Immersive Virtual Reality Scenarios Applied to Static Bike Exercises to be Used in Rehabilitation and Therapeutic Settings

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DOI: *https://doi.org/10.17979/spu.23.c56*

Abstract: The advent of virtual reality has introduced a valuable tool for rehabilitation and therapy by providing safe and controlled environments that promote physical and cognitive activities in an intuitive and engaging manner. The aim of this project is to design a platform that enables dual-task training—combining physical and cognitive activities—as a novel intervention for individuals with cerebral palsy. The system integrates static bike exercises with cognitive challenges presented within an immersive and pleasant virtual environment. The project was developed using the Unity game engine and deployed on the Meta Quest 3 VR headset, with WEMOS ESP32 microcontrollers measuring the user's pedaling cadence. This approach seeks to combine therapeutic effectiveness with user engagement through gamified feedback and interactive design.

1 Introduction

In the realm of physical therapy, "dual task training" (Novak et al., 2020) is referred to as the practice of engaging an individual in two tasks simultaneously, one physical, and one cognitive. This could be something more menial like walking and having a conversation at the same time, or a more elaborate scenario, like reading out loud while balancing on an unstable surface. This practise often shows improved results over doing cognitive and physical therapy independently, and has been widely accepted and used in many real cases.

Though this may not be immediately obvious, the principles of dual task training apply to some videogames that use motion controls, specifically those who require a wider range of motion from the user; while this was mostly relegated as a secondary selling point in most videogames, several products were produced and marketed with said health benefits as the main appeal. Another advantage of this formula is that even though at its core it is a tool used to promote exercise, its inherent nature as a videogame retains many strong factors to ensure user retention: the instant positive feedback, interesting and alluring presentation, and measurable and comparable results all compound into an experience that is enjoyable to the user and creates a desire to be repeated, all while the user is inadvertently training their balance, hand-eye coordination, and reflexes, much like how traditional sports would but in a safer and less straining environment (Freeman et al., 2022).

Following this formula, the use of virtual reality creates a stronger and more appealing experience for the user, building on the principles and advantages that interactive media bring as a medium. Being able to control the camera and interact with the environment using the natural movement of the body results in an environment that is more intuitive and entertaining (Immersive Rehab, 2024).

2 Objectives

The project aims to create a virtual reality application (a VR videogame) that will be used during static bike exercise sessions, the exercise of choice deemed most approachable and beneficial for the majority of users; even if not looking to stimulate a targeted range of motion, static biking still fits into many "generic" exercise routines assigned based on the movement autonomy of the user. Depending on the needs of the user, the static bike used will either be an adapted mounted bicycle with actionable handlebar, or a hand-operated device that provides assisted pedalling.

The application will place the user in a pleasant scene, and the user will advance through the scene as though they were using a real bike inside the application, using the cycling motion of the user as input.

Periodically, the user will be presented with what has been defined as a "cognitive activity", that aims to engage the user's mental abilities while still requiring physical effort. The cognitive activity proposed for this project presents the user with a screen and three graphic elements: two at the top opposite corners, and one at the bottom, in the middle. The bottom element can be propelled upwards by pedalling, and can be moved to the sides using a second range of motion. All elements are visually tagged with a "label", either a number or a color, depending on the user's cognitive ability. One of the top elements will have the same label as the user-controlled element: the aim of the activity is to lead the element towards the matching label, with the other unmatched element counting as a failed completion.

The number of successes will be tallied up during exercise, and at the end of the session, the user will be shown a history of their recent performance to show their growth and hopefully encourage them.

Given these notions, the following requirements were created:

- Create a virtual reality videogame that is safe to use during static bike exercise for both leg-operated and hand-operated users. Said videogame will consist of at least an infinitely scrolling stage and an interface where cognitive activities will take place.
- Use the user's pedalling cadence as input for the videogame.
- Allow customization and monitoring of the experience by a trained physician, depending on the needs of the user.
- Enrich the experience by using traditional videogame elements to ensure user retention and promote repeated use of the activity.

3 Technologies used

- **VR headset:** Meta Quest 3 VR headset and controllers.
- **VR application development platform:** Unity Engine.
- **Pedalling sensor:** A handmade wireless device with a gyroscope that is attached to the patient's legs or arms was created for the project. For the assembly of the device, a WEMOS ESP-32 microcontroller with 18650 Battery Holder was used as a base. Rotational data is read using a GY-521 MPU6050 accelerometer/gyroscope (Espressif Systems, 2024)

- **Sensor-headset communication:** Arduino Bluetooth Plugin by Tony Abou Zaidan was the choice for this project, because it specifically mentions communication between an Android device (the Meta Quest 3 is Android-based) and an ESP32 board as a tested and supported scenario.

Complementary technology:

- **Arduino IDE:** Used to write, compile, and flash the code for the microcontrollers (Unity Asset Store, 2024).
- **Bluetooth Serial Terminal:** An Android application capable of communicating with HC-X Bluetooth devices.
- **Meta Quest Developer Hub, Meta Quest Link, and the Meta Horizon mobile companion app:** Officially supported software that significantly reduces complexity while working with the Meta Quest headset (Meta, 2024).
- **Blender:** Open source 3D editor, chosen due to its ubiquity as the de-facto free software for 3D editing.

4 Methodology

An incremental development methodology was applied. The phases were analysis, design, implementation, and testing of the different technological increments needed to create a basic functional prototype for the project, followed by a review of the first user testing session and the feedback obtained.

4.1 First increment: Wireless rotation sensor

- **Bluetooth transmissions:** Bluetooth communication is performed using the SerialBT library provided by the ESP32 Arduino repository, using the built-in capabilities of the microcontroller board.
- **Gyroscope readings:** Rotation readings are performed using a GY521 MPU6050 gyroscope-accelerometer unit. The GY521 acts as a slave to the main board and transmits data using the I2C protocol. The MPU6050 module is a 6-axis motion tracking device (3 gyroscopes and 3 accelerometers) that uses gravity and other physical principles to measure changes in angular velocity. Communication between the main board and the gyroscope slave is handled using the Wire library.
- **Physical assembly:** The physical assembly will consist of two pieces: the WEMOS ESP32 board and the GY521 module. Four connections are required between them: voltage (both 5V and 3.3V are supported), ground, SDA, and SCL. SDA (Serial data) and SCL (Serial clock) are required to establish I2C communication. The SDA and SCL need to be connected to any two digital pins on the main board, though most boards have two specialised digital pins for I2C communication with dedicated features, and will produce lesser results if using other pins. However, the ESP32 fully supports I2C on all digital pins, which will facilitate a more straightforward assembly. The used pins must be declared during I2C initialisation, otherwise the default pins will be used.

  Early testing were done by soldering exposed pins to both components and connecting them with female-to-female cables. The goal of this device is to be attached to a bike pedal which will be in constant motion, so this configuration is not viable: the final assembly must have all connections soldered, must be compact, and must have as little stray cables as possible.

4.2 Second increment: Unity Bluetooth reader

Construction for this phase of the project begins with a basic VR scene (In order to test Bluetooth connections in the VR headset) with a panel (A UI element with text objects whose implementation is mostly irrelevant) where debug information will be displayed

4.3 Third increment: Videogame baseline

The user will be placed on a straight virtual road atop a virtual bike, and as they continue to pedal faster or slower, their surrounding environment will move in accordance. A first prototype of a moving stage was implemented to test all technical aspects of connections with the sensor device and the sensation of movement.

The visual appearance of the prototype terrain chunks was designed to most easily identify faults in the scrolling system: the main concerns were Z-fighting due to a badly set up anchor system, and draw distance object popping, which is an issue for us since the player will always be looking towards where new objects are "spawning". Another important factor for us was to see how much the speed of the chunks impacted motion sickness in the user, with higher speed first person viewpoints more commonly being associated with nausea.

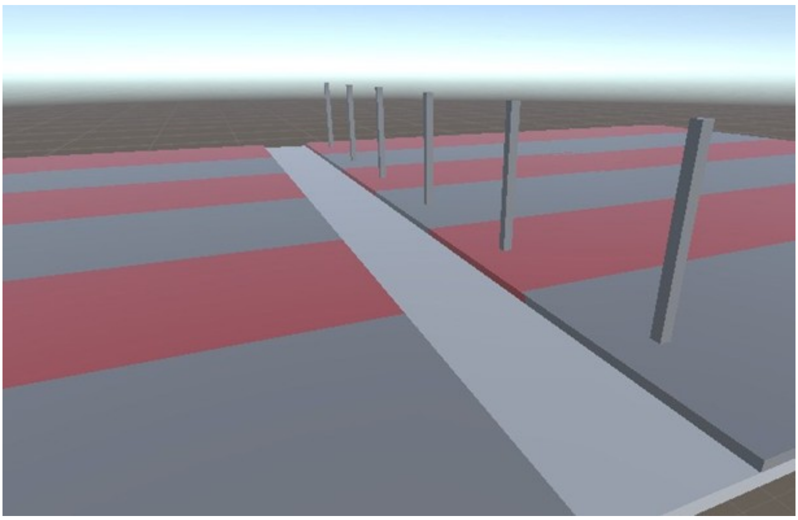

Figure 1: Prototype terrain chunks, designed to be blocky and plain in order to highlight graphic infidelities.

4.4 Prototype assembly and first user testing session

Given all the assets developed so far, all that was needed to create a working prototype was to adapt the Unity Bluetooth reader into the videogame baseline and an infinite scenery with a sense of movement and that does not seem repetitive.

4.5 First iteration of improvements

Now that all basic technology is properly understood and a basic prototype with all core functionality has been implemented, the project moves on to incorporate all remaining requested features. In no particular order, these are:

- A secondary cognitive activity
- Per-user tracking of historic performance to promote continued use.

- An interface to configure the exercise session (in the prototype, this is done using controller shortcuts midsession).
- General graphical improvements and polish.

Alongside this, the following new objectives came up during the first user testing session:

- Revisit the issue of attaching the microcontroller assembly to the static bike pedals.
- Revisit the issue of malfunctioning microcontrollers due to poor assembly.
- In-game player positional resetter.

4.6 Second user testing session

Before carrying out the session, the terrain chunks and skybox were replaced by assets that more closely resembled the desired final look of the game to remove the "prototype" feel and give the users a more complete experience. A 3D model of a bike was also added to the player object, so that it looks as if the player is riding it.

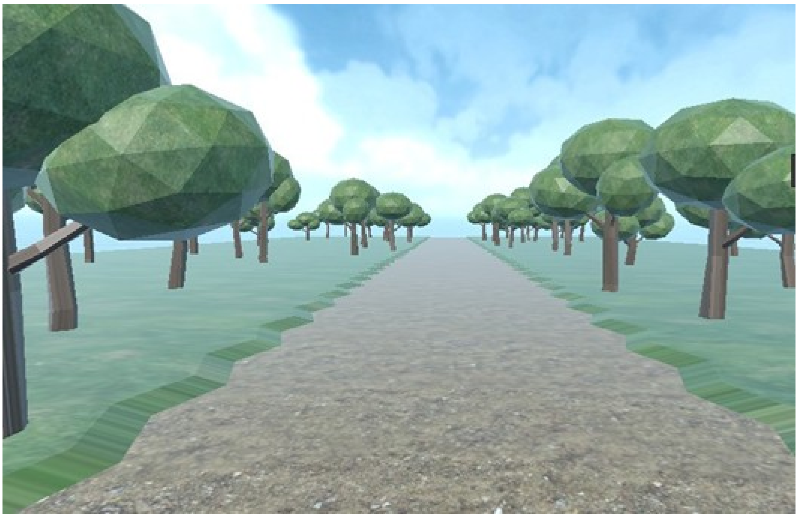

Figure 2: Upgraded graphics for the project.

Going into this testing session, the main concern was to observe and gauge the user's reaction to the cognitive activity-collectible system.

Once again, this session was carried out by a hand pedal user and a leg pedal user, while supervised by a physical therapist. Because of scheduling issues, the participants are different people from last testing session's users.

A note was made to add a session setting to modify the rate at which pedal events occur. Based on current observations, a simple "double mode" for leg users that required two partial pedal completions per pedal event would be sufficient, since all exercise sessions so far have had a moderate pace, but new stricter ones might be necessary if more intense routines were to be added.

On the topic of game speed, it was observed during testing that the cognitive activity was completable too quickly; the panel wasn't shown a sufficient enough time for the user to grasp the situation and interact with it quickly. This happened independently from the "double game speed" phenomenon described earlier. The values were tweaked so the player controlled canvas reached the top in a little over twice the pedalling events required previously.

Finally, the cognitive activity showed a huge bias for choosing the right side as the correct target. Since the system random call is "true random", this could simply be confirmation bias. After checking a larger sample size, distribution of random results did appear to balance over a period of time, but since the phenomenon was consistently observed throughout the session, a bias compensation system was put in place: rather than randomly deciding between left and right every time the activity begins, the random function is periodically used to determine how often to switch between left and right, ranging from every time, to every three times as of current implementation.

A quick inside test showed a more natural feeling distribution with this system, and so it was approved.

4.7 Second iteration of improvements

Two features remaining to implement:

- A pre-game interface where the supervising therapist will be able to adjust several settings.
- Player profiles that will track historic per-user performance.

Settings interface
To have a screen before game execution where different settings can be adjusted, the first step is to create a space before game execution. This is usually achieved by creating a separate scene that takes place before the game.

A more straightforward and easier solution seen in single-scene games, such as this project and many other VR and mobile games, is to halt all game logic until a "game execution" signal is broadcasted, and present the main menu in said single scene.

This VR project uses a single-scene setup where all game logic is paused until a start signal is broadcast. A game manager class re-enables disabled objects at runtime, using a serialized list instead of tags for clarity. The VR interface is controlled with Meta Quest hand controllers as pointers, enabled through the XR Toolkit and interactable UI menus.

Technicians can configure session duration and select Bluetooth devices for each input type, with settings saved for future sessions. Once the user is ready with the headset, the technician activates the game, and the game manager enables all objects, launching the session seamlessly.

The project uses a simple single-scene setup where all game logic is paused until a start signal is given, with the main menu displayed in that same scene. Game objects are disabled in the editor and later reactivated at runtime by a game manager, which was implemented using a serialized list rather than a tag-based system for clarity. Game mechanics such as Bluetooth listeners and movement managers are disabled until the start signal, ensuring control while still keeping their references accessible.

For VR menus, the project follows standard Meta Quest practices: controllers act as pointers through the XR Toolkit and hand interactors, enabling interaction with world-space UI buttons. Technicians can configure session duration and Bluetooth device selection, with preferences saved for later use. Once the user wears the headset, the technician activates the game via the game manager, which re-enables all objects and launches the experience.

5 Conclusions

All the requested features have been successfully implemented, resulting in a functional prototype ready for integration into real therapeutic sessions. Although further improvements could be made—particularly in visual presentation and microcontroller design—the system has demonstrated its feasibility and is scheduled for pilot implementation at ASPACE Coruña in the near future. The established Bluetooth infrastructure not only supports this project but also facilitates the development of new VR-based rehabilitation tools with custom peripherals, thereby expanding opportunities for therapeutic enrichment. Future work will include refining hardware design, enhancing graphical fidelity, and conducting broader user studies to validate clinical effectiveness. Thanks to the multiplatform capabilities of the Unity Engine, the application could also be adapted for mobile devices, extending its accessibility for home-based exercise at a lower cost. Beyond rehabilitation, the integration of peripherals highlights potential applications in entertainment, where adapted input systems could allow static bikes or similar devices to be repurposed as video game controllers.

Bibliography

Espressif Systems. Esp32 series datasheet, version 3.9. *https://www.espressif.com/sites/default/files/documentation/esp32_datasheet_en.pdf*, 2024. [Online; accessed June-2024].

D. Freeman, S. Lambe, T. Kabir, A. Petit, L. Rosebrock, L.-M. Yu, R. Dudley, K. Chapman, A. Morrison, E. O'Regan, C. Aynsworth, J. Jones, E. Murphy, R. Powling, U. Galal, J. Grabey, A. Rovira, J. Martin, C. Hollis, D. M. Clark, F. Waite, J. Altunkaya, H. Andleeb, A. Bergin, E. Bold, J. Bond, K. Bransby-Adams, S. Brown, C. Chan, N. Chauhan, M. Craven, J. Freeman, J. Geddes, A. Goodsell, L. Jenner, A. Kenny, J. Leal, J. Mitchell, H. Peel, M. Pervez, E. Prouten, E. Roberts, D. Robotham, H. Walker, and J. West. Automated virtual reality therapy to treat agoraphobic avoidance and distress in patients with psychosis (gamechange): a multicentre, parallel-group, single-blind, randomised, controlled trial in england with mediation and moderation analyses. *The Lancet Psychiatry*, 9(5):375–388, 2022.

Immersive Rehab. Digital therapeutics neurorehabilitation programs. *https://immersiverehab.com*, 2024. [Online; accessed June-2024].

Meta. Meta developer hub. *https://develop-ers.meta.com/horizon*, 2024. [Online; accessed December-2024].

I. Novak, C. Morgan, M. Fahey, M. Finch-Edmondson, C. Galea, A. Hines, K. Langdon, M. M. Namara, M. C. B. Paton, H. Popat, B. Shore, A. Khamis, E. Stanton, O. P. Finemore, A. Tricks, A. te Velde, L. Dark, N. Morton, and N. Badawi. State of the evidence traffic lights 2019: Systematic review of interventions for preventing and treating children with cerebral palsy. *Current Neurology and Neuroscience Reports*, 20(2):3, 2020. URL *https://doi.org/10.1007/s11910-020-1022-z*.

Unity Asset Store. Arduino bluetooth plugin. *https://assetstore.unity.com/packages/tools/input-management/arduino-bluetooth-plugin-98960*, 2024. [Online; accessed December-2024].