to be instrumental during free-roaming and navigation tasks involving potential stressors (e.g., novel objects, fear stimuli, conspecifics, or autonomous agents). [3-5] This recruitment of regions involved in both regulation and exploration reflects the strategy of switching between these behaviors observed in rats during these paradigms. The current research investigates the effectiveness of neural oscillations in these brain regions as control signals for robotic navigation, using the natural hierarchy of rodent subcortical activity as a decision-making architecture for a self-monitoring neurorobotic system. Building such hierarchical control systems with self-regulatory mechanisms is crucial for developing intelligent robotics that perform natural tasks as biological agents do.

Material, Methods and Results: For this study, we utilize PiRat, a rat-sized robot used in several previous rat-robot interaction studies. [3] In our simple paradigm, the robot is equipped with a two-dimensional action space A and a five-dimensional state space S (Fig. 1). We begin our investigation with an offline training procedure using data from previous recording sessions, during which rats with tetrode implants in the CA2 region of the hippocampus (CA2) and stereotrodes in the medial amygdala (MeA) and main olfactory bulb (MOB) were allowed to roam freely in the presence of a conspecific. [3] During offline training, a behavioral cloning (BC) neural network model designed in PyTorch was trained to generate action a ∈ A based on state s ∈ S (70/30 train/test split). We then ran the model on the remaining test data, and the actions generated by the model at each timestep were combined into a continuous trajectory of resulting positions. These were compared to the actual rat positions at each corresponding timestep, serving as a metric for how rodent-like the robot's free roaming behavior was. At the current stage of this work, we have learned a state and action space for the paradigm, and are in the development stages of the BC model.

$$\mathbf{S} = \{\mathbf{s} : (\mathbf{x}, \mathbf{y}, \mathbf{M}(\mathbf{LFP_{mob}}), \mathbf{LFP_{amyg}}, \mathbf{M}(\mathbf{LFP_{ca2}})) | \mathbf{x}, \mathbf{y}, \mathbf{LFP} \in \mathbf{R}\}$$

$$\mathbf{M}(\mathbf{x}(\mathbf{t})) = \arg \max_{\mathbf{f} : \in [\mathbf{2}, \mathbf{12}]} \mathbf{P}(\mathbf{f})$$

$$\mathbf{A} = \{\mathbf{a} : (\mathbf{v}, \theta) | \mathbf{v} \in [-\mathbf{1}, \mathbf{1}], \theta \in [\mathbf{0}, \pi]\}$$

Figure 1: *State space (S) and Action space (A) defined for behavioral cloning model. Function M denotes frequency with greatest power within the theta frequency band (range chosen based on previous work). [3]*

Conclusion: The defined state and action spaces demonstrate that rodent-like exploratory and regulatory behaviors may be generated via streams of local field potential data from CA2, MOB, and MeA.

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Accuracy Analysis of P300 BCI Famous Face Stimuli

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Introduction: The P300 brain-computer interface (BCI) paradigm relies on stimuli to elicit a P300 response in a BCI user. For the P300 BCIs that use flashing stimuli, prior literature [1] has shown that P300 systems that flash famous faces yield higher accuracy rates than the traditional flashing text stimuli. Currently the University of Michigan Direct Brain Interface (UMDBI) lab uses a tiled, repeating pattern of 16 famous faces as the flashing stimulus (Fig. 1). Faces are arranged to maximize visual contrast between adjacent faces. This study investigates if the different faces produce different accuracy in P300 BCI use.

Methods: The P300 BCI data analyzed for this investigation was collected from 5 participants over 6 sessions (about a week apart) using a P300 BCI to access a PRC-Saltillo communication device keyboard with word prediction. For each participant, the BCI was calibrated with data from 20 selections at 15 sequences and the number of sequences optimized for use. The calibration data included 12 of the 16 faces (missing Hathaway, RM, Redford, and Tan). Participants tested BCI performance by copying sentences and composing picture descriptions using both correction of errors and word prediction. Test data had an average of 552.8 selections per participant (range 388-633 selections). An offline analysis of the recorded selections was conducted using a Chi-squared test to assess whether accuracy was dependent on the face stimulus overlaying the intended target. Subsequent pairwise z-tests, with multiple comparison adjustments, were performed to identify the face stimuli that have significant differences in accuracy compared to others.

Results: The Chi-squared test showed significant differences in accuracy based on the face stimulus. Pairwise z-tests indicated that faces Hathaway, RM, and Tan had significantly lower accuracy than multiple other face stimuli. The percentage of intended selections per face varied from 0.43% to 13.64% (see Fig. 2). No statistically significant conclusions could be drawn for face Berry due to its infrequent selection rate (0.43%).

Figure 1: *Tiled faces used as stimuli (without the names) create visual contrast between adjacent faces.*

Conclusion: The 3 face stimuli with significantly lower performance were not included in the calibration session, which could contribute to the lower accuracy. The low percentage of times that these faces were the target also reduces the ability to access accuracy. Apart from these 3 faces the accuracy was relatively consistent between the different faces. Future studies should include all faces as targets in the calibration data and provide better balance of use of each face as the target during testing.

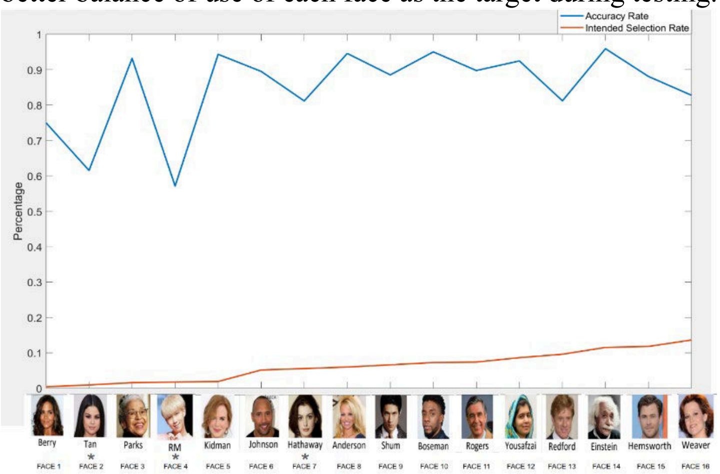

Figure 2: *Graph of the Accuracy and Intended selection rate of the 16 faces stimuli sorted by Intended selection rate. (*) Mark low accuracy faces.*

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Distinguishing foveal and peripheral vision from brain activity using fNIRS

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Introduction: Vision plays a crucial role in exploring our surroundings. It helps us to avoid dangerous situations and to respond to changes in the environment. The ability to recognize and interpret these scenarios is linked to the visual field, which is made up of both peripheral and foveal vision[1]. While foveal vision allows individuals to focus on specific details, peripheral vision enables to monitor what is happening around [2]. These aspects of vision provide essential information for performing daily tasks, such as navigation, where it's important to be aware of both the body's position and the objects nearby. We used fNIRS to detect differences in neural activity when central and peripheral vision stimuli are presented.

Material, Methods and Results: This study aims to determine whether fNIRS signals can distinguish cerebral responses to visual stimuli presented in central vision versus those in the peripheral. The experiment featured the projection of an optotype based on the Snellen chart that moved across the horizontal plane in two stages: first within the central vision, and then outside that field while the subject maintains focus on the center. Brain hemodynamic responses were recorded using the NIRx NIRScout device, which employed eight detectors and 16 emitters arranged over the somatosensory cortex and occipital lobe. Data processing was carried out using a custom Python algorithm, which performed a comparative analysis of various classification models based on statistical features and determined channels exhibiting the most significant differences. As a result, the algorithm distinguished between events involving foveal and peripheral vision. Additionally, it was possible to identify the region where variability is greater (see Fig. 1) and also determine that the Boosted Trees model achieved the highest classification accuracy (0.833) in these instances.

Conclusion: This study demonstrates the capability of fNIRS to distinguish neural activity between central and peripheral vision, highlighting its potential as a less invasive method for monitoring brain activity. Simultaneously, it provides valuable insights for the development of Brain-Computer Interface (BCI) systems using fNIRS-based neural signals to assist with navigation through vision. These findings serve as a starting point for future research, setting the stage for the creation of more advanced systems aimed at improving navigation and interaction through neural signals.

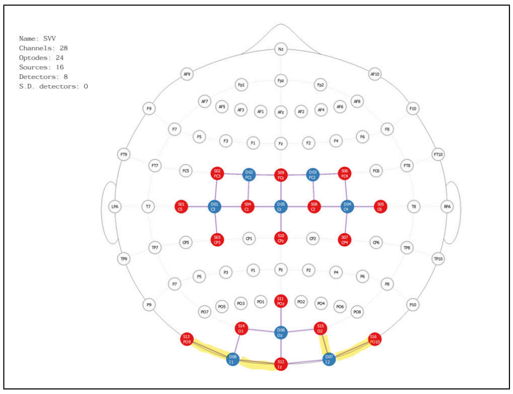

Figure 1: *Region identified with significant difference in central and peripheral vision*

Acknowledgments and Disclosures: This work was made possible through funding from CONAHCYT and the resources provided by INAOE.

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Smart Gel-Enabled EEG Systems for Brain-Computer Interfaces in Children with Profound Motor Impairments

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Introduction:

Millions of children worldwide are cognitively capable but unable to move or speak, leaving families seeking solutions to support their right to play, communicate, and interact. Brain-computer interfaces (BCIs) offer a groundbreaking opportunity for these children to engage with their environment [1]. However, children remain significantly underserved in BCI research, with less than 2% of studies focusing on this population [2]. Addressing this gap is critical to enabling these children to express themselves and benefit from assistive technologies. Current EEG headsets used in BCI systems face significant challenges in daily use. For all-day measurement, the current EEG technology requires manual injection of conductive hydrogel into each electrode. The gel is commercially available and has toothpaste-like consistency. After applying it for a day, the gel dries up, gets jammed to hair, and is laborious to wash off. In addition, the current headsets require restrictive chin straps and transverse tightening to ensure for high-quality signals obtained using the conductive gel. For children with smaller head shapes and repetitive movements, overtightened caps cause discomfort, particularly for those with hypersensitivity. These barriers often force children to rely on less effective headsets, limiting their ability to benefit from BCI advancements and the life-changing potential of this technology [3].

Material, Methods and Results:

To improve on the current EEG headset design, a smart gel-enabled EEG system is under developing for practical daily EEG use. A polyampholyte sticky conductive gel is designed to transition from a solid-like consistency with firm adhesion to a water-like flow on demand. The precursor solutions are polymerized under UV for 8-10 hours to form the sticky conductive gel. When the gel is in the solid-like state, the highly adhesive property of the gel ensures firm adhesion between the scalp and the electrodes. The developed gel can also extend extensively with unaffected electrical conductivity. This allows EEG headset to experience head movements but still ensures high quality signals and adequate adhesion between the electrodes and the scalp. When needed, the bonding in the polyampholyte hydrogel can be disrupted by high concentration of salt. As a result, the solid-like gel is transitioned into a water-like flow using salt water. This transition in consistency allows for easier cleanup process after the end of the headset usage. This sticky hydrogel has been tested and compared to the current commercially available gel typically used in BCI systems. The EEG Quality Index was calculated and compared between the two gels under several different conditions including with and without the use of the chin strap. The preliminary data has indicated our proposed hydrogel was able to maintain a greater similarity in signal quality to the cleaned epoch of data even once the chin strap was released, as compared to the commercially available gel.

Conclusion:

This early result highlights the potential of our proposed gel to maintain high signal quality without applying continuous tension. With the highly adhesiveness and the controlled detachment of proposed gel, the EEG headset design is promising in providing reliable signals in less constrained conditions making the headset suitable for more situations in real life.

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Parametric control of neurons in IT cortex as a stringent generalization test for deep encoding models

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Introduction: Deep neural network (DNN) models have potential to transform our understanding of how sensory inputs are processed in cortex. While many models increasingly achieve high neural predictivity, a critical question is whether their predictive capacity generalizes robustly beyond the original training domain. We propose that a model's ability to control neural responses—rather than merely predict them—serves as a powerful indicator of such generalization. ***Materials, Methods and Results:*** Using neural recordings in macaque inferotemporal (IT) cortex, we compared two DNN-based encoding models: a standard ResNet-50 and an adversarially robust variant. Both achieved comparable predictive performance (R^2) for natural images, yet differed substantially in their capacity for *parametric control*. We used an explainable AI method called "feature accentuation" to synthesize new images that systematically varied along each model's encoding axes. These accentuated stimuli were then presented to the same animal under identical conditions the next day. We found that stimuli from the robust model achieved precise modulation of neural firing: responses reliably and predictably aligned with each feature level. In contrast, baseline ResNet-derived stimuli showed far weaker parametric control. Qualitative analyses further showed that robust model accentuations emphasized cohesive object-like contours, whereas baseline accentuations altered mostly textural patterns. ***Conclusion:*** Parametric control offers a stronger test of whether an encoding model has genuinely identified the features represented in neural populations. This form of generalization will be essential for encoding-model-based BCI systems that must reliably operate under new conditions and stimuli. By identifying models whose representations support accurate neural modulation, this approach paves the way for more robust, flexible BCIs.

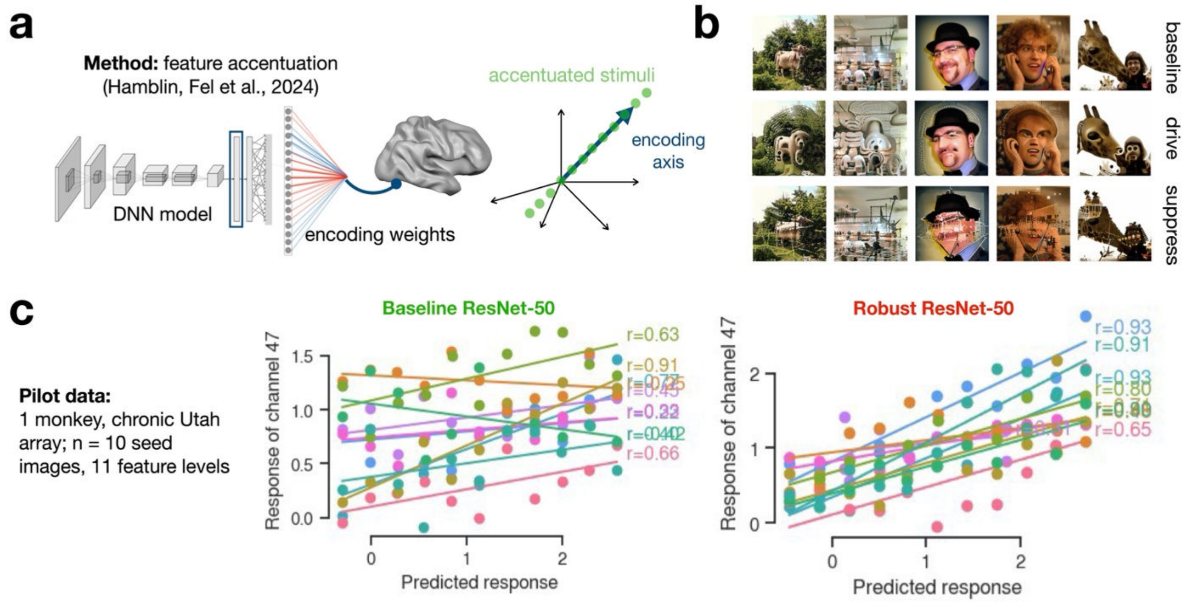

Figure 1: (a) Schematic of the feature accentuation pipeline, which uses a DNN's encoding axes to generate "drive" and "suppress" stimuli at even intervals. (b) Example accentuated images from baseline vs. robust models. (c) Pilot data reveal stronger parametric control by the robust ResNet-50 (right) than by the baseline ResNet-50 (left), as indicated by higher correlations between predicted and recorded responses.

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Learning cause and effect using a BCI: two case studies

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Introduction: Brain-computer interface (BCI)-based interventions are inherently complex, making causal mechanistic studies difficult and expensive. Consequently, few BCI technologies have been translated to the clinic or to daily use. New recognition that the central nervous system (CNS) remains plastic throughout life, and new understanding of how muscle-based skills are learned and maintained can provide insight into how a BCI might provide opportunities for translation. The new *Heksor/ Negotiated Equilibrium* paradigm explains how skills are acquired and maintained in the continually changing CNS. The network of neurons and synapses that maintains a skill was recently given the name heksor [1]. The concurrent adaptations of overlapping heksors require a *negotiated equilibrium* of CNS properties that ensures the maintenance of all their skills [2]. In this environment, targeted plasticity can have broad effects. Here, we present case studies of two individuals for whom BCI training improved ostensibly unrelated aspects of their CNS function. Further insight into how a BCI might emulate CNS processes and function more like muscle-based skills may improve BCI reliability and hold hope for widespread use of BCIs in translation.

Materials, Methods and Results: Participants were two non-speaking males with no useful motor control. P1, age 16, was diagnosed with cerebral palsy and was blind. P2, age 5, was diagnosed with GM3 synthase deficiency and had impaired vision and audition of cortical origin. Both were discharged from standard-of-care rehabilitation therapy due to failure to progress. Subsequently, they were enrolled in and completed 13 (P1) and 7 (P2) EEG-based motor imagery sessions (S). Signals were recorded with the Emotiv Epoc X cap and 14 saline Ag/AgCl electrodes at standard locations using Emotiv software. At each session, participants were asked to calibrate their BCI by following verbal instructions to either relax or imagine moving [pushing (P1), or hand tapping (P2)] 7-10 times for each condition. During sessions, P1 used the Assistive Technology Hub to turn on music and P2 used the Think2Switch to activate and maintain a switch-adaptive bubble maker. Level of engagement was followed using the Pediatric Rehabilitation Intervention Measure of Engagement - Service Provider version (PRIME-SP) (Scale 0-3, for affective, behavioral, and cognitive involvement) [3].

Both P1 and P2 demonstrated an understanding of cause and effect by session (S)2 of BCI training, i.e., they used motor imagery to successfully control their BCI. Both have re-entered regular hospital therapy where they continue to use a BCI, and, additionally, to practice with a conventional mechanical switch–P1 practicing with either hand and P2 practicing left finger movement. Prior to BCI training, PRIME SP scores for both participants were 0-1 for all categories. At Screening, P1 was rated at 3 for affective, 2 for behavioral and cognitive involvement. P2 was rated at 2 for affective, 1 for behavioral and cognitive. At S13, P1 was rated 3 for affective, behavioral and cognitive, and at S6, P2 was rated: 3 for affective, 2 for behavioral and cognitive. These scores indicate high engagement.

Conclusion: These two examples of improved ostensibly unrelated aspects of CNS function could reflect a re-negotiated equilibrium between heksors. However, these observations must be confirmed through investigation into the signals used for BCI control and into the repeatability and longevity of these effects.

Acknowledgments and Disclosures: We thank Eli Kinney-Lang and the BCI4KIDS program. NCAN support provided by NIH/NIBIB P41 EB018783 (Wolpaw) and Stratton VA Medical Center. The authors have no conflicts of interest.

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Neural Symbolic Regression for Interpretable & Efficient Brain-Computer Interfaces

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***Introduction**:* Brain-computer interfaces (BCIs) offer transformative potential for underserved populations like children with neurological disabilities, by enabling environmental interaction via direct neural signals[1]. Scalable deep learning (DL) algorithms needed to learn from these signals effectively are central to improving BCI performance. However, the black-box nature and computational demands of DL pose many challenges to clinical deployment, mechanistic research, patient accessibility and do not provide the adaptability needed for pediatric BCI applications, wherein each child's unique neurodevelopmental profile necessitates continually-learning algorithms that can support personalized solutions.

***Material, Methods and Results**:* We present a novel DL architecture that addresses these challenges by learning concise, interpretable mathematical expressions, while serving as a drop-in replacement for the most common DL module in DL/BCI pipelines– multilayer perceptrons (MLPs). Unlike traditional MLPs that learn opaque representations, our symbolic regression (SR) model aims to discover simple equations that describe the underlying relationships in data, and builds on past neuro-symbolic methods[2] by introducing: (1) self-compressive training via adaptive pruning, quantization and hyperparameter selection; (2) single-phase training compatible with standard DL workflows; (3) support for discontinuous operators via neural arithmetic logic units[3]; and (4) automatic feature selection for high-dimensional datasets. Preliminary evaluation on BCI Competition IV Dataset 2a [4] with standard training features demonstrate that the symbolic expressions obtained achieve higher classification accuracy than MLPs (52% vs. 47%), reduce model size by ~91%, inference time by ~83% and yield readable equations to compute classification class probabilities for motor imagery (Fig. 1c). Such interpretability may enable neurophysiological hypothesis generation, and the reduced computational overhead can facilitate deployment on resource-constrained devices common in clinical settings.

***Conclusion**:* These improvements in efficiency and interpretability provide a foundation for more accessible and personalized BCI systems– aspiring to benefit pediatric applications where understanding individual variation and enabling widespread deployment are crucial for clinical success.

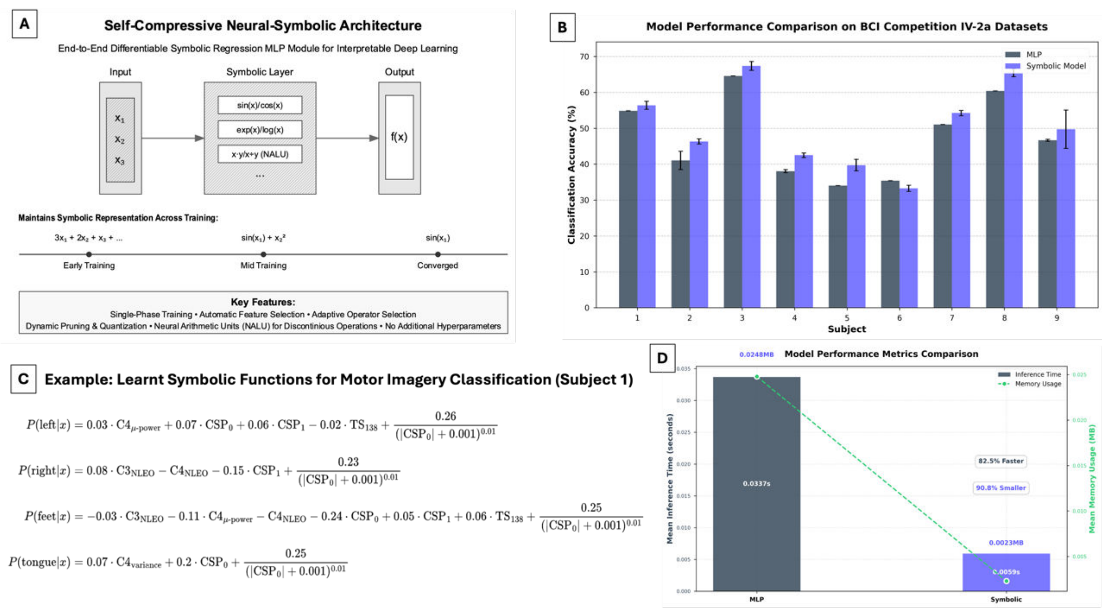

Figure 1: ***A)** Proposed self-compressive architecture that maintains concise symbolic representations across training.* ***B)** Classification performance across subjects compared to standard multilayer perceptron (MLP).* ***C)** Example of learnt symbolic classifiers for Subject 1 (C3/C4 ≈ motor cortex electrodes; CSP = Common Spatial Pattern features; NLEO = Nonlinear Energy Operator; μ-power ≈ motor-related mu-band power).* ***D)** Model compression and inference time comparisons against standard MLP (n = 5).*

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Improving Speech Perception Through Brain-Driven Target Speech Selection

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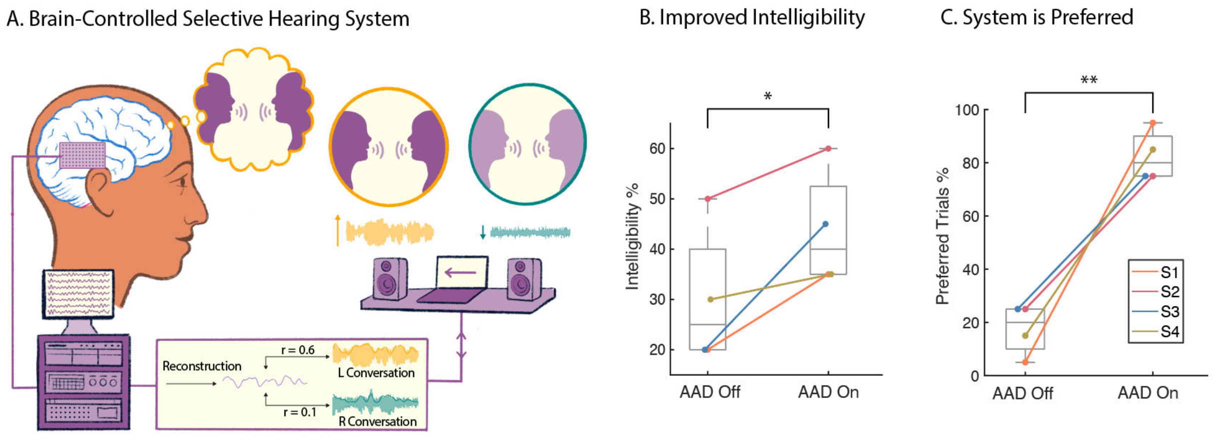
Introduction: Environments with multiple competing conversations and background noise create significant challenges for focusing on a single speaker, particularly for individuals with hearing difficulties. Current hearing aids rely on techniques like directional microphones and beamforming, which often fail to align with the wearer's dynamic listening intent. Auditory attention decoding (AAD) presents a promising alternative by using neural data to identify the listener's target of attention and selectively enhance the desired speech signal relative to background noise.

Gap: While extensive research has focused on improving AAD algorithmic accuracy in offline settings, there has been limited exploration of real-time, closed-loop systems. Existing non-invasive approaches, though valuable, often exhibit slower response times and reduced accuracy. Importantly, no prior studies have demonstrated improved listening outcomes such as speech intelligibility or listening effort reduction. This leaves a critical gap in understanding the practical benefits of real-time AAD systems.

Methods: We developed and evaluated a real-time closed-loop AAD system (Figure 1A) with four self-reported normal-hearing participants (S1-S4) implanted with brain electrodes during epilepsy treatment. Participants were tasked with focusing on one of two competing conversations while the system dynamically adapted to their attention shifts.

Results: Utilizing invasive electroencephalography (iEEG), the system accurately decoded and enhanced the attended conversation. This led to significant improvements in speech intelligibility (Figure 1B) and reduced listening effort (Figure 1C), as corroborated by pupillometry. Importantly, participants could seamlessly switch attention between the two competing conversations, with the system adapting dynamically to their shifts in focus. All participants reported that the system would be useful, and psychophysical testing on individuals with hearing impairments further validated its effectiveness.

Significance: This study is the first to demonstrate that real-time, closed-loop AAD can improve both objective and subjective hearing outcomes. By bridging the gap between decoding success and practical auditory benefits, this work marks a significant step toward the development of brain-controlled hearing devices capable of improving auditory experiences in challenging listening environments for both normal-hearing and hard-of-hearing individuals.



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Unsupervised Manifold Stabilization Method for Across-Session Brain-Computer Interface Decoding

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Introduction: Brain-computer interfaces (BCIs) aim to convert cortical activities into motor commands to operate external devices, offering hope for individuals with movement disorders such as spinal cord injury (SCI). However, a major challenge for real-time BCIs is the variability in neural activities across sessions, requiring frequent recalibration to maintain decoding accuracy. One solution involves projecting neural signal onto low-dimensional manifolds and aligning them using methods such as canonical correlation analysis (CCA). However, CCA relies on knowing the subject's true intentions, such as target direction, which is often impractical in real-world applications. To address this, we developed an unsupervised approach to estimate target direction prior to alignment.

Material, Methods, and Results: An automatic algorithm Unsupervised Neural Manifold Alignment Decoding (UnMAD), was proposed to decode movement parameters without requiring target labels. UnMAD integrates three main stages: (1) Dimensionality reduction for extracting manifolds, (2) Discrete trajectory decoding for predicting target labels, and (3) Continuous movement decoding for aligning and decoding. We evaluated the proposed approach against two baseline methods: a supervised decoder that calibrates using day-k neural and behavioral data, and an unsupervised algorithm called distribution alignment decoding (DAD). DAD matches predicted movements on day k with historical manifold distributions through distribution alignment techniques. The primary goal was to decode 2D velocity (Fig. 1 A) from the neural activity of the primary motor cortex of two monkeys (Monkey C and Monkey M) during a reach center-out task. UnMAD compensated for manifold variability across two different recording sessions in two monkeys, increasing the average correlation between manifolds from R=0.47 (before UnMAD) to R=0.97 (after UnMAD). In decoding movement velocities (Fig. 1B-D) UnMAD outperformed unsupervised DAD approach in the average decoding performance (R^2= 0.65 vs. 0.21). Also, UnMAD achieved 84% of the decoding performance of the CCA supervised method (R^2= 0.65 vs. 0.77).

Conclusion: UnMAD provides an unsupervised approach for stabilizing neural manifolds without requiring target labels, making it promising for clinical applications of BCIs for individuals with SCIs.

Acknowledgments and Disclosures: The authors declare no conflicts of interest.

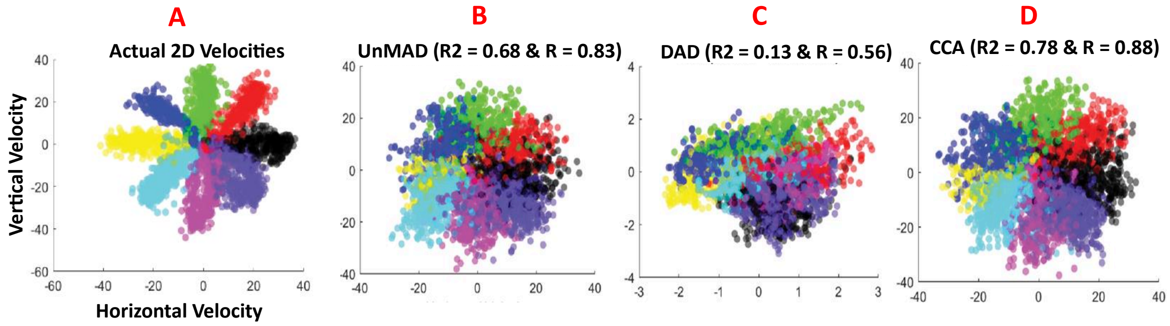

Figure 1: Representation of hand 2D velocities and decoding performances. (A) *Actual 2D velocity.* (B-D) Comparison of predicted hand velocities of Monkey C using three different methods, UnMAD (B), DAD (C), and CCA (D). Each dot represents a time point, and different colors correspond to the eight distinct target directions.

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Brain-Informed Auditory Scene Understanding: A Listener-Aware Auditory Foundation Model for Personalized Speech Processing

Xilin Jiang[1,2], Sukru Samet Dindar[1,2], Vishal Choudhari[1,2], Stephan Bickel[3,4], Ashesh D. Mehta[3,4], Catherine Schevon[5], Guy M. McKhann[5], Adeen Flinker[6], Daniel Friedman[6], Nima Mesgarani[1,2*] (nima@ee.columbia.edu)

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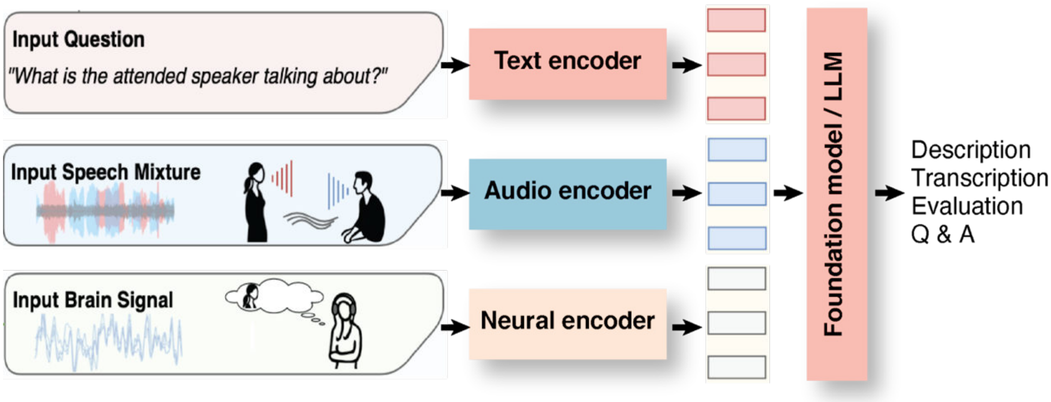
Introduction: Auditory foundation models represented by auditory large language models (LLMs) process speech and text inputs to analyze speech mixtures, recognize speakers, and transcribe content. However, they operate independently of the listener's perceptual experience, treating all auditory inputs equally. In reality, auditory perception is inherently selective—different listeners focus on different elements of the same acoustic scene at different times. We introduce a novel foundation model that extends auditory LLMs beyond traditional multimodal inputs by incorporating neural data from the listener, enabling personalized auditory scene understanding.

Gap: While multimodal foundation models integrate text and audio, they lack a mechanism to account for individual auditory attention. Existing models cannot distinguish between foreground and background speech based on the listener's intent, limiting their ability to provide personalized responses about the scene. Prior research in auditory attention decoding (AAD) has demonstrated that neural signals can reveal which speaker a person is focusing on, but this has not been integrated into auditory LLMs for selective response generation.

Methods: We introduce an attention-aware framework that integrates neural recordings into an auditory LLM, enabling selective speech processing. Our approach consists of two key steps. First, using intracranial EEG (iEEG) data, we decode the listener's auditory focus, predicting an attention token that represents the attended speaker. This token is derived from speaker-specific neural features, allowing the model to differentiate between attended and ignored speech sources. Next, the predicted attention token is incorporated into an auditory LLM's input, allowing it to generate responses that align with the listener's perceptual focus. A chain-of-thought reasoning mechanism ensures that transcriptions, summaries, and speech enhancements prioritize the listener's intended speaker while also enabling background summarization if needed.

Results: Our model enables a range of listener-personalized tasks, including speaker-aware transcription, selective speech enhancement, and customized background summarization. Experimental results demonstrate that the model can accurately extract and process speech from the attended source while filtering out distractions, outperforming traditional auditory foundation models that lack neural integration.

Significance: This work represents the first integration of listener-specific neural signals into a foundation model for auditory scene understanding, bridging the gap between passive speech processing and human-centered auditory AI. By extending auditory LLMs beyond text and audio to include neural data, we move toward AI systems that dynamically adapt to human perception. This advancement has significant implications for assistive hearing technologies, human-computer interaction, and personalized AI-driven auditory experiences.



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Extensive, non-uniform neural activation from intracortical electrical stimulation drives weak sensory perception in mice

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Introduction: Electrical brain stimulation (EBS) is a powerful tool for modulating neural activity and influencing behavior, with growing potential for use in cortical prostheses to evoke perceptible sensations and provide sensory feedback. While biophysical models and clinical psychophysics offer insights into EBS effectiveness, *in vivo* validation is limited. This project aims to directly measure neural responses to single pulses of EBS in mouse V1 with high spatial precision, exploring the volume of evoked potentials, direct and circuit-wide responses of single neurons, and what EBS-evoked neural activity drives detectable sensations.

Material, methods, and results: We simultaneously implanted three Neuropixels orthogonal to a stimulating electrode in mouse primary visual cortex, allowing three-dimensional sampling of neural tissue around a source of stimulation. First, the volume of the evoked potential increases sub-linearly with stimulation amplitude. Further, the shape of the evoked potential was non-uniform, extending asymmetrically through cortex and less likely to penetrate subcortically beyond the corpus callosum (figure 1a). Next, we explored the direct single unit spiking response within the volume of activated tissue. Increasing amplitude recruits more directly responsive cells (example unit in figure 1b), but overall activation remains sparse, peaking at ~10%. Fast-spiking units (putative inhibitory cells) were more likely to be directly activated and clustered closer to the electrode than regular-spiking units. Despite sparse direct activation of single units, we observed large, synchronous circuit responses spreading asymmetrically through the cortex but not subcortically (figure 1c). Lastly, we tested the behavioral availability of single pulses and trains of V1 EBS compared to visual stimuli of varying contrasts. The same single pulses that generated large, evoked potentials and synchronous circuit responses were weakly detected, comparable to 2-4% contrast visual stimuli, while high frequency trains were more detectable, comparable to 8% contrast visual stimuli (figure1d).

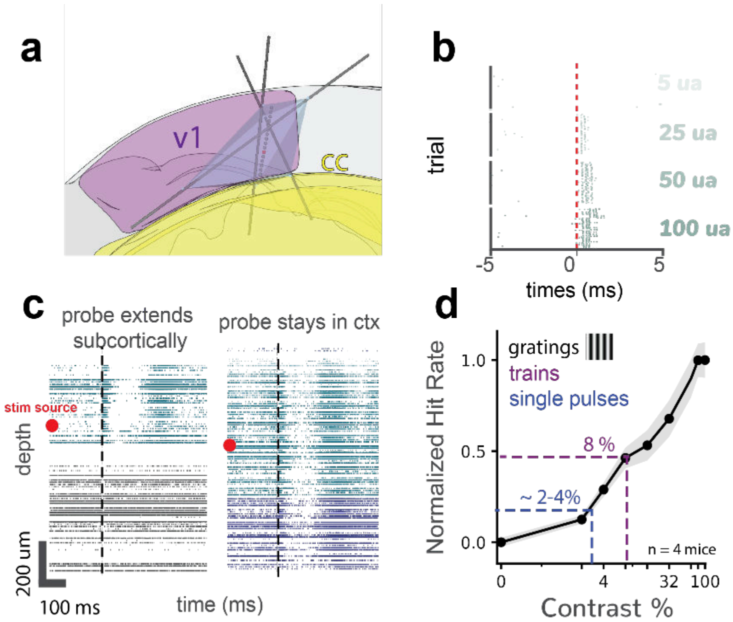

Figure 1 a) asymmetric evoked potential (blue) with anatomical borders. b) example raster of direct responding unit. c) stacked raster of single units extending subcortically (left) and through cortex (right). d) behavioral detection of visual and EBS stimuli (single pulses: blue, trains: purple)

Conclusion: Overall, we show that the volume of evoked potentials is non-uniform, direct single-unit activation is sparse, and circuit responses are large and asymmetric yet weakly behaviorally available. Together, this suggests that EBS nonuniformly propagates through neural tissues, influenced by anatomical heterogeneity such as white matter boundaries and functional connectivity. Further, these results provide critical insights into the importance of neural specificity over activation strength when applying EBS to write information into the brain and call for spatiotemporal stimulation patterns that may better recapitulate sensory stimuli.

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Semantic Decoding Advances in BCI via the Novel Graded Inventory of Semantic Triggers (GIST)

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Introduction: Semantic decoding involves directly mapping neural activity to concepts, offering the potential to communicate entire concepts through *Semantic BCIs,* without having to translate them into words, e.g., via traditional BCI spellers [1]. This could significantly enhance information transfer rates, particularly for users with sensory impairments who cannot rely on exogenous stimuli for BCI control. Despite various paradigms for triggering semantic signals having been tested, significant challenges remain, such as the limited functional relevance of concept categories, confounding effects of cue stimuli, and delayed ideation during experiments.

Material, Methods and Results: To address existing limitations in semantic decoding experimental designs, we have developed a novel, gamified paradigm: the Graded Inventory of Semantic Triggers (GIST). GIST is specifically designed to enhance participant engagement and to more naturally evoke concepts, thereby increasing the strength of the associated semantic signals. Our paradigm, a word-guessing game adapted from [2] and [3], incorporates three semantic classes: food, musical instruments, and body parts. A unique set of 3 clues is presented for 432 trials. Each clue increases in specificity across the Superordinate (e.g., 'Is an organic object.'), Ordinate (e.g., 'Has the same colour as its name.') and Subordinate (e.g., 'Is high in vitamin C.') levels. Participants are instructed to perform a spacebar press when they have correctly identified the target word. This paradigm feature has been integrated to assist with intra-trial signal tracking and to boost participant engagement, as per [4]. Our preliminary analyses currently focus on the comprehensive extraction of signal features across different domains, feature selection using a fusion of filter-based methods and classification with Support Vector Machines (SVM). Thus far we have collected data from 8 participants, with the intention of collecting 20 participants in total. We have successfully classified all 2-class problem variants at the single-participant level, food *vs* musical instruments (avg.=72.5%, $p<0.05$), food *vs* body parts (avg.=73.2%, $p<0.05$) and body parts *vs* musical instruments (avg.=73.3%, $p<0.05$) in 4 of our 8 participants. Work is ongoing to enhance classification accuracies for the 3-class problem (food *vs* musical instruments *vs* body parts). Notably, the GIST paradigm demonstrates significant potential as the foundation for a mental imagery feedback training system that could enable real-time, bottom-up, concept decoding. GIST thus represents an important stepping-stone towards advancing BCI communication systems, with broad implications for the future of BCI design.

Conclusion: We introduce the Graded Inventory of Semantic Triggers (GIST): a gamified paradigm for naturally evoking semantic concepts and corresponding neural signals. Given our preliminary results, we believe that this platform and associated analysis pipeline will significantly improve the effectiveness of Semantic BCIs for communication applications.

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