

Employing Optical Brain Imaging for Real-Time Assessment of Brain Functions During Immersive Virtual Reality: Harnessing Potential for Neurorehabilitation

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Presenter:

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She obtained her bachelor in Computer Engineering from University of Guilan, Iran. Currently she is a second-year master's student at the Electrical and Computer Engineering department of University of Manitoba, Winnipeg, Canada.

Her research interests include Neurorehabilitation, Real-time Brain Imaging, Applications of VR in Personalized Rehabilitation, and AI-driven Therapy.



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Introduction

Problem:

- Lack of Real-time Monitoring in Neurorehabilitation
- Pre- vs. Post-intervention Comparisons
- No Continuous Insights During Therapy

Objective:

- Integrate iVR and fNIRS
- Real-time Brain Activity Monitoring During iVR Tasks

Significance:

- Portable, Non-invasive Monitoring
- Enhances Cognitive and Motor Functions
- Real-time Brain Engagement Analysis for Neurorehabilitation



<https://www.artinis.com/blogpost-all/2022/combining-virtual-reality-and-portable-fnirs>

Background

iVR in Neurorehabilitation:

- Interactive, multi-sensory environment (visual, auditory, haptic)
- Enhances cognitive and motor functions
- Promotes neuroplasticity in neurological rehabilitation

Challenges in Current iVR Research:

- No real-time brain activity monitoring
- Pre- vs. post-therapy comparisons limit continuous insights

fNIRS:

- Non-invasive optical brain imaging
- Measures cortical hemodynamic activity
- Portable, motion-resistant, cost-effective vs. fMR

Objectives of the Study

Develop & Test:

- iVR-fNIRS platform for real-time brain monitoring during iVR tasks

Brain Monitoring Focus:

- Target: Motor Cortices, DLPFC (motor & executive control)

Tasks:

- Real-world rehabilitation tasks (e.g., hand-grasping)
- Engage motor and cognitive functions



Image generated by OpenAI's GPT-4 model, accessed through ChatGPT.

fNIRS Mechanism

Principle:

- Uses near-infrared light to measure brain activity
- Light penetrates the skull and interacts with brain tissue

Light Trajectory:

- Light is emitted by the source (LEDs or lasers)
- Travels through brain tissue
- Detectors measure the intensity of transmitted light after it passes through the tissue

Absorption:

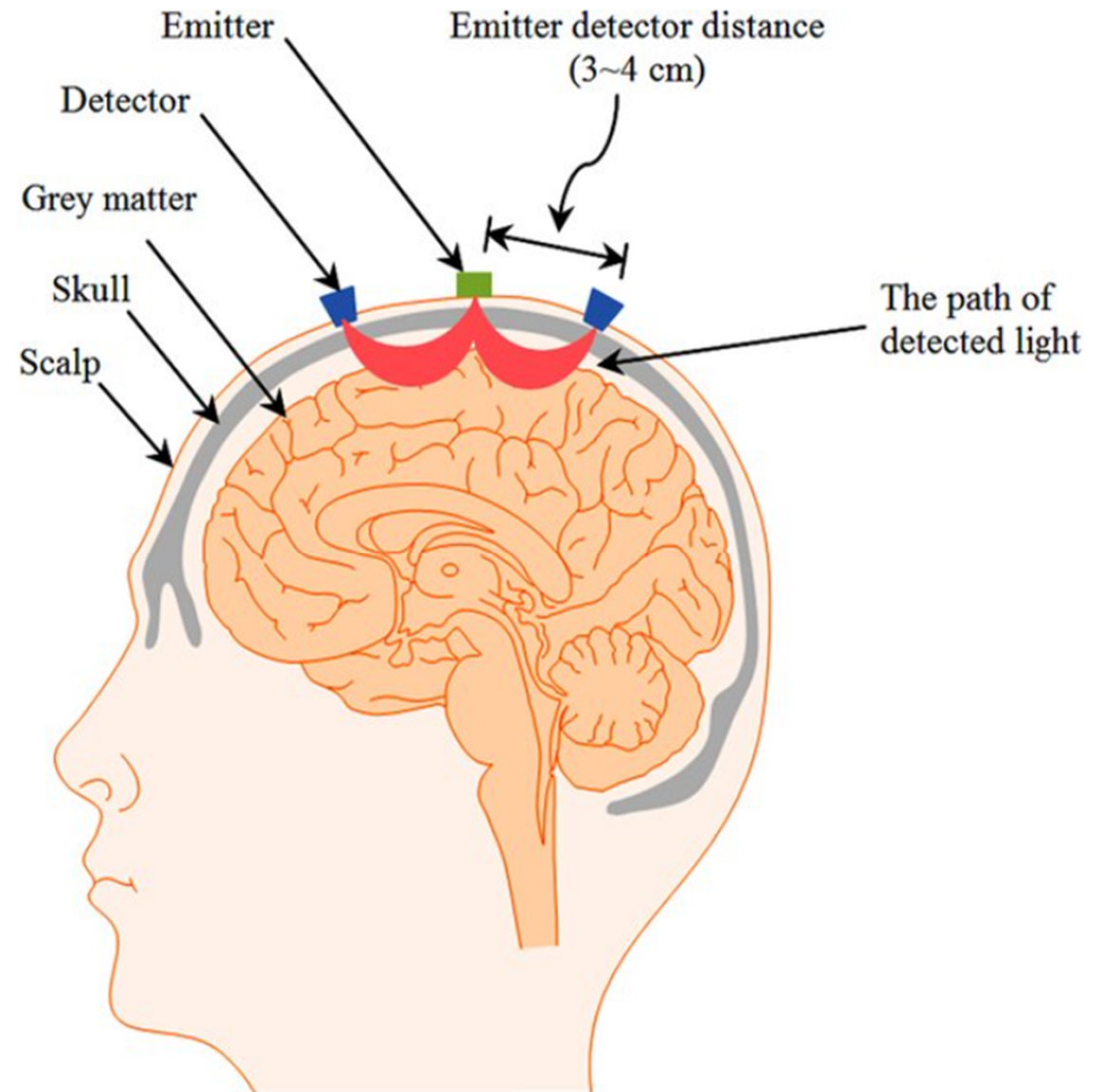
- Hemoglobin absorbs light
- HbO and HbR absorb light differently

Hemoglobin Dynamics:

- **HbO** (oxygenated hemoglobin) absorbs less light at certain wavelengths
- **HbR** (deoxygenated hemoglobin) absorbs more light
- Changes in HbO and HbR concentration indicate brain activity (hemodynamic response)

Data Interpretation:

- Light absorption differences = brain activation



Methodology

Integrated Platform:

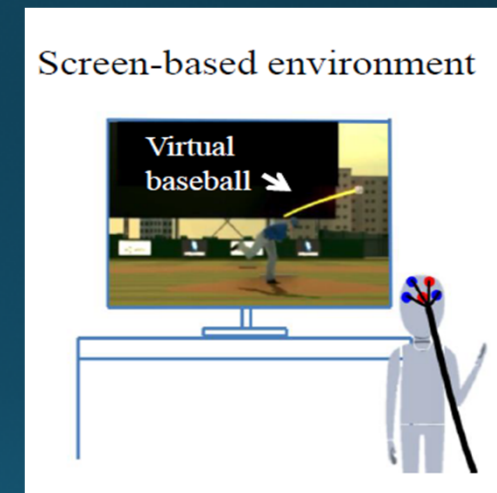
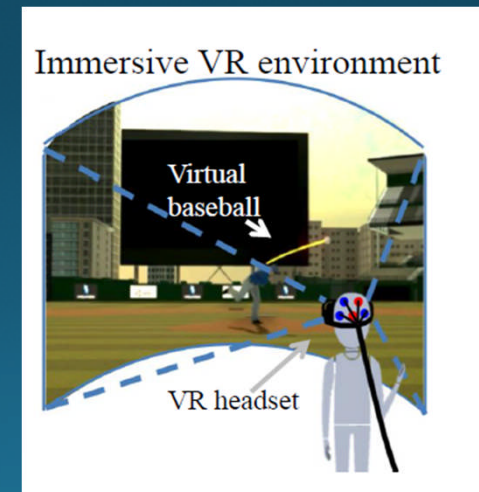
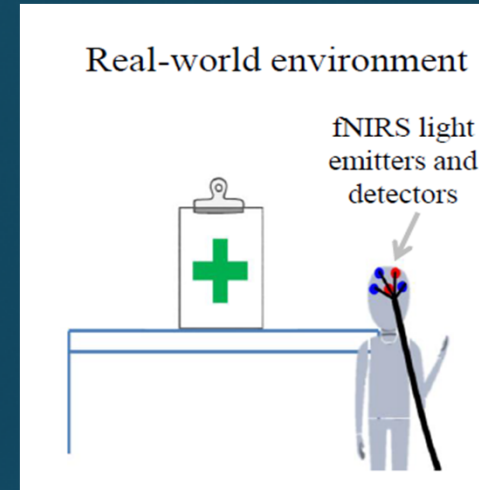
- **Hardware:**
 - HTC Vive Pro VR headset (immersive VR tasks)
 - Rogue Research Inc. multichannel fNIRS system (real-time brain activity measurement)
- **Purpose:**
 - Seamless integration of brain activity data with immersive VR tasks
- **Task Design:**
 - Hand-grasping movements mimicking rehabilitation exercises to evaluate motor and executive control functions



Methodology

Experimental Setup:

- **Task Environments:**
 - **Real-World:** Tasks with clipboard indicators (green/red)
 - **Non-Immersive VR:** Tasks on a computer screen with a virtual avatar
 - **Fully Immersive VR:** Tasks in a VR baseball game (HTC Vive Pro headset)
- **Procedure:**
 - Each task performed 8 times per session
 - Brain activity monitored in M₁ (Motor Cortices) and DLPFC (Pre-Frontal Cortex)



Methodology - VR Game Development

Purpose:

- Simulate real-world rehabilitation tasks in an immersive virtual environment

Game Design:

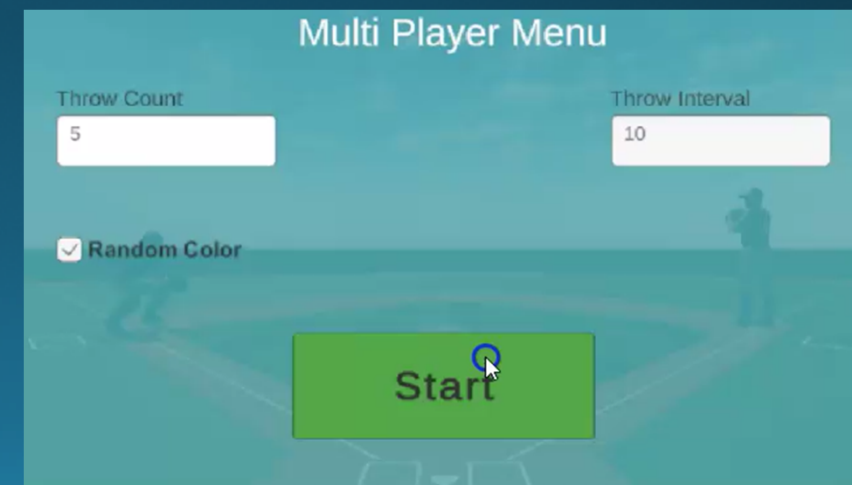
- Developed using the Unity engine
- Focused on hand-grasping tasks, mimicking baseball-catching actions

Task Details:

- Participants perform hand-grasping movements in response to virtual baseball throws
- Two modes:
 - **Single-player:** Interactive mode
 - **Multi-player:** Observational mode

Goal:

- Engage motor and cognitive regions for neurorehabilitation tasks



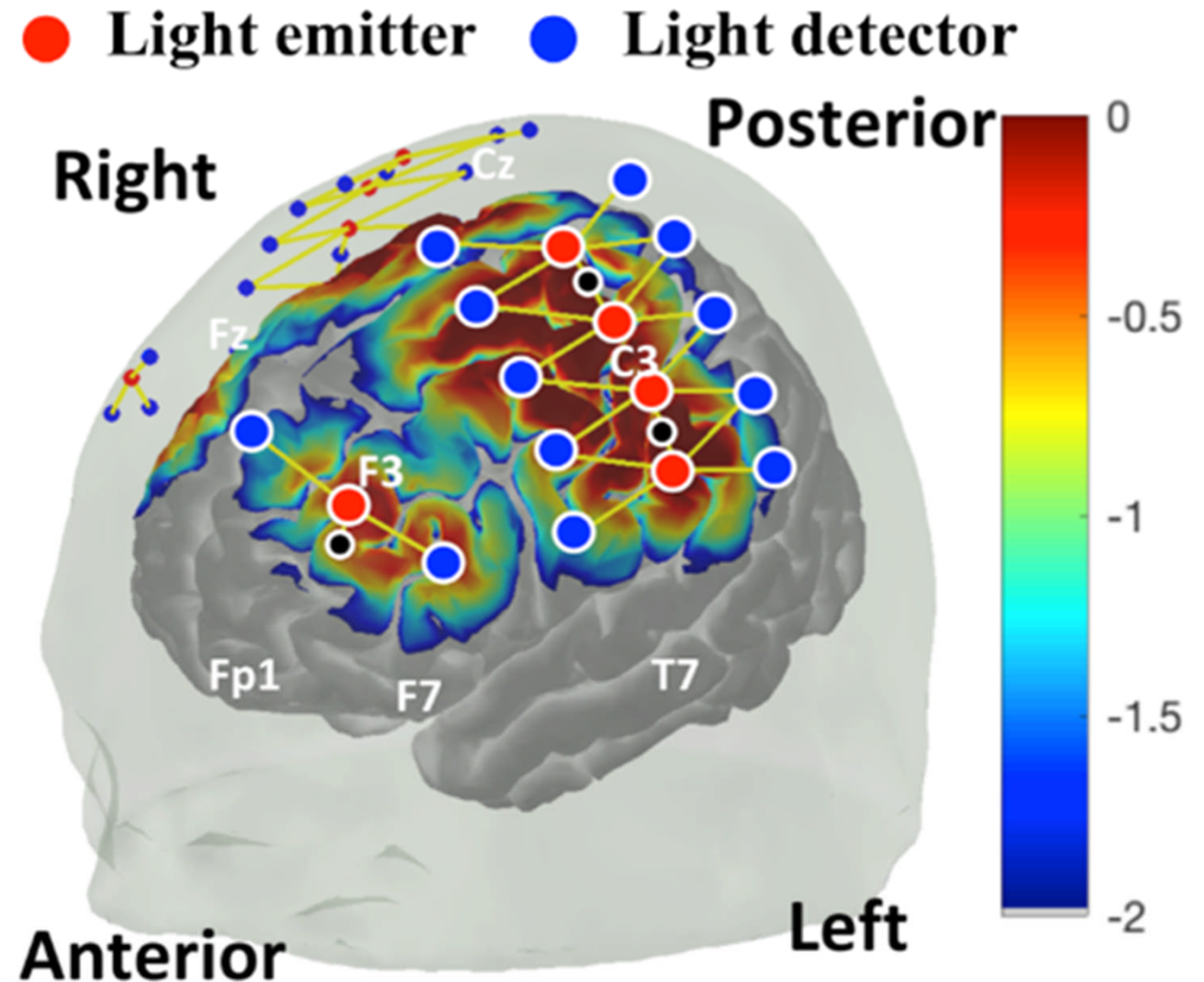
Results - Signal Quality

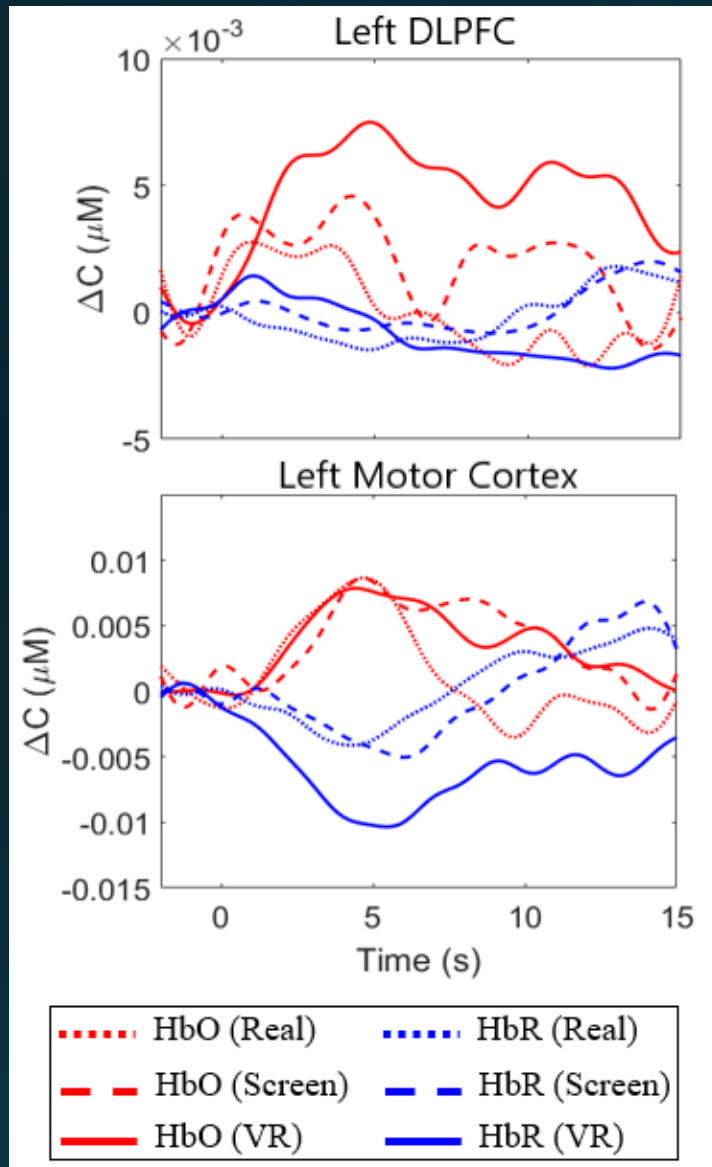
Signal-to-Noise Ratio:

- No interference between fNIRS and VR
- High signal-to-noise ratio ($\sim 32 \pm 13$ dB)
- Reliable fNIRS data during immersive iVR tasks

Brain Activation:

- Hemodynamic responses (HbO increase, HbR decrease)
- Key regions: M₁, DLPFC
- Observed during hand-grasping tasks across all environments





Results - Comparison Across Environments

Increased Neural Activation:

- Higher HbO increase, lower HbR decrease
- Stronger brain engagement during iVR tasks

Functional Connectivity:

- Enhanced M₁-DLPFC connectivity
- Better coordination between motor and cognitive processes

Results – Functional Connectivity

Enhanced Connectivity:

- Increased functional connectivity between M1 and DLPFC during iVR tasks
- Suggests better coordination between motor and cognitive processes

iVR vs. Other Environments:

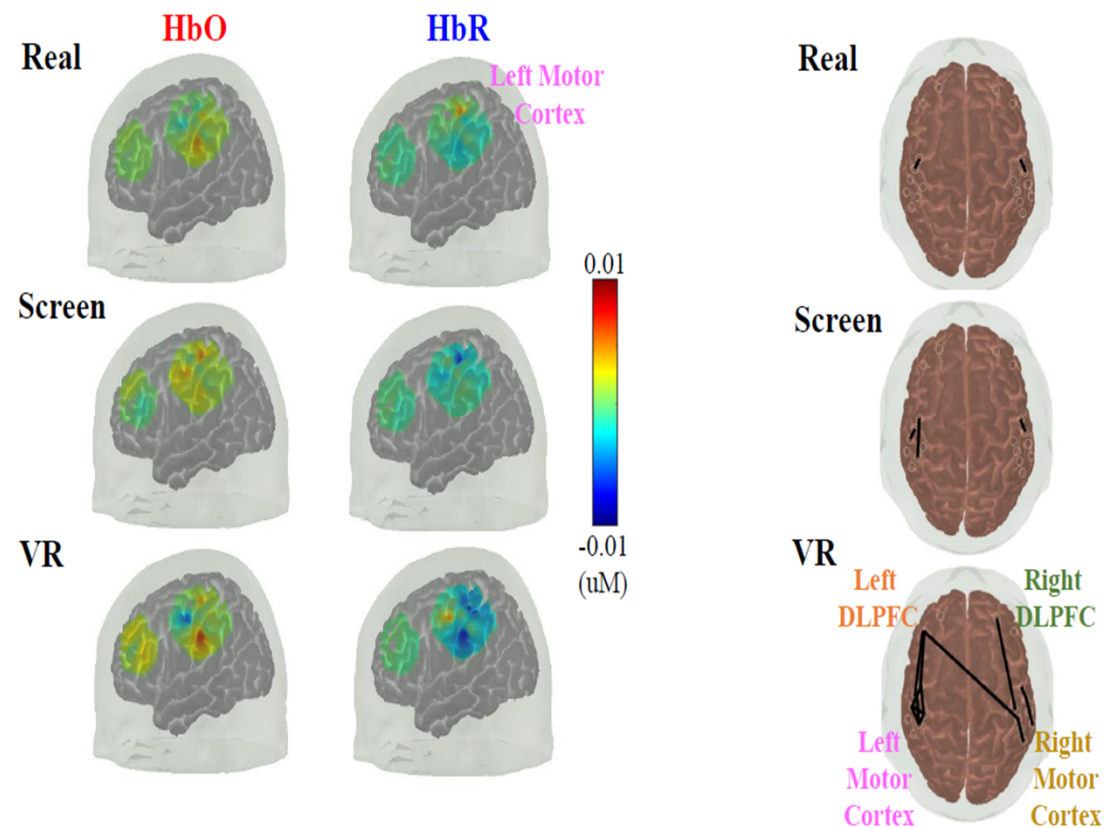
- Stronger network connections in iVR compared to real-world and screen-based tasks

Connectivity Analysis:

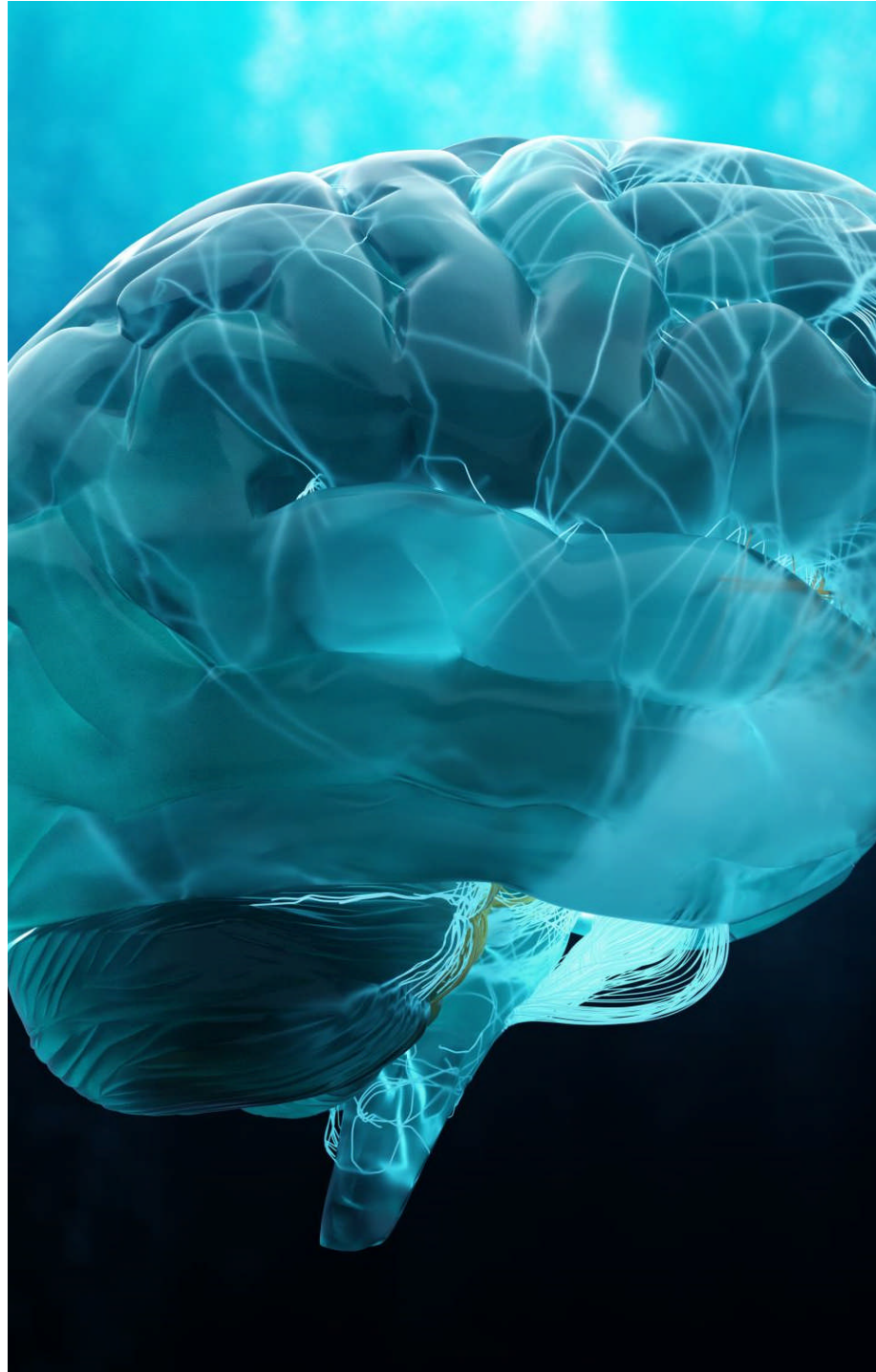
- More co-functioning brain areas observed during iVR tasks
- Significant connectivity between M1 and DLPFC during immersive tasks

Implications:

- Indicates improved engagement of motor and cognitive control functions in iVR



Connectivity analysis showed more connected brain areas during iVR task than the other environments, $p < 0.05$, false discovery rate-corrected.



Discussion - Implications

iVR as a Neurorehabilitation Tool:

- Immersive, engaging rehabilitation
- Improves brain activity and connectivity

Absence of Haptic Feedback:

- Enhanced brain activation without tactile feedback
- Opens possibilities for home-based therapy

Potential for Wider Use:

- More effective rehabilitative effect
- Requires further investigation in clinical neurorehabilitation

Conclusion

Key Findings:

- Higher brain activation, improved connectivity in iVR tasks
- Potential for neurorehabilitation

Next Steps:

- Expand study to larger sample
- Add haptic feedback to iVR
- Integrate AI for personalized rehab programs

Long-Term Impact:

- AI optimizing rehab programs based on real-time brain data

Thank you for your time!

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