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# Therapy Reloaded: Mixed Reality Games for Hand Rehabilitation

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***Abstract*—This paper presents "Therapy Reloaded" (TR), an innovative mixed reality (MR) platform designed to enhance rehabilitation for individuals with neurological conditions such as Cerebral Palsy, Multiple Sclerosis, Stroke, and Brain Injury. TR integrates gamification into physiotherapy, transforming traditional therapeutic techniques into engaging experiences. The platform utilises the Meta Quest 3 headset to enable hand tracking, allowing for individualised settings that accommodate for varying degrees of hand mobility. A robust calibration process ensures accurate hand pose recognition, facilitating seamless user input during gameplay. The MR Treadmill game, a core component of the platform, encourages repetitive hand movements through interactive challenges set in a visually enriched environment. Data collected during sessions are relayed to the TR Portal, enabling clinicians to monitor patient progress and adapt gameplay to improve therapeutic outcomes. Allowing rehabilitation goals to be achieved with engaging gameplay, TR aims to improve adherence to physiotherapy, enhance motor control, and ultimately promote better health outcomes for its users.**

***Index Terms*—Head Mounted Device, Mixed Reality, Hand Tracking Sensor, Serious Games, Rehabilitation**

## I. Introduction

Physiotherapy and its associated techniques are important components of rehabilitation, helping to mitigate the effects of neurological conditions such as Cerebral Palsy (CP), Multiple Sclerosis (MS), stroke, and other rehabilitative disorders that may benefit from this form of therapy [1]. However, it is crucial for individuals to continue using these therapeutic techniques at home, even though the process can be difficult and tedious. The effectiveness of such practices at home may vary due to different scenarios and circumstances. There is a consensus that an effective rehabilitation should engage active involvement of the subject, be individualised, age and developmentally appropriate and goal-directed [2].

To enhance the appeal, enjoyment, and motivation regarding consistent participation in physiotherapy, it can be transformed into a gamified experience [3]. The process of gamification consists of the application of game design elements, such as challenges, rewards, and interactive aspects in a non-gaming context. The achievements of the games are aligned with therapeutic objectives. This approach makes the therapy more appealing, and encourages regular participation and increased repetition in what is often referred to as serious gaming - thereby enhancing the therapeutic experience [4].

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This paper introduces Therapy Reloaded (TR), an award-winning medical gaming platform designed for individuals undergoing rehabilitation with neurological challenges. The system primarily facilitates the improvement of gross motor and hand function by engaging users in serious video games [5]. These games are tailored to make the solution as accessible as possible to the target audience and ensure that they meet the diverse range of physiotherapy movements to promote the advancement of motor control skills.

This paper presents the mechanics for calibration and translating the Meta Quest 3 (MQ3) Hand Tracking sensor readings from the Head Mounted Device (HMD) into game controller values which are also sent to the Database Management System (DBMS) for clinicians to review after a play session. The values from the DBMS are then displayed in a more readable and visual graph format for interpretation by therapists and medical professionals in the TR Portal. Therefore, the individual reviewing the data can assess the time period and see if there has been a change in the individual's fine motor control through their hand movements.

The contributions included are as follows:

1) A unique approach to calibration using action and relaxed poses.
2) A technique to calculate the weighted average in regard to the data outputs to remove any discrepancies.
3) The creation of a new approach to selecting a level by using fine motor control.
4) Gamification of therapy for patients with motor impairments or neurological limitations using Mixed Reality (MR) - which will keep individuals interested and engaged in physiotherapy.
5) The incorporation of a level editor to easily make and create more levels.

Section II presents previous work in the area of Virtual Reality (VR), Augmented Reality (AR), and MR games, their therapeutic usage, and similar solutions. Section III describes the background of the current platform and therapeutic video games on the TR system. Section IV presents the hand calibration process, gameplay description, feature set and in-built objectives such as moving obstacles. Section V provides the results and evaluation, including selected testing results and other technical aspects. Finally, Section VI provides an overall discussion of this paper and presents potential future works.

## II. Related Work

The integration of serious games has become a transformative approach in the field of physiotherapy. Particularly in long-term care processes, such as rehabilitation, playful concepts are gaining importance. Several systematic review papers, for example, [6] and [7], conclude that whilst results of gamified therapy are similar or superior to Conventional Therapy (CT), there is a broad consensus among authors that increased motivation to the exercise program is a significant benefit. Improvements in quality of life and perceived health status were also observed. Several studies report positive results in motor recovery using VR-based interventions. A 2022 meta-analysis by Cortés-Pérez et al. [8] demonstrated that VR-based therapies are better than CT at reducing fatigue and improving the mental dimension of quality of life in patients with MS, and Domínguez-Téllez [9] found similar relationship for patients with stroke. A comprehensive assessment of various advanced technologies in maximising stroke recovery, including but not limited to VR, has been recently prepared by Amin et al. [10].

Several papers examine VR, AR, and MR-based gamified solutions that aid rehabilitation and therapy. Liao et al. [11] developed a set of three VR mini-games to support patients with upper limb rehabilitation. Caserman, Liu, and Göbel [12] use sophisticated full-body motion recognition based on Hidden Markov Models (HMM) to enhance their VR experience; their solution is intended for yoga learners, but can be extended to therapeutical ”exergames”. Gmez-Portes et al. [13] propose PhyRe UP!, a gamified mixed reality system to provide home rehabilitation for stroke patients; their experimental results demonstrate that the combination of mixed reality and gamification significantly influences the accuracy of rehabilitation exercises previously defined by therapists. Banaga and O'Sullivan [14] use wearable sensors to improve cognitive and motor functions of stroke patients in a mixed reality dancing experience; they use embodiment phenomenon to enable their patients to feel like they have control over their bodies beyond their mobility issues.

Another approach is presented by Chen et al. [15]. They developed a 3D-printed multi-functional assistive hand device called '3DP-MFHD'. This is used to ascertain the individual hand movements including grasping, pinching and other types of motions related to the hand inclusive of the thumb and index fingers. This prototype device was tested on individuals with chronic stroke as part of their home rehabilitation plan.

Further to this, Wang et al. [16] used the Leap Motion Controller which is a low-cost device used to interact in a virtual environment through technologies such as MR. This is to help provide therapy to individuals with neurological limitations inclusive of the aforementioned Stroke and CP. In their developed solution, the authors have used music therapy which they call 'musical sonification' in the context of the protocol created called 'SonicHand' [17].

## III. Platform and Games

TR is an award-winning medical gaming platform primarily aimed at individuals with neurological conditions such as CP, MS and Stroke [10]. TR helps individuals manage their mobility and condition(s) more effectively through therapeutic gaming methods in particular with the use of an MR headset.

The pipeline diagram and its associated components shown in Figure 1, illustrate the essential components and processes of the TR ecosystem. The initial phase involves the therapist evaluating the game for the participant with the neurological condition. Based upon this decision, the game will be launched in the user's headset.

Once the gameplay session is concluded, the data is sent to the TR Portal (a web-based application) where the data and gameplay outputs can be viewed and clinically assessed. This is also where the parents, carers, or guardians can view the relevant player(s) and monitor their fine motor control ability. There is an option to make player accounts anonymous, via the 'Generate Username' functionality when adding a new player. This allows for pseudo-anonymised data, in line with the General Data Protection Regulation (GDPR) and Data Protection Act (DPA) 2018 guidelines [4].

The TR Portal also provides additional player management options, such as deactivating player accounts - for example during longer breaks in therapy to activate previously deactivated accounts. In addition, clinicians can share participant accounts, with parents/carers and also other members of multidisciplinary teams [4].

The Portal is intricately connected to a DBMS, which relays data to the back-end processing as shown in 1. This includes such entities as the duration of sessions and levels tables. The sessions table contains the start and end times of sessions, which can be used to produce gameplay analytics, such as retention rate [18]. It also includes information related to the MR data outputs [4].

## IV. Methodology

The Mixed Reality and Hand Tracking are crucial elements of MR Treadmill experience, designed to empower and entertain the players. This process incorporates the personalisation of the player's experience, particularly based on fine motor control and hand movements. The Meta Quest 3 technology enables devices to recognise and interpret hand movements and gestures without the need for physical controllers — an advantage for individuals with neurological limitations or mobility issues affecting fine motor control. Since each player has a unique range of mobility, their readings will differ from others. This highlights the importance of a robust, secure, and user-friendly calibration process.

In subsequent sections, we will characterise the calibration process (Section IV-A) and our Mixed reality game (Section IV-B).

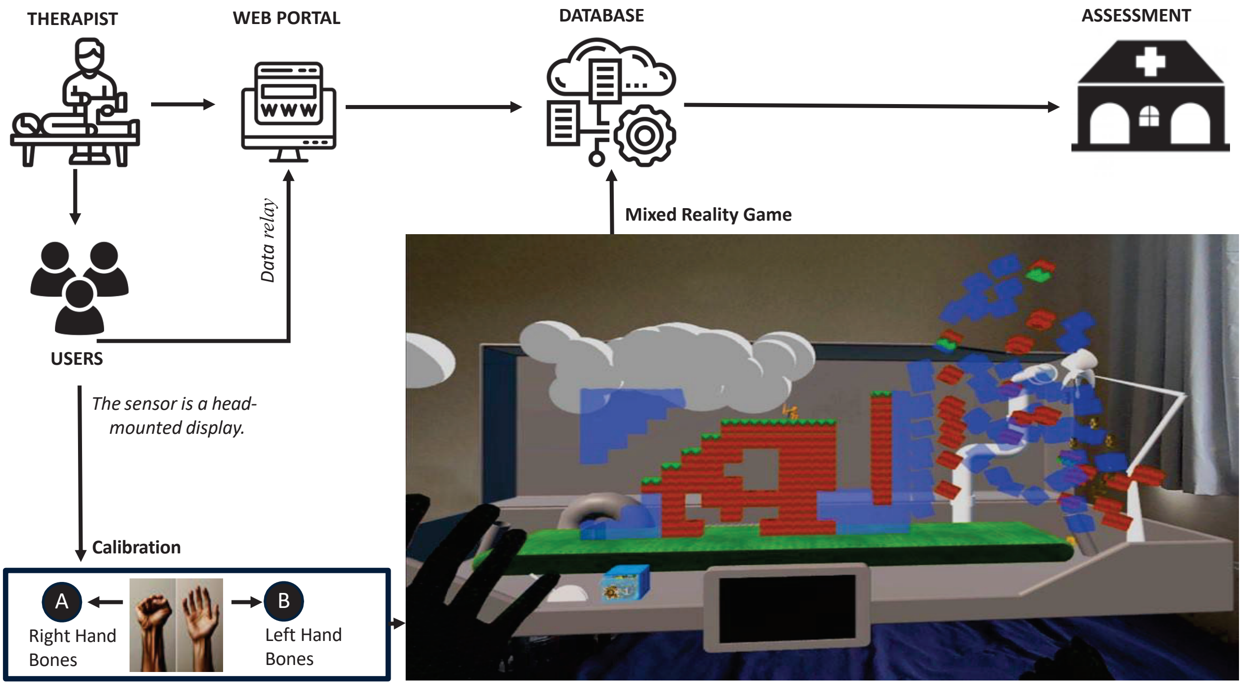



Fig. 1. Therapy Reloaded Pipeline Diagram for use with Mixed Reality

### A. Calibration of Hand Pose

Games require user input similarly to all types of software applications. For games, this is typically done through a keyboard and mouse or, alternatively, via a controller. However, for MR applications user input is typically handled using the controllers that come with the headset - with some games now using the headsets hand tracking abilities to control the game mechanics. Newer VR HMD provide hand tracking capabilities including being able to detect and identify if a hand action is being performed in a specific pose.

Therefore, a new method for providing input is required. After careful consideration, it was decided that each hand should output a one-dimensional floating point range, similar to a joystick as you can only move it in the left and right directions. This was chosen due to individual variability in hand mobility. Some players may be able to move each finger individually, giving significantly more scope for movement. However, other individuals may only be able to move one finger. Additionally, by restricting each hand to only outputting one value - it allows for all of the player base to participate regardless of their hand mobility ensuring equality among players.

The next aspect to decide was what the output of each hand should be based on. After consideration, a decision was reached that it should represent the difference between two poses. These two poses would be much like a thumbs up in that it is a known movement of all of the fingers in the hand. However, unlike a thumbs up it would be defined by the user during the calibration process. The two poses are 'Relaxed' and 'Action', 'Relaxed' is the hand in a rest position whereas 'Action' is the hand in an action state which will often be defined by a player's clinician. For example, extending your fingers as much as possible.

The calibration process starts by requesting the player to keep their hands visible at all times. This is done to ensure that the MR headset can keep track of their hands and scan the orientation of the fingers correctly. Following this, the player is advised to put their hands into the 'Relaxed' position. Once their hands are detected to be still, this pose is recorded and stored as the 'Relaxed' position.

Following this, a message is put on-screen to inform them that the relaxed calibration worked and has been completed. Consequently, the players are told to put their hands into the 'Action' position - once their hands are detected to be still this pose is recorded and stored. Finally, a message informing the individual that calibration has finished appears, and then the MR Treadmill game will commence.

The calibration process takes into account all 17 bones in an individual's fingers. For an extensive list and breakdown of all the bones in the hand used during the calibration refer to Table I. However, this process has the capability to exclude digits, if this feature is required by the medical professional or therapist.

The process of calculating the weighted average, represented by $\bar{x}$ in equation 1, is used to determine the most accurate value based upon the input data. $x_i$ represents the individual data values, with more recent values assigned a greater importance. This is accomplished by assigning

TABLE I
THE FINGERS AND ASSOCIATED BONES TAKEN INTO ACCOUNT

| Digit | Bone |
|---|---|
| Thumb | Trapezium<br>Metacarpal<br>Proximal Phalange<br>Distal Phalange |
| Index | Proximal Phalange<br>Intermediate Phalange<br>Distal Phalange |
| Middle | Proximal Phalange<br>Intermediate Phalange<br>Distal Phalange |
| Ring | Proximal Phalange<br>Intermediate Phalange<br>Distal Phalange |
| Pinky | Metacarpal Phalange<br>Proximal Phalange<br>Intermediate Phalange<br>Distal Phalange |

weights, defined as $w_i$ to each value on the gradient scale, where the higher weight values are given to the most recent data values. This method ensures that the game responds with a final value that matches the player's actual hand position, preventing any noticeable lag in their input. The weighted sum of the values is normalised by dividing by the sum of the weights:

$$\bar{x} = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i} \tag{1}$$

### B. Mixed Reality Platform Game for Hand Action

At TR, we have developed a platform-based game that utilizes MR and hand-tracking to harness the power of these technologies and allow users to enjoy the features and associated in-game environment. The game uses a HMD, which is a conventional VR headset - MQ3 capable of providing MR experience using the Passthrough capabilities. Users can see their physical environment through the headset's cameras, and the digital content, similar to that used in VR, is overlaid onto it. Our solution largely follows the stationary MR paradigm: users are typically seated, observing and interacting with a small scene unfolding in front of them, entirely embedded in their real-world environment. This approach minimises the risk of motion sickness, nausea, or headaches compared to a typical VR experience [14].

The game, entitled MR Treadmill, features a small robotic character placed in the middle of a conveyor belt, or treadmill. The movement of the treadmill allows the player character to navigate through diverse environments and face multiple obstacles while maintaining the overall stationary nature of the game. The game controls, including treadmill movement and character jumping, are entirely managed through a hand-tracking system that distinguishes between two main hand configurations, or poses:

1) **The action pose**. This position is typically defined by the therapist at the start of the physiotherapy process, but is usually either full finger extension (open hand) or finger flexion (closed hand).
2) **The relaxed pose**. This is the natural position of the hand, which may vary between patients, but it should always be distinguishable from the action pose.

The primary goal is to add gamification to the rehabilitation process with a specific focus on targeting hand and finger movements. The game encourages patients to engage in repetitive hand movements such as flexion (closing the hand to form a fist) and extension (opening the hand fully). By integrating these movements into the game's core mechanics, MR Treadmill aims to make rehabilitation exercises more engaging and enjoyable.

The game[1] was developed using the Unity game engine as the primary development platform due to its lightweight build process and extensibility. This platform was also chosen for its Android support and rapid prototyping capabilities and Meta Extended Reality (XR) All-in-One Software Development Kit (SDK) to utilise Meta Quest's 3 features including full-colour pass-through that allows the players to see a real-time view of their surroundings. Furthermore, the Blender application was used for creating the 3D models and generating textures for them, and alternative software programs such as Photoshop were used for creating 2D User Interface (UI) and particle sprites. For a visual representation of these UI elements refer to Table II.

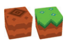
The core idea was to develop a platform-based game that could be customised for individuals with different needs and requirements such as a one-handed mode where the character movement automatically happens, and the focus is on avoiding obstacles that require the most amount of hand movement. Various difficulty levels have been implemented, so the players with less mobility can utilise the game effectively. The game's grid-based design allowed for the implementation of a Level Editor (Fig. 2), enabling both developers and users to create custom maps, thus adding more content and variety in the process. Furthermore, this increased game replayability, retention rate and average time per level [18]. These metrics indicate that the game has a therapeutic value, while empowering the players with neurological limitations to improve and manage their hand mobility and fine motor control more effectively.

Please see the following for the description of corresponding keys included in Figure 2.

- Level Data: The user can modify the level's name, preview the level thumbnail, and set the time and score limits for scoring purposes.
- Buttons: Play Button, Save Button, Capture Thumbnail Button and Toggle Side Menu Button.
- Block Selector: Allows the user to select blocks to place in the level. (The original location is under the Level Data (Buttons) UI element, the current position just for representation).

[1]Gameplay video: https://youtu.be/m-r-DRkIBDs

TABLE II
THE IN-GAME OBJECTS TO TAKE INTO CONSIDERATION FOR THE PLAYER

| Sprite | Block/Item | Description |
|---|---|---|
|  | Dirt/Grass | Static blocks that the character can collide with from all directions. |
|  | Swamp | Slows down the character when the player swims in it. |
|  | Water | The character can swim in it along the vertical axis (either upwards or downwards). |
|  | Wind Generator | Generates an upward wind current that pushes the player if the Glider is in use. |
|  | Reverse | Reverses the movement direction of the character and the conveyor belt. |
|  | Checkpoint | Re-activates the checkpoint where the character can respawn if they fall off the level. |
|  | Score Gear | A collectable item that grants score. |
|  | Finish Flag | The level ends when the character reaches it. |
|  | Patrol Enemy | Moving entity that pushes the character back upon collision. |
|  | Music | Starts playing the selected music (visible only in the level editor). |
|  | Start | The starting point of the map. (visible only in the level editor). |
|  | Drill | Can destroy solid blocks upon collision. (e.g. Grass and Dirt Block). |
|  | Glider | Can slowly descend instead of falling, or ascend if the character collides with a Wind current). |
|  | Thruster | Can fly upwards or downwards and move forward automatically if the character is behind it). |

- Layer Selector: Enables the user to switch between layers and place different blocks in the same grid slot for greater versatility.
- Block Grid: The grid where blocks are placed.
- Editor Customisation: Users can customise the editor's background and grid colour, adjust the grid width, or toggle the visibility of horizontal and vertical lines for improved visibility.
- Scroll Bar: Allows navigation across the map, moving left and right.

A high score feature further improves individual and player engagement by challenging them to play again on different levels enhancing its replay ability. For a full list of all the in-game objects included in the game, please refer to Table II.

Testing was performed with non-therapy requiring players to ensure the game's mechanics were intuitive and responsive.

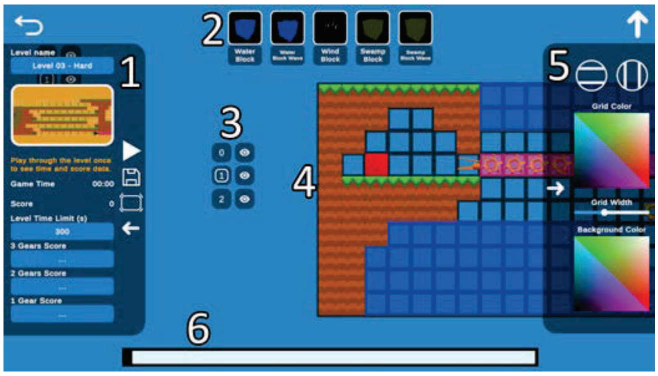



Fig. 2. Editor UI

## V. RESULTS AND EVALUATION

During the development of the project, several challenges arose when creating the game with the Meta Quest 3 headset. The headset's tracking system is not always ideal for hand movements, as certain elements can be inaccurate and lead to discrepancies. These variations may differ from person to person due to differences in sensor detection. As a result, we closely monitored the angles of finger movements and, after performing several calculations, discovered that if all fingers move within a certain margin of error, the end result and data output can be significantly affected. For example, in one instance, the percentage of hand contractions increased by approximately 2%. This had direct repercussions on gameplay and the user experience, resulting in a less functional game.

The solution to this issue was to smooth the values provided by the headset. We sampled the last 120 frames - approximately 2 seconds of data - allowing us to smooth and adjust the current position and readings for greater accuracy. This ensured a more reliable data output, which is crucial when being assessed by medical professionals and therapists.

A visual representation of the game interface, specifically the menu, can be seen in Figure 3. The game menu is designed to be intuitive, easy to use, and free of clutter, avoiding distractions that might confuse players with neurological limitations. For instance, if a player with limited hand mobility - such as in the case of cerebral palsy (CP) - wants to select one of the three menu options, the game includes functionality that allows them to do so by holding their hand in position for approximately 4 seconds. This feature enables players to interact with the game, regardless of their hand motor ability or fine motor control, and serves as an introduction to the control mechanics for new players.

## VI. CONCLUSION

In this paper, we have proposed a unique and innovative technique to design a MR game which helps individuals with neurological limitations to experience the real-world and the in-game environment in unison. This is through the MQ3 headset which supports both of these technologies, and unlike VR there is minimal aspect of motion sickness or nausea

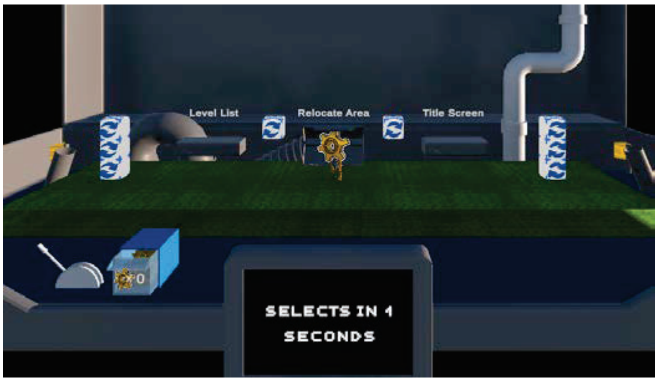



Fig. 3. The Game Menu

to take into account. We used full-colour pass-through when developing MR Treadmill to ensure suitability for the target audience. Furthermore, we also enabled the weighted average on the raw and processed data outputs before it is sent to the database for viewing on the Portal by therapists and medical professionals – therefore eliminating discrepancies before they reach the end user. As aforementioned, the actions the player needs to perform are 'Action' and 'Relaxed'. These two hand movements need to always be visible in the screen boundaries to interact with the in-game world effectively to ensure a playable and fun experience for the individual.

In relation to future improvements, there is a consideration such as using additional sensors or using AI to generate the next level based on the users previous performance. This would be for the purpose of adding an element of adaptive gameplay which would be tailored to a specific player and can be monitored by a medical professional or therapist to see if there has been a change over time when they are analysing their readings on the TR Portal.

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