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An Online Application of a 3D BCI Combined with Virtual Reality for Upper Limb Control

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Background and Aims

Background

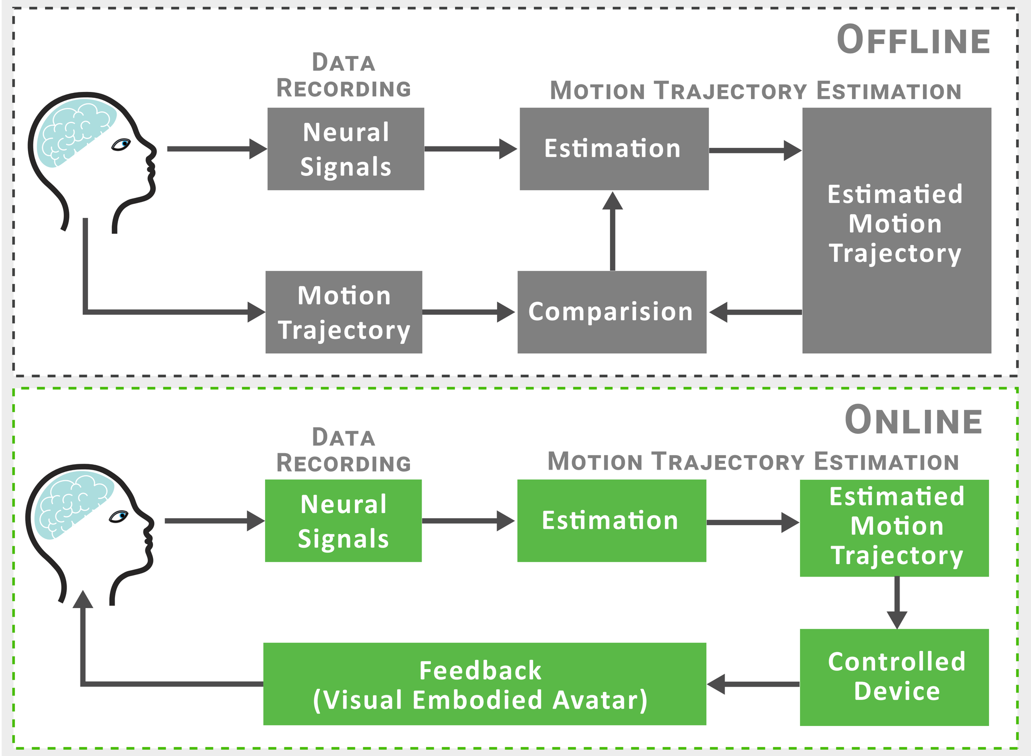
- Non-invasive electroencephalogram (**EEG**) based brain-computer interface (**BCI**) can potentially achieve three-dimensional (**3D**) control using only brain signals [1]
- **Motion trajectory prediction** (**MTP**) is a method that may be used for translating **imagined 3D movement** into virtual limb control. This process requires the capture of actual kinematic of limb motion trajectory in an experimental setup to perform MTP [2]
- Virtual reality (**VR**) allows for natural, **embodied virtual limb feedback** and has the potential to create improved experimental BCI training paradigms through an increased presence in applications such as reach target tasks [3]
- Previous work, **decoding imagined 3D trajectory of the arm** found that presenting 3D movements on a 2D screen counterintuitive as feedback [2]

Aims and Objectives

- Develop an experimental setup for **3D BCI limb control with embodied VR feedback**
- Pilot the setup with participants performing arm reach tasks using the online 3D BCI
- Assess the impact on **imagined 3D movement correlation and presence in the virtual environment**

Motion Trajectory Prediction – Online BCI

Motion Trajectory Prediction

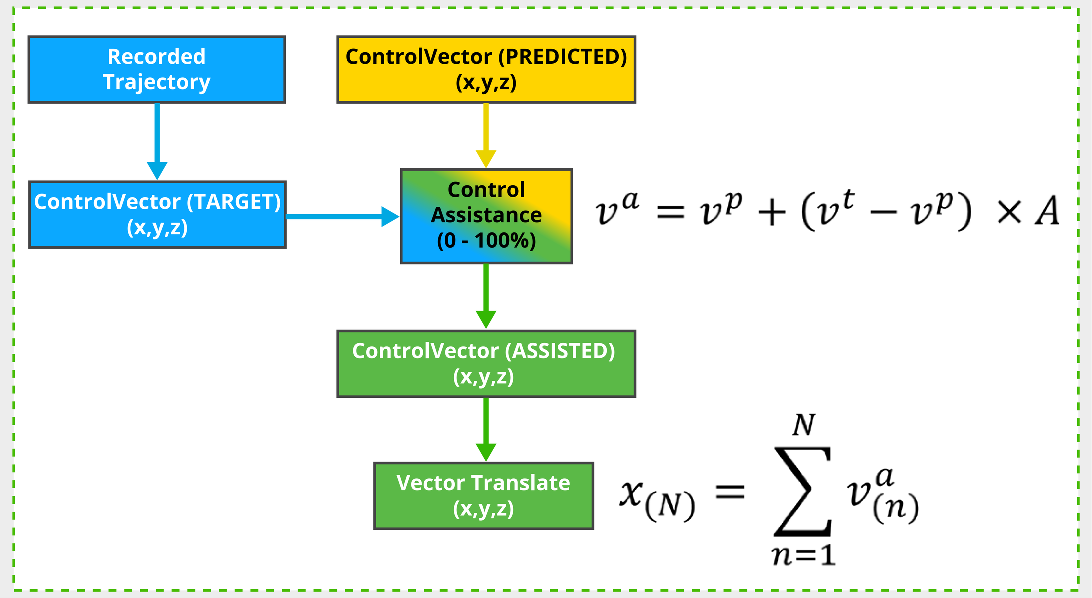


Kinematic Data Estimation Module [4]

$$v_{ij}[t] = a_{ij} + \sum_{n=1}^{N}\sum_{f=1}^{B}\sum_{k=0}^{L} b_{ijnfk}S_{jnf}[t-k] + \varepsilon_{ij}[t]$$

Online BCI Control Module

- **Predicted Velocity** - BCI MTP
- **Target Velocity** - Unity Engine
- **Assisted Velocity** - x, y, z control velocity discriminated between predicted and target
- The **Virtual Arm** is moved by translating the virtual arm wrist position using the **Assisted** velocity

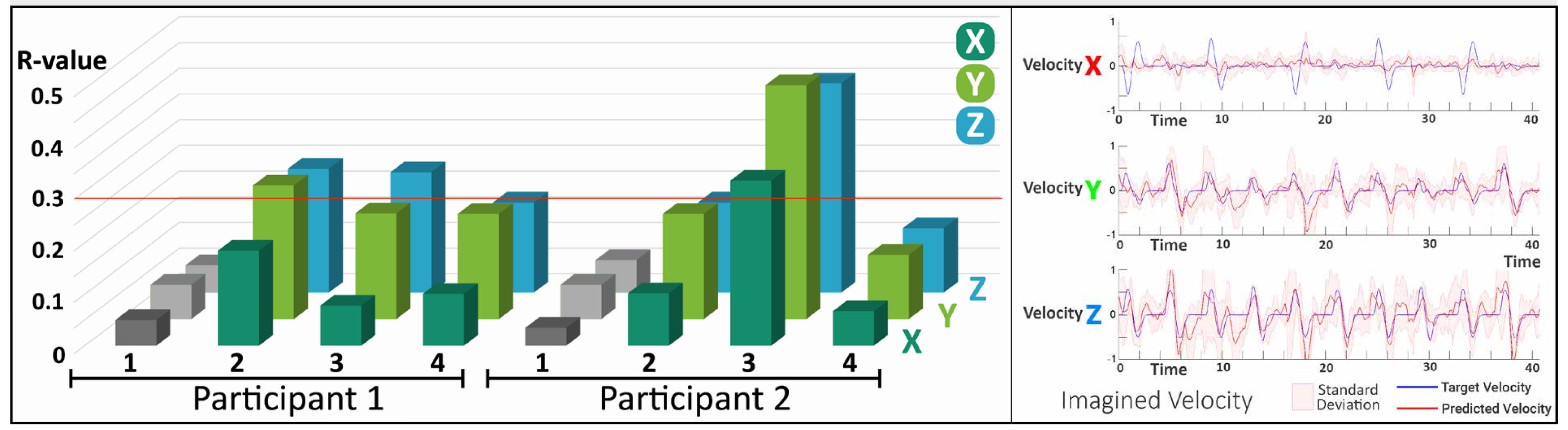


$$v^a = v^p + (v^t - v^p) \times A$$

$$x_{(N)} = \sum_{n=1}^{N} v^a_{(n)}$$

Results

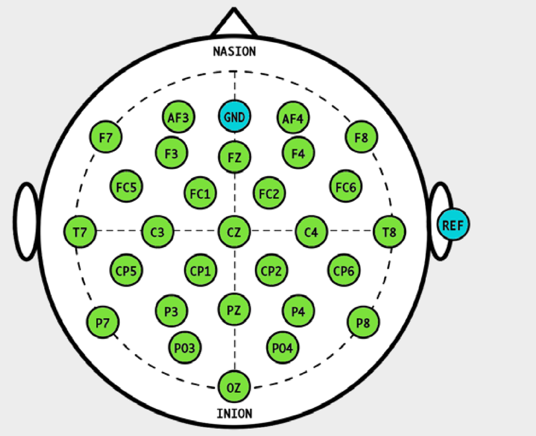
- Average correlation accuracy from all sessions was **r=0.203 ±0.092, p<0.12**
- Highest achieved accuracy was **r=0.39 ±0.131, p<0.28**
- Velocity reconstruction showed a reasonable degree of timing synchronicity between the target and predicted velocity
- X-axis (lateral) performed poorly compared to Y (vertical) and Z (depth)
- Presence (**PQ**) [5] scored highly in '**Possibility to Act**' (**33/49**) and self-reported performance using the system (**12/14**)



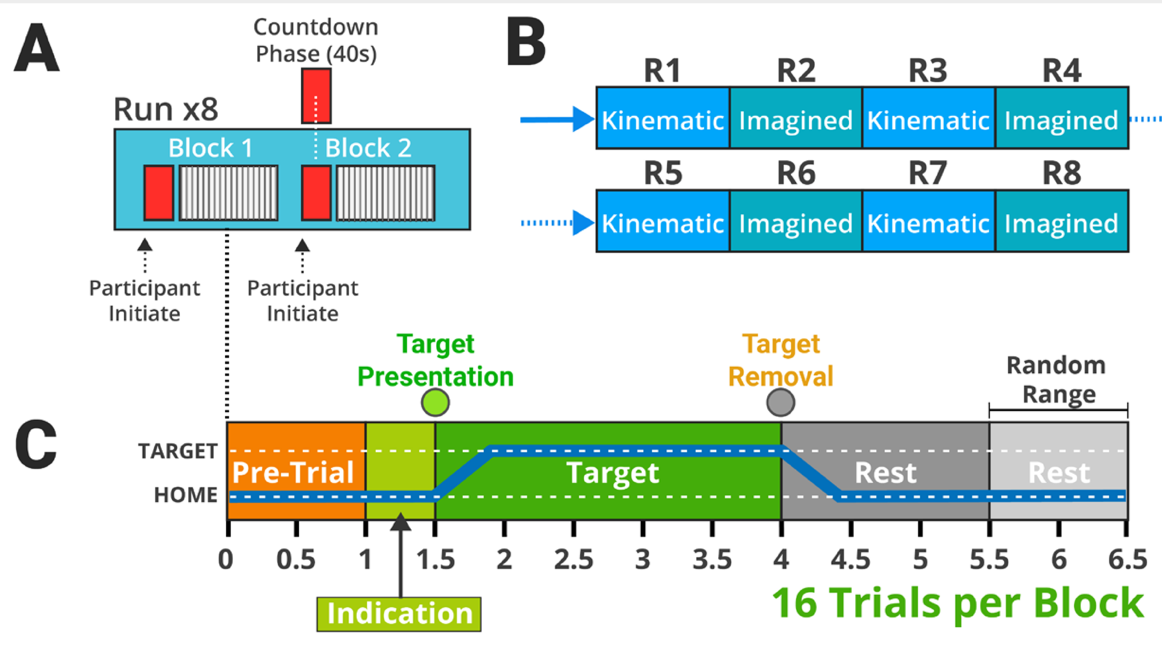
Data Acquisition and Trial Timing

BCI Sessions

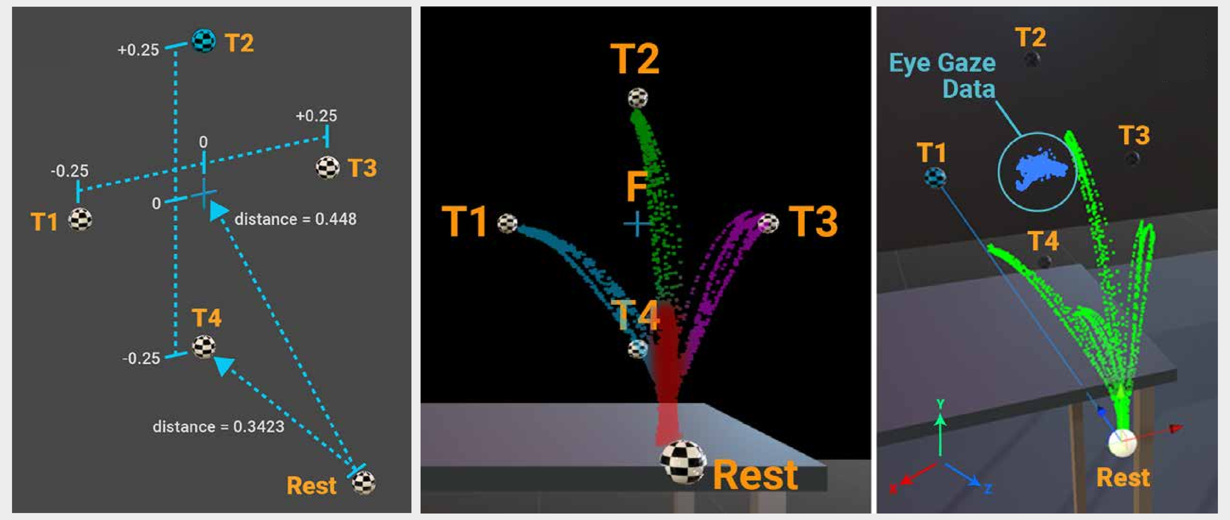
- **2** participants
- **4** sessions each
- **Kinematic** arm reach tasks with corresponding **imagined** movement arm reach tasks
- **EEG** - g.tec g.Nautilus - 28 active electrode recorded at 250 Hz
- **Kinematic** - Vive Tracker 3.0 tracked by 4 Lighthouse Base Stations recorded at 60 Hz



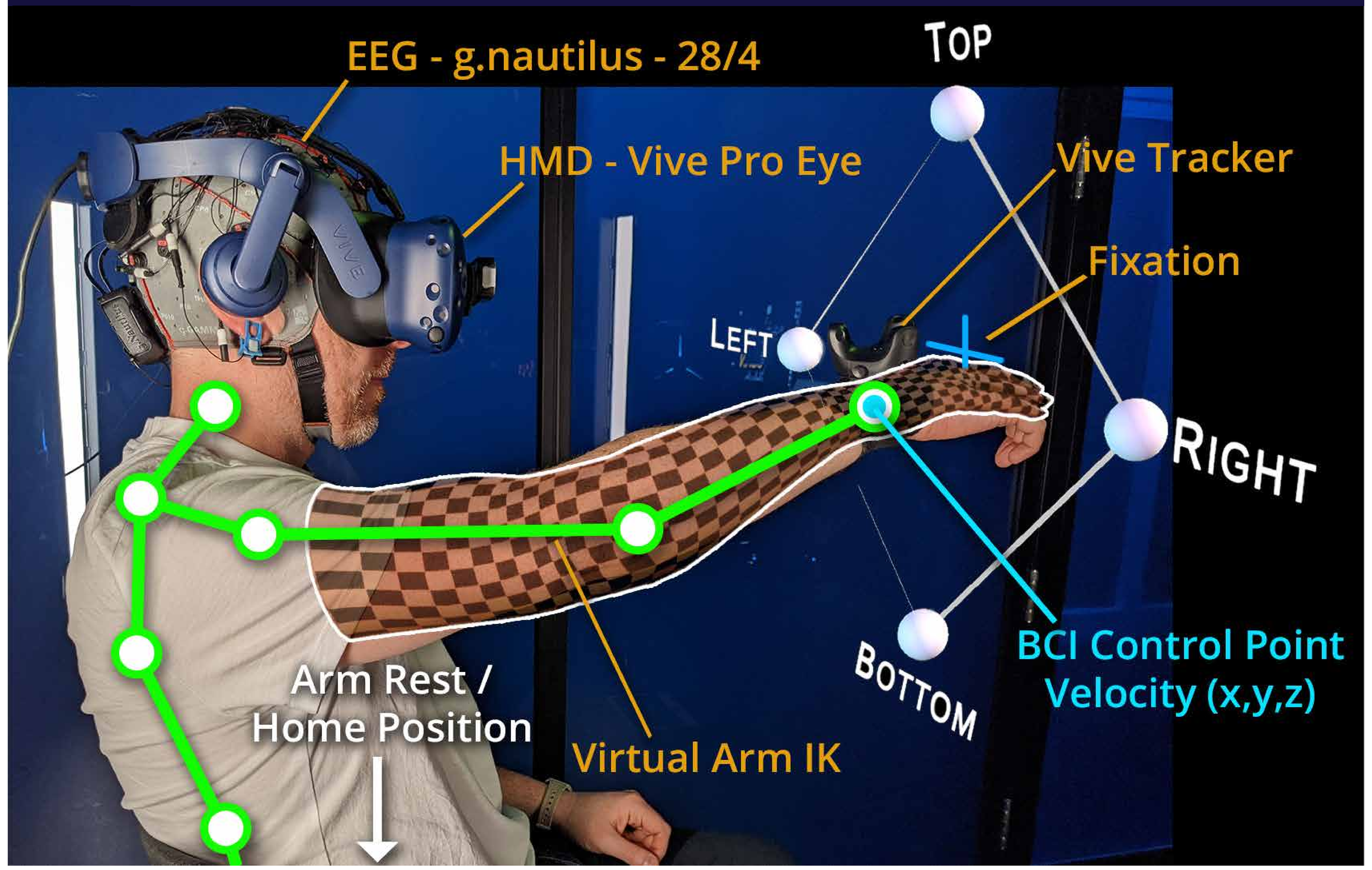
Single Session: 8 Runs - 2 Blocks per Run - 256 Trials



Reach Target setup **Motion Capture Co-ordinates**



Experimental Setup



Conculsion and Future Scope

- Demonstrates that the feasibility of using VR and embodied feedback to enable training to accomplish limited control of a virtual upper limb using a movement independent control signal derived from the brain with a 3D BCI
- Low Correlation in offline analysis on average but a single session achieved a moderately high accuracy
- Participants felt present within the experimental setup and experienced a level of control over the virtual arm with trajectory assistance
- Further work and wider trials required to determine potential benefits of VR embodied feedback vs 2D screen-based
- Potential applications in neural engineering beyond virtual limb control, such as robotics, and prosthetics, with possible benefits in motor skill rehabilitation or training.

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