Reaching and Grasping in a Virtual Reality Environment in Patients with Stroke: an AI Approach

Theoretical background

The worldwide prevalence of disability is around 20% (WHO, 2011)[1]. In industrialised societies, the most frequent cause of motor disability with loss of personal autonomy is represented by acquired brain lesions[2]. Despite the progress of knowledge on the regeneration of damaged nervous tissues, no solutions are foreseen in the short term to promote a complete recovery[3].

In the meantime, one of the most attractive alternatives is represented by the use of artificial intelligence (AI) technologies[4]: assistive and/or robotic devices to vicariate the damaged neuronal networks by artificially recreating the lost sensorimotor functions to make up for the severe motor disabilities. To develop such AI technology, it is essential to extract effortlessly the intention to perform an action from the information elaborated within a brain network supervising action control and planning. This cerebral network is involved when performing an action, during its observation and mental imagination. In particular, action planning is supervised[5] by a dorso-dorsal stream, monitoring the manipulation-related action regardless of action prior knowledge (from the occipital to the premotor areas through the superior parietal lobe) and a ventro-dorsal stream processing the specific (functional) use of known objects (from the occipital to the premotor areas through the inferior parietal lobe).

Aims and Hypotheses

This study aims to validate machine learning algorithms to predict action intention based on the analysis of multi-componential signals. These algorithms will extrapolate and reveal the patterns of interaction between brain and physiological indexes and their temporal interplay. To extrapolate action intention, participants will be immersed in virtual reality (VR) scenarios while executing, observing and mentally imaging object-directed actions. The instructions will require to grasp the object to use it functionally (ventro-dorsal stream) or move it spatially (dorso-dorsal stream). Results achieved by testing healthy participants will be matched with the ones extracted from neurological patients to develop two separate machine learning models to compare the multi-componential psychophysiological patterns.

We hypothesise that comparing the activation pattern in the 3 experimental conditions (observation, execution, and motor imagination) will highlight the correlation between the planning phase (in the left parietal cortex) and the specific importance of the brain and physiological features in the two groups.

Method

Participants: A convenient number of healthy participants (N=40) will be recruited. Besides them, participants with acquired motor disability due to cortical or subcortical stroke (N=20), aged between 18 and 70, will be recruited at the IRCCS of Neurological Sciences of Bologna. Patients with lesions in the left parietal lobe, causing deficits in action planning, will not be included.

Machine Learning needs a large amount of training data which can hardly be achieved by standard participant recruitment. Then, starting from the data points collected from the above-described sample, a synthetic dataset will be created with generative AI techniques. Following the rule of thumb commonly used in Machine Learning[6] *10*number of features*number of classes to predict* about 4 million data points will be produced for both healthy control and patients.

Tools: The virtual reality environment will be presented on an HTC Vive Pro Eye, which allows eye movement recording. Leap Motion system will track and implement the participants' bodies within the VR. GTEC Nautilus Pro 32-channel wireless system will record electroencephalographic

(EEG) signals. Biopac system will record electromyographic (EMG) signals from hand and triceps muscles. Movement Imagery Questionnaire-3[7] will measure motor imagery ability.

Neuropsychological tests will be administered to patients to measure participants' attentional, perceptual, memory and reasoning abilities and apraxia (a deficit in action planning and implementation).

Procedure

First, participants complete the Movement Imagery Questionnaire-3. Then, in a within-subjects design VR experiment, participants (1) observe, (2) imagine, (3) execute two different types of reaching and grasping actions on an object: a) grasping to use it functionally (grasp to use condition) and b) move it (grasp to move condition). Data from all trackers (eye movements, EEG and EMG) will be recorded. The entire procedure will take about 60 min.

Statistical analyses: The data analysis will follow four steps:

1) Data will be pre-processed by removing outliers and artefacts. Missing data will be replaced with imputation techniques. Then, data will be resampled to have a comparable sampling rate;
2) For each population (controls and patients), synthetic data will be created with Generative AI;
3) For each population and experimental condition (observation, motor imagery and execution), a supervised Deep Learning architecture (e.g., Recurrent Neural Network and Transformers) will be used with three types of input features: EEG, EMG and Eye-Tracking. Each feature will be a time-series 3D array of shape [examples, channels, datapoints]. According to these features, the model will predict two types of action intention: grasp to use and grasp to move the object (binary classification problem). Each model will be trained on synthetic data. Actual data will be divided into a validation set, used for the model's parameters and hyperparameters tuning, and a test set to measure the final model performance evaluated for Accuracy, F1 Score, Precision and Recall;
4) Explainable AI techniques, such as Local Interpretable Model-Agnostic Explanations (LIME[8]) and SHapley Additive exPlanations (SHAP[9]), will be used to understand features' importance and their relation with the predicted variables.

Commitment to request ethical approval: The protocol will be submitted as an amendment of an ongoing project to the AVEC Ethics Committee of Emilia-Romagna.

Expected Results and Implications

We expect that AI will extract the most salient components of intention as a function of the performed type of action. We expect that eye movement pattern over the functional parts of the object coupled with neural EEG activity mainly over electrodes located within the inferior-parietal lobule (part of the ventro-dorsal stream) will play greater importance than other features in predicting the intention to grasp to use the object. On the contrary, when objects are grasped to be moved, we expect high feature importance on eye movement located on graspable parts and an EEG neural activation over the dorso-dorsal stream (superior parietal lobule).

These AI models will help enhance patients' control of assistive technologies, such as exoskeletons or prostheses, by integrating multiple cerebral and psychophysiological indices to extract action intention and vicariate their lost sensorimotor functions.

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Project activities

- Ethical clearance
- Task preparation
- Recruitment
- Experimental protocol administration
- Continuous data monitoring and analysis
- Drafting scientific paper/conference abstract
- Writing the final report

Training activities

- Deepening the knowledge about the action-observation system
- Deepening the machine learning techniques
- Supervision for scientific writing (papers and conference abstracts)

Timing of activities

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Feasibility

The main risk is insufficient participant recruitment. However, the project is connected to ongoing activities within a European project (MAIA) that allow us to compensate for shortages in recruitment. Moreover, collaborating with IRCCS of Neurological Sciences with the MAIA project will ensure recruiting the patients.

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