# Exploring Cognitive Functions and Balance Through Virtual Reality

## Development of The Tower of London and N-Back Test Games

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MOVE Lab
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## Introduction

- **Virtual reality (VR)**
  - A transformative tool in neurorehabilitation offers controlled multisensory environments for motor and cognitive rehabilitation.
  - Moon et al. (2021) demonstrated the feasibility of a VR-based balance and cognition training system.

- Our project advances this work by
  (1) **enhancing ecological validity** with a realistic VR environment
  (2) **optimizing a dual-task paradigm**, embedding cognitive tasks like the **n-back test** and **Tower of London**

- This integrated approach enables a real-time tracking of balance-cognition progress, addressing a critical limitation in longitudinal VR rehabilitation trials.

## Requirements

- **Functional requirements**
  - Enable interaction with objects (e.g., selecting letters in the n-back test, moving rings in the Tower of London test).
  - Enforce the Tower of London rule: only the top ring can be moved.
  - Present sequential letters in the n-back test for identifying matches.
  - Collect and store balance data using external sensors (e.g., force plates).
  - Log gameplay data, including scores, movement patterns, and balance measurements, for analysis.

- **Non-functional requirements**
  - Data collection must avoid gameplay lag or performance issues.
  - Encrypt and securely store user data per privacy standards.
  - Ensure system resilience to prevent data loss during crashes.
  - Optimize VR interactions to reduce motion sickness; offer teleportation movement options.

## Design

- Meta Quest hardware connects to cognitive games via Unity's XR frameworks and official VR SDKs.
- Unity manages compatibility, linking Meta Quest sensors and hand tracking through a USB-C connection.
- Unity handles rendering, generating environments and sending frames to the headset.
- This setup allows testing in the MOVE Lab at New Hampshire Hall, integrating the force plate with VR games.

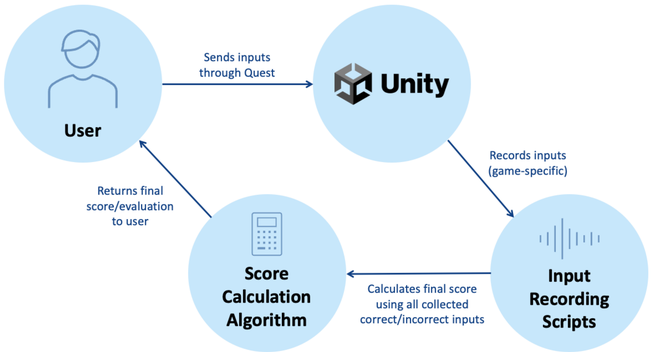


Fig 1. Game design workflow

## Implementation

- Developed with Unity3D for its modern VR support.
- Used custom assets with C++ and C# for interactive effects.
- Targeted Meta Quest 2 & 3 devices.
- Integrated a MOVE Lab Force Plate to measure balance impact during gameplay.

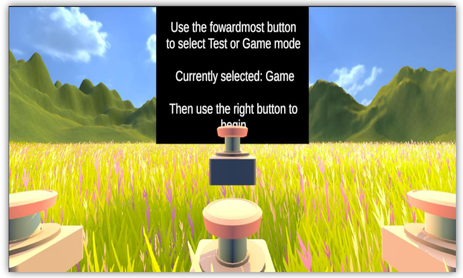


Fig 2 n-back test gameplay

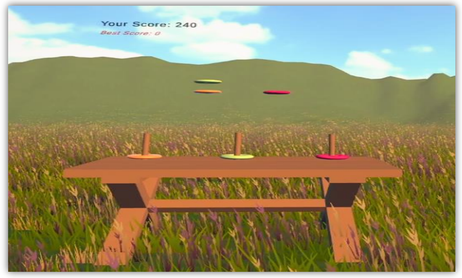


Fig 3 Tower of London gameplay

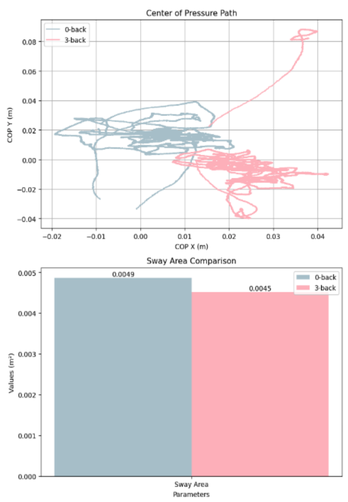


Fig 4. Center of pressure path and sway area comparison between 0-back and 3-back tests

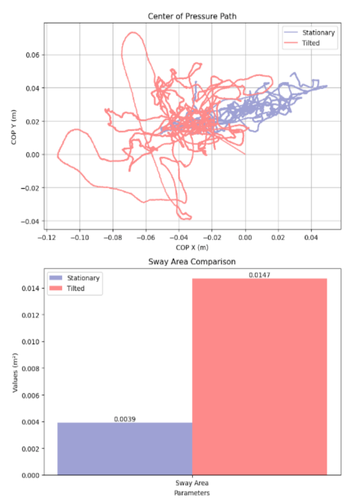


Fig 5. Center of pressure path and sway area comparison between stationary and tilted VR environments

## Testing

- Testing was conducted in Unity3D using trial and error to refine mechanics.
- Gameplay elements were adjusted to ensure proper functionality.
- Meta Quest 2 & 3 headsets were used for immersive, real-world testing.
- Combining both methods ensured smooth, balanced, and effective gameplay.

## Outcomes

- Successfully developed VR-based cognitive assessment games, n-back test and Tower of London
- Enhanced ecological validity by creating a realistic VR environment
- Integrated balance data collection during gameplay → Simultaneously evaluate cognitive function and postural control
- Successfully recorded and stored both cognitive game data and force plate data
- Demonstrated feasibility of integrating motor and cognitive rehabilitation in a VR setting

## Challenges and Solutions

- **Unity learning curve**
  - Spent several weeks learning Unity and its coding principles.
- **GitHub challenges**
  - Faced issues with Unity files in GitHub, but resolved by using VSCode for easier collaboration.
- **VR integration**
  - Learned how to implement VR functions and features through research.
- **Outcome**
  - Despite challenges, successfully delivered a working product.

## Acknowledgments

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