Motion Capture Game to Increase User Engagement for Home Physiotherapy

DAPP 2 Final Report

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Abstract

Patients suffering long-term disabilities are prone to disinterest in completing home-based physiotherapy due to its monotonous nature, despite it being a vital supplement to in-clinic sessions. A survey conducted revealed that only 27% of youths regularly completed their prescribed home-based therapy. Our aim was thus to create an exergaming solution to incentivise home-based therapy, while simultaneously collecting and processing movement data that may aid in tracking patients' progress. Background research on physiotherapists and target users demonstrated the need for a system that rewarded consistent effort and had enjoyable gameplay, suitable for the demographic, without incentivising overtraining. It is important to simultaneously record information for repetition count, fatigue and pain levels, as well as goniometric data.

Thus, we decided that a game with a light-hearted storyline, engaging visuals and reward mechanism, with motion capture elements was necessary. Evaluating existing game engines, motion capture models and demographic preferences, we selected Unity as a platform to create an RPG-based game, *Worm Up,* that included exercise-based minigames and utilised the Nuitrack SDK and 3D camera Astra S for skeletal tracking. Features, including animal avatars and familiar UK landmarks in gameplay, make it suitable for children, while maintaining interest in the storyline. Measures of the player's progress, such as character level, in-game location, and avatar, as well as physiotherapeutic data are logged automatically into a Google Firebase database at the end of each session. Data is exported from Firebase at fixed intervals by the application *Flatly*, after which it is automatically processed and uploaded for the physiotherapist to log in and access on our Wix website.

Software testing of the RPG showed consistent loading and uploading of data from Firebase, with ease in registering and logging in users, as well as accurate information on the player's game progress. User-testing at this stage was limited to small-group feedback of concept and design which favourably highlighted storyline and character design, but further testing is required in evaluating the efficacy of the product on the target demographic.

Software testing of the accuracy of our motion capture model showed a 4.79% error in joint angle measurement across the 180° field where user is facing the camera, which was reduced to 3.31% when maintaining a slanted position. Additionally, across a series of 20 replicate sessions, the repetition count increased only when the expected motion was performed accurately.

The product has largely met the requirements outlined in the PSD[1], but limitations at this stage include having only one minigame, which reduces the disabilities that the product caters for and diversity of the game. However, with the infrastructure for progress and data logging in place, further minigames are much more easily incorporated. Additionally, the physiotherapist interface should be migrated to a custom domain as the product sales, for greater flexibility, increased storage, and no external ads.

[1] Product Specification Document

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1.1 Motivation and Aim of the Project

Patients suffering from long-term disabilities require physiotherapy. Those of the younger demographic are especially prone to disinterest over time, due to the task's repetitive nature. This manifests in out-of-session home therapy, which requires consistent self-motivation and engagement. Our data shows that only 27% of young people completed their at-home physiotherapy exercises frequently. For the 61% who did not, the main reason given was their boredom after a certain amount of time[2]. This presents a problem particularly for those with serious disabilities whose quality of life is dependent on their ability to complete their home therapy and recover.

To ameliorate this issue, our group proposes an exergame platform that increases patient engagement during such sessions and decreases monotony by implementing an interactive element, while simultaneously taking goniometric measurements of movements, allowing physiotherapists to better track and assess patient progress.

1.2 Background Research

1.2.1 Research on Target User Requirements

At the beginning of our research, we planned to tailor our physiotherapy system to children from the John Chilton school, thus deciding on the target age range of 7-19 [1] and the incorporation of video game interaction. [2] Despite being unable to contact the school, the target age range remained.

We first researched major physical impairments associated with common neurological disabilities in children. Cerebral palsy - in particular spastic hemiplegia [3], and other long-term conditions such as spinal cord injuries require out-of-session physiotherapy. They are emotionally challenging to recover from as the exercises are difficult and repetitive. However, the user must complete the prescribed therapeutic exercises to regain lost or weakened functionality. We subsequently split our research into two facets: the requirements in game elements appeal specifically to our youthful demographic and the relevant data collection for physiotherapists.

Research conducted on target user requirements	A. Children are motivated by games that allow them to make their own decisions, such as having customizable avatars. [4] B. Children are more engaged by a creative storyline and in-game music. [5] C. Some children may have poor grip strength, so the motion tracking device should not be held or attached. [6] D. Children have difficulty concentrating on a task for a long time, so the game should be short in length. [7] E. Children may feel frustrated if the game is too difficult, therefore the difficulty level should match the user's ability, to encourage ongoing engagement. [4] F. Children are motivated by rewards, so the user should be rewarded for completing the exercises. [5]
Research conducted regarding type	• Goniometric measurements of joint angles during exercises, including maximum values

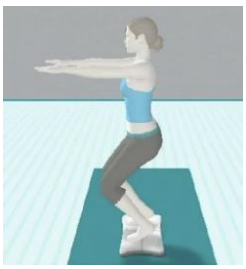
[2] Refer to Appendix F for the results of the survey conducted.

of data to collect [8]	• Pain level during exercise, using the standard Visual Analogue Scale of pain • Number of repetitions achieved The physiotherapists also provided important safety guidelines for home therapy: • Users should not be sweating or hyperventilating, so game length should be kept short • A timer and maximum repetition count should be set to prevent patients from over-exercising

Table 1. Results of information collected regarding user and physiotherapist requirements

1.2.2 Research on Existing Exergames

Exergames were researched to identify the key requisites for our design. They are commonly used for both rehabilitation and fitness purposes and require visual feedback to make the game engaging and challenging [9].This motivates the user to adhere to their prescribed exercise routine.

Nintendo Wii (Wii Fit/Wii Sport)	User Requirements Met	• Personalisable features, such as avatars (*Miis*) [10] • User-friendly interface • Strength-training exercises in Wii Fit
	User Requirements Failed	• Gameplay requires a hand-held input device (Remote Plus) for motion tracking. [6] • Exercises do not target user disabilities.
	Game Examples	  *Figure 1. Nintendo Wii Fit - skiing game using the Wii Balance Board, and associated movement*

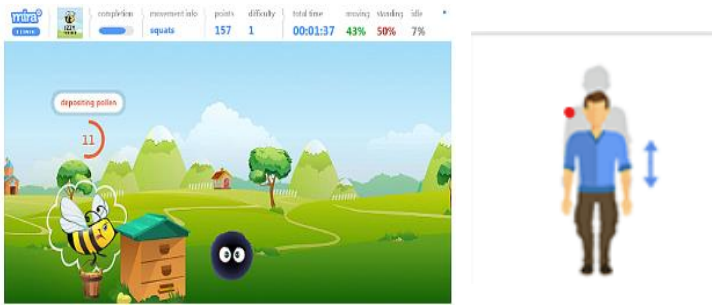
Microsoft Kinect (Mira)	User Requirements Met	• Exergames are hands-free. The Kinect includes an RGB[3] camera and depth sensor, allowing the user to interact with the game via 3D motion capture. [6] • User-performance feedback[4] system is implemented to track user progress. • Real-time automatic performance assessment allows the physiotherapist to access user data, such as ROM[5] and joint movement speed (Figure 3). • Obtains useful feedback such as pain levels and emotional state from the user. [11]
	User Requirements Failed	• The exergames do not follow a storyline, so gameplay would be less engaging in the long term. • The system is expensive (£2,500/unit).
	Game Examples	 *Figure 2. Izzy the Bee - Users can control the bee by squatting or with hip abduction movements.*  *Figure 3. Mira User Feedback Page*

Table 2. Existing exergaming systems and their shortcomings for our applications

[3] Refer to Appendix E for definition.
[4] For example, gameplay duration, number of successfully performed exercises
[5] Refer to Appendix E for definition.

1.2.3 Research on Game Engine

The two researched game development engines, Unity and Unreal, are free for students. We have chosen Unity due to the following reasons:

Unity	Unreal
C# is the primary programming language, which is easier to learn than C++.	C++ is the primary programming language.
More beginner friendly for 2D game development due to the variety of online resources available.	Require specialising in very high-level graphical performance, which is unnecessary for our games.

Table 3. Comparison between Unity and Unreal

1.2.4 Research on Motion Capture System

1.2.4.1 Comparison of Markered and Markerless Technology

Markered and Markerless Technologies are the two main motion capture techniques. We have chosen Markerless Technology after considering the following:

Markered Technology	Markerless Technology	Better Option
The use of markers may cause discomfort to the user and it is also harder to wear.	The use of video analysis removes the need for markers thus allowing for more user freedom.	Markerless
May impair user movement depending on implementation	Allows natural user movement.	Markerless
Higher accuracy [12]	Lower accuracy	Markered
More flexible in terms of distance from the recording device	Less flexible in terms of distance from the recording device	Markered

Table 4. Comparison between the markered technology and markerless technology

1.2.4.2 Motion Capture Model

Various deep-learning models are available in Python. The models perform a matrix analysis on various key points identified on the body, through which goniometric data including maximum flexion and abduction angles are obtained.

	TensorFlow's MoveNet	**OpenPose**	**BlazePose**	**Nuitrack**
Key Points	17	135	33	17
Minimum threshold FPS	30	0.3 [13]	30 [14]	30
Co-ordinates outputted	2D	3D	3D	3D
Computational power required	Low	High	Low	Depends on the number of skeletons tracked

Table 5. Comparison of motion capture models researched

Figure 4. Pose detection with MoveNet and TensorFlow.js [15] *(on the left) and pose detection with OpenPose (on the right)*

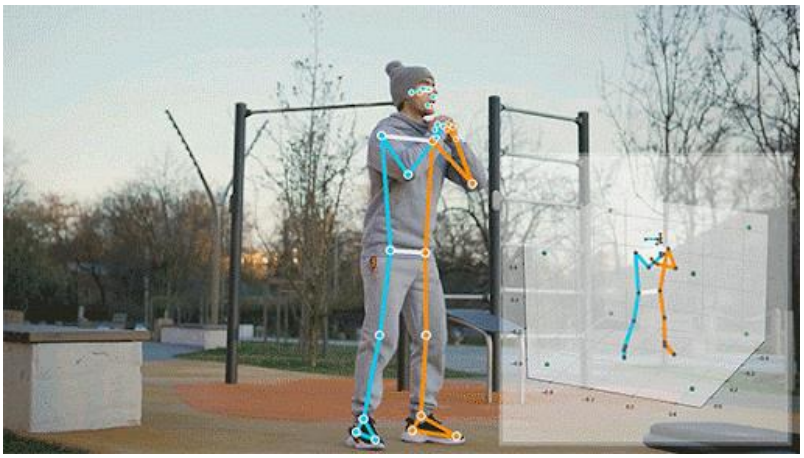


Figure 5. 3D Pose Detection with MediaPipe BlazePose GHUM **Error! Bookmark not defined.** [28]

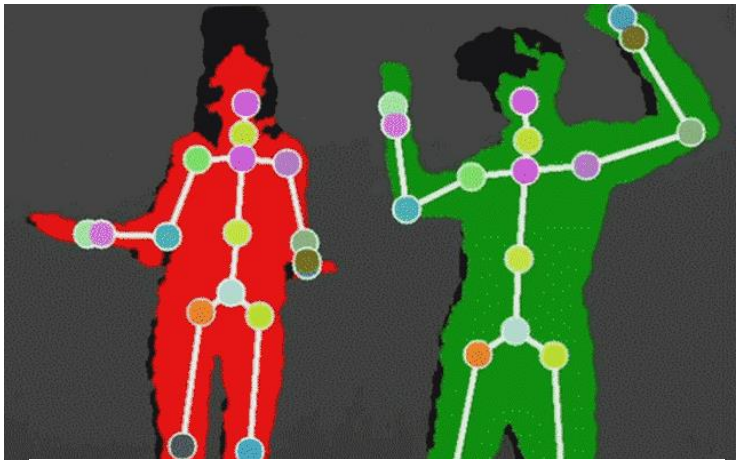


Figure 6. Skeleton tracking software - Nuitrack SDK

[16]

Nuitrack was chosen for our project due to its ability to output 3D co-ordinates without providing too much redundant data. It is a middleware software that leverages on depth and colour stream data of a compatible 3D camera. It also allows Unity plugins which we can develop our own games, whilst simultaneously using the built-in 3D angle detection function, which simplifies the process of obtaining the angle of motion of the user.

1.2.5 Data Processing

- MATLAB Method:

Initial research to convert point clouds of skeletons generated through the motion capture models suggests the use of MATLAB matrix. It relies on 3D real coordinates of minimally 3 non-collinear points per limb segment (e.g. the forearm) to obtain a segment-fixed frame of reference (sFOR). The sFOR yields a 3x3 rotational matrix ($^{camera}_{segment}R$) of the segment relative to the camera. Combining this with the 3x1 translational vector ($^{camera}_{forearm}P$), the vector position of the sFOR from the origin of the camera coordinate system, gives the 4x4 transformation matrix ($^{camera}_{forearm}T$) of the limb segment:

$$^{camera}_{forearm}T = \begin{bmatrix} ^{cam}_{farm}R & ^{cam}_{farm}P \\ 0 \quad 0 \quad 0 & 1 \end{bmatrix}$$

A transformation matrix relating 2 limb segments ($^{upperarm}_{forearm}T$) is calculated as follows:

$$^{upperarm}_{forearm}T = {}^{cam}_{uarm}T^{-1} \cdot {}^{cam}_{farm}T = \begin{bmatrix} ^{uarm}_{farm}R & ^{uarm}_{farm}P \\ 0 \quad 0 \quad 0 & 1 \end{bmatrix}$$

Using Euler's rotation method and given that r_{ij} gives the element of R in the *i*-th row and *j*-th column, the flexion angle α, abduction angle β, and rotation angle γ, are calculated from R as follows using an inbuilt arctangent function of MATLAB ($\arctan 2$) that considers angles in all four quadrants:

$$\alpha = arctan2(\frac{r_{21}}{r_{11}})$$

$$\beta = arctan2(\frac{-r_{31}}{\sqrt{{r_{11}}^2 + {r_{22}}^2}})$$

$$\gamma = arctan2(\frac{r_{32}}{r_{33}})$$

Repeating this calculation using positional data for all video frames allows for a plot of all 3 angle types against time for a desired joint (e.g the elbow).

- Python Method:

Having selected a markerless model of motion capture, the data outputted largely consists of joint data of the skeleton, which was insufficient to provide the 3 points per segment necessitated in the Euler rotation method. Additionally, MATLAB was less suitable in automating the process of angle calculation and plotting, raising issues in real-time analysis. We therefore chose a Python-based model for angle calculation. Getting the 3D coordinates of each joint, the angle θ between limb segments can be found using the dot product equation:

$$A \cdot B = |A||B| \cos\theta$$

The angles obtained are then plotted against time and saved as .png files to be uploaded onto the physiotherapist interface.

1.2.6 Research on Data Collection Platforms

Our research suggested three data collection platforms - AWS**Error! Bookmark not defined.**, MongoDB and Firebase. We have chosen Firebase as it is the most compatible option with our project.

AWSError! Bookmark not defined. **/ MongoDB**	**Firebase**
Steeper learning curve	More beginner friendly
Better Global Scalability	Suitable for small-scale projects, like ours
Both are suitable for real-time applications, store and sync real-time data	

Table 6. Table shows the comparison between AWS/ MongoDB and Firebase

1.2.7 Research on Motion Capture 3D Camera

We decided to use an external camera for motion capture since the camera quality could differ significantly between users with an inbuilt camera. The 3D camera developed by Orbbec is the most suitable option, according to our comparisons (Table 7).

In the event that Orbbec discontinues the Astra, the Asus Xtion Pro would be an appropriate alternative, based on its availability and compatibility with Nuitrack.

	Kinect	**Orbbec Astra**	**ASUS Xtion Pro**
Price point	$199.00	$149.99	$245.00
Compatibility with motion tracking models (Nuitrack)	Yes	Yes	Yes
Current State	Discontinued	Available	Available
Mass (g)	910	260	700

Table 7. Comparison between Motion Capture 3D Camera

2 Requirements Definition

2.1 Functionality and Performance

The game should:

- Focus on physiotherapy purposes
- Function on standard computers

Target specific rehabilitation movements for which we chose bicep extension (Figure 7)

- Be entertaining enough to motivate users to follow prescribed exercise routine
- Connected to a motion sensor to track real-time user movements
- Log the user data from each session onto a cloud/real-time database
- Export the data onto an interface for the physiotherapist to access and track progress
- Have a user-friendly interface for both the patient and the physiotherapist

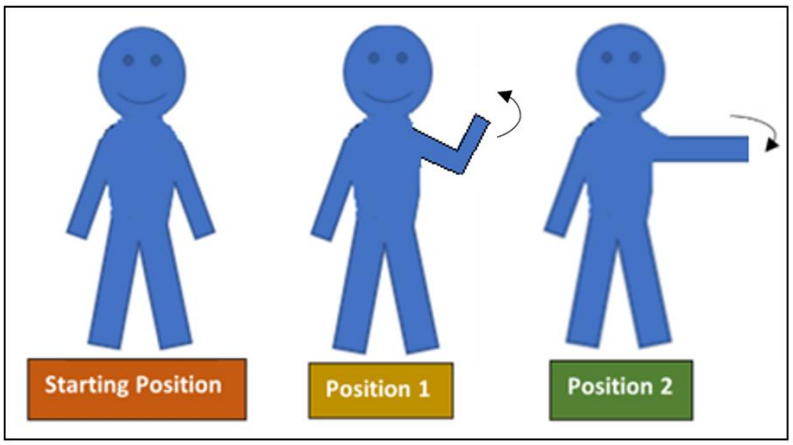


Figure 7. Bicep extension exercise

2.2 Size and Weight

An area of no more than 2.5m by 2.5m should be available for the detection of the user's full body. It should weigh less than 2kg for ease of usage, set-up and storage.

2.3 Usability, Interface, and Ergonomics

The UI[6] should be straightforward. Simple language should be used and the process of setting-up should be clear and concise. The gameplay should not have long, wordy instructions or long waiting times. The motion sensor must be usable by children with gripping difficulties and should therefore be markerless.

2.4 Portability

The device should be packaged well and durable enough to withstand normal parameters of rough handling.

[6] Refer to Appendix E for definition

2.5 Safety and Security

The product should test for proper calibration and set-up prior to each session to reduce inaccuracies in data collection which may lead to misinterpretation. An adult supervisor must be present throughout the gameplay to prevent physical injuries from falling for example. The data must also be stored on a secure database.

2.6 Cost

The product should be cheaper compared to existing solutions on the market, which is below £2,500. A profit margin should be maintained keeping in mind distribution costs without compromising on the quality of materials.

3 Final Design

3.1 Design Choices

After conducting a morphological analysis, we concluded that our game concept was to be an RPG with exercised-based minigames embedded within the storyline[7]. Thus, the final product consists of our proprietary video game, *Worm Up,* shipped with the 3D camera Orbbec Astra.

3.2 Games

3.2.1 Worm up (RPG)

3.2.1.1 Overall RPG Storyline

The main character is an archetypical ‘mad scientist’ conducting an experiment to make his body disappear. However, due to miscalculations, he is left as a spirit and thus begins the adventure to regain his human form. This is presented to the user in the form of an animated, introductory cutscene:

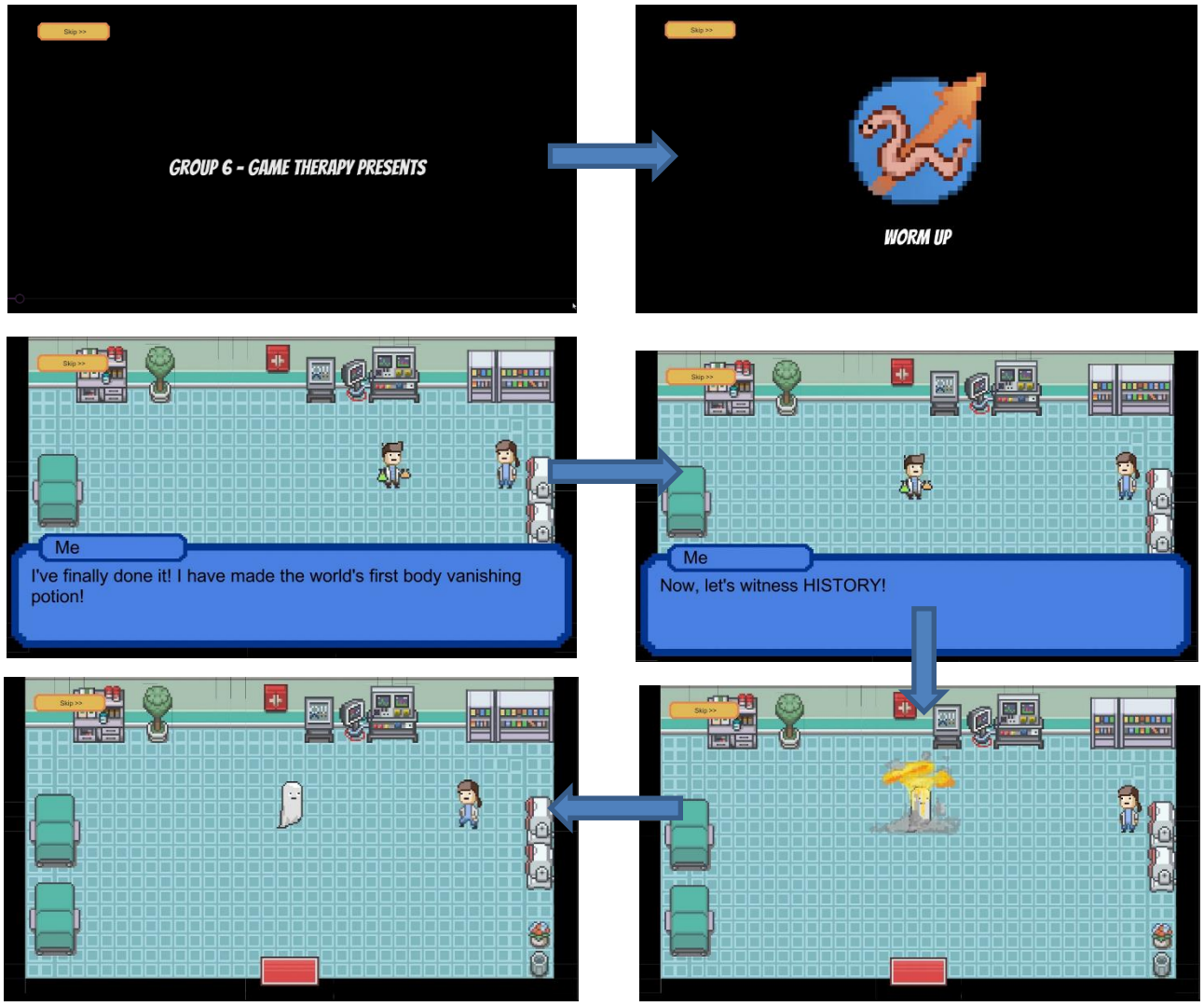


Figure 8. After the user has logged in, the RPG starts. We have included an introductory cut scene with preprepared script such that the user easily picks up the story.

[7] We demonstrated how we obtained our game concept using morphological analysis in Appendix G

Once the cutscene ends, the control menu displays the gameplay instructions:

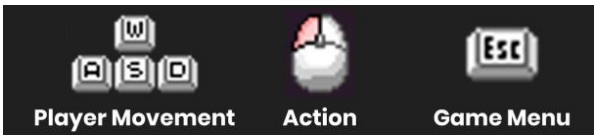


Figure2 9. User control menu

Users with limited ROM should have parental/carer support when navigating around the RPG scenes, as these require the use of a keyboard and mouse.

The user is guided through dialogues and interactions with NPCs[8], some of which are relevant to the plot while others are for entertainment. This leads to their interaction with the Fisherman NPC, and thus the initiation of the fishing exergame.

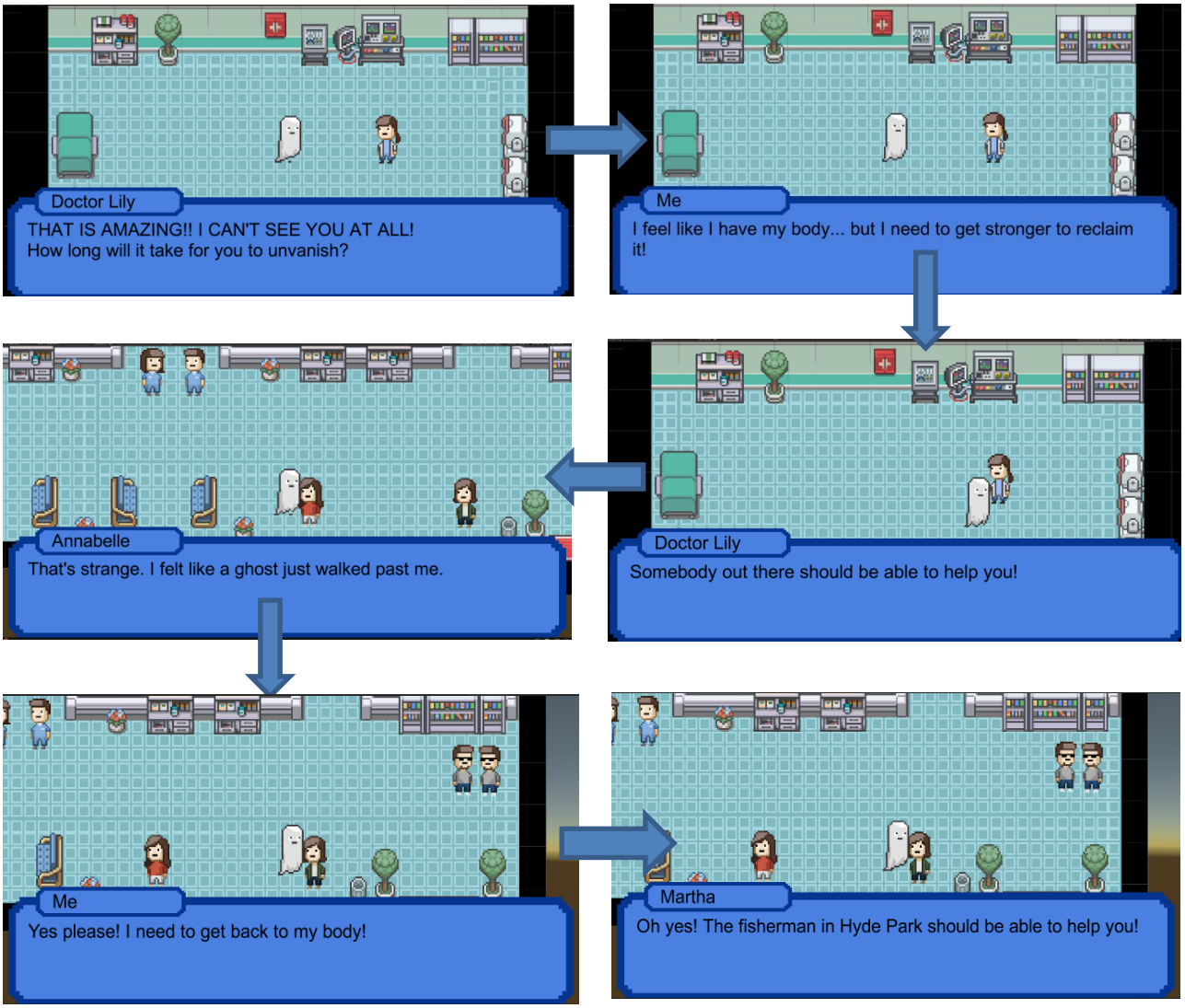


Figure3 10. Interaction with NPCs

[8] Refer to Appendix E for definition

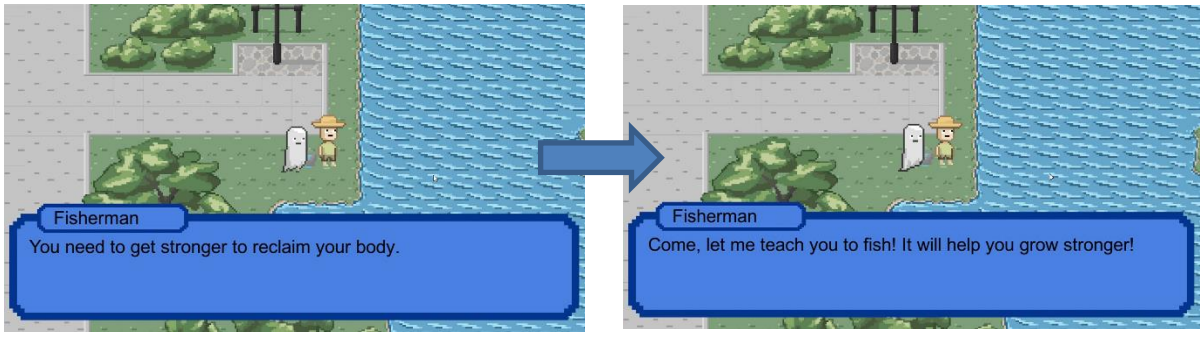


Figure 11. The goal is to find the fisherman in Hyde Park who will launch the minigame

The user learns that he must get stronger to reclaim his body. The user will gain XP in the process of getting stronger and upon earning enough XP, the user will level up and sequentially progress through a hierarchy (Figure 13) ultimately regaining his human form.

Figure 12. New character unlocked after XP reaches threshold through playing of minigame

Figure 13. Hierarchy of characters

At certain points in the character hierarchy, the player will be presented with the opportunity to choose their preferred avatar (e.g. dog or cat), giving the user more freedom over their experience. The following key storyline elements were added for the below reasons:

Key storyline element	Reason for choosing the element
Progression up the character hierarchy	Allows for higher user engagement by providing the user with the ability to grow in game, visually monitor their game progress and collect cute animal avatars. More animals can be added to the character hierarchy to increase the length of the game for long-term users
Use of familiar landmarks	Provides user with a sense of attachment to the game.

Game concept of character growing stronger up the hierarchy	The metaphor of growing stronger through completing exercises implies the importance of home physiotherapy and increases long-term motivation.

Table 8. Reasons for choosing the key storyline elements

3.3.2.3 Key Scenes

The game has two primary scenes populated with NPCs and minigames at this stage:

Figure 14. Hospital Scene

Figure 15. Hyde Park Scene

3.2.2 Game Features

3.2.2.1 Login Page

Opening the game launches the login page, from which existing users can login and first-time users can register (Figure 16). This information is stored in the real-time database of Firebase. After logging in, the user's game progress is saved onto Firebase whenever they press the save button or log out through the in-game menu (Figure 17). When logging in for the first time, the game launches into the introductory cutscene, otherwise, their last in-game position is retrieved.

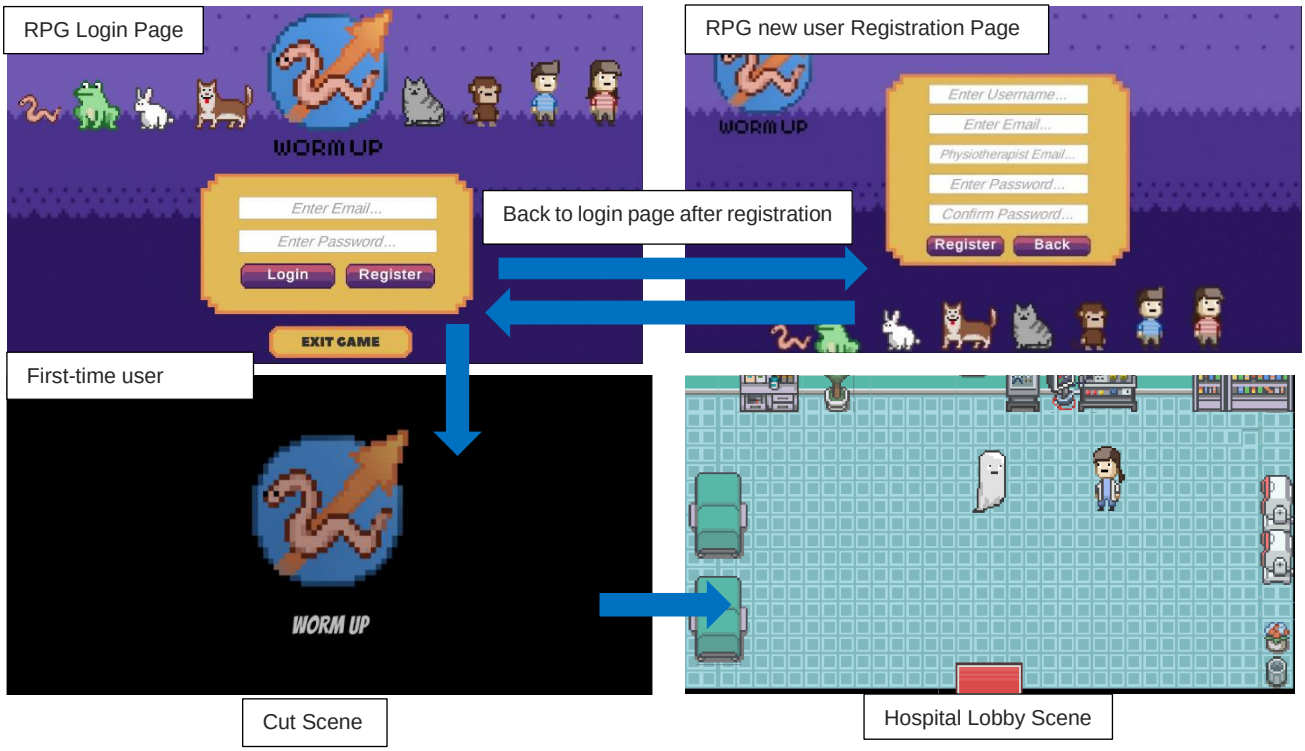


Figure 16. Flowchart showing how the login/registration page and the transition to the game scenes

3.2.2.2 In-Game Menu

The player can pause the RPG at any time, through use of the esc key[9]. The in-game menu will be displayed, with options shown in the Figure 17.

This allows the user to take a break when desired, save game progress, view their in-game statistics or log out. When user finishes their session, the log out button signs them out and saves the session data and their user location on Firebase.

[9] https://www.flaticon.com/free-icon/escape

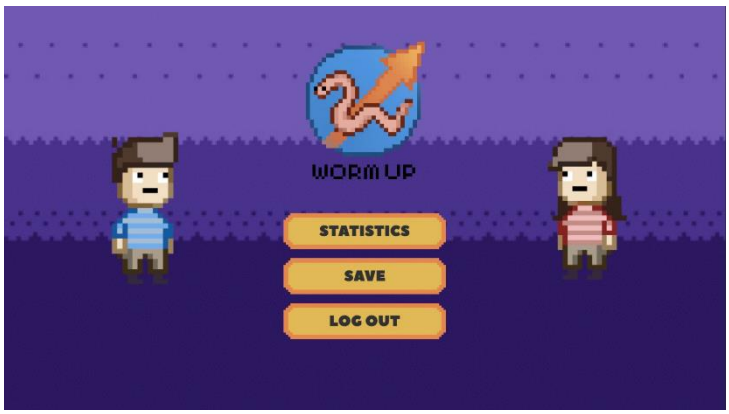


Figure 17. Pop-up in-game menu when the user pauses the game

3.2.3 Absurd Fishing (minigame)

3.2.3.1 Game Structure

The fishing minigame launches automatically when the dialogue with the Fisherman NPC ends, as outlined in section 3.3.2.1:

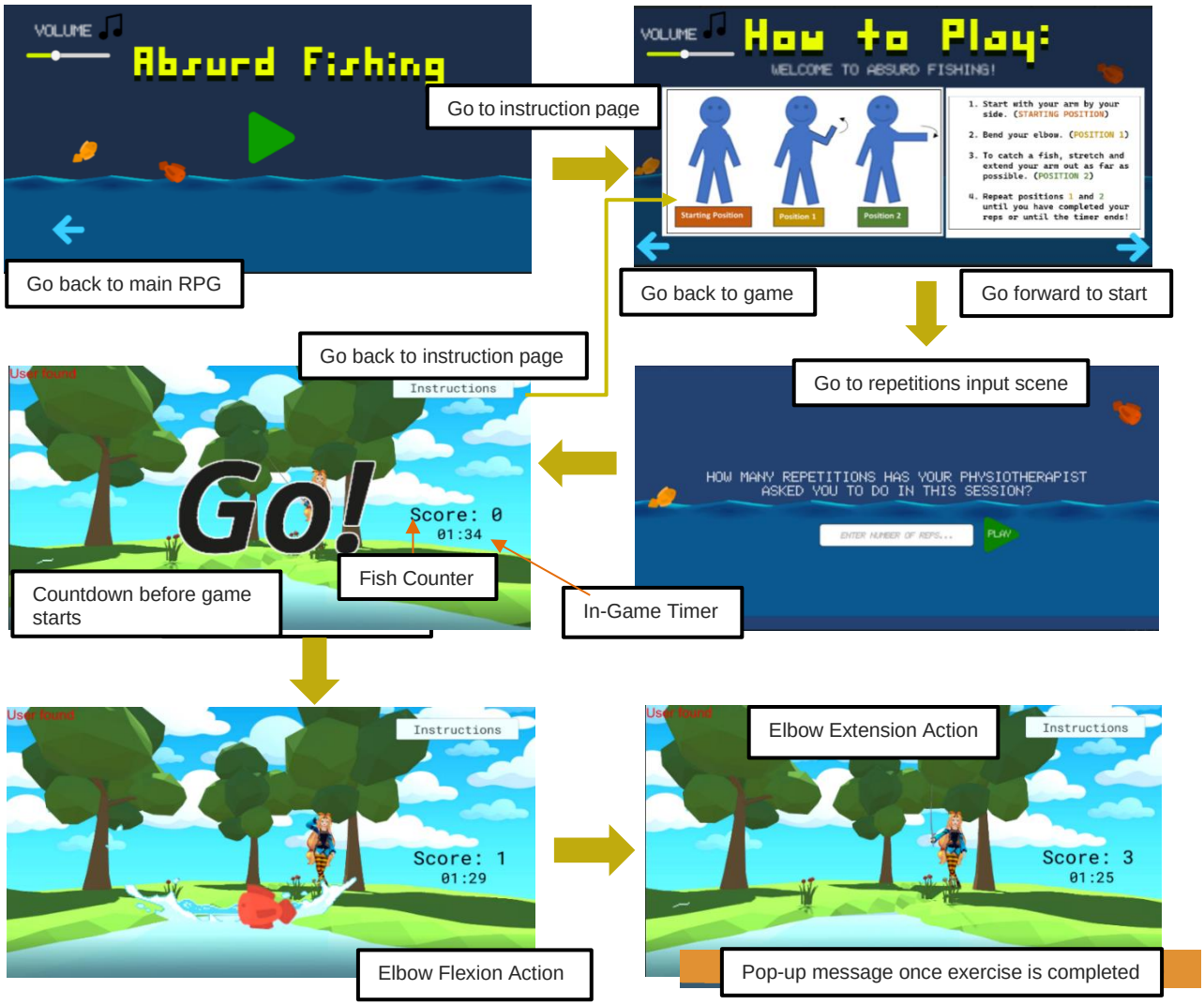


Figure 18. Flowchart showing how the Absurd Fishing minigame works

The minigame launches into an instruction scene outlining prompts on how the user will be able to successfully complete it.

3.2.3.2 Minigame Design

The ‘Absurd Fishing’ Minigame is a biceps stretching exercise to build upper body strength and mobility. The game involves the user fishing with a virtual fishing rod, controlled by elbow flexion and extension movements, under a 90 second time limit. The goal is to catch as many fish as possible by performing the exercise for a certain number of repetitions within the stipulated time limit.

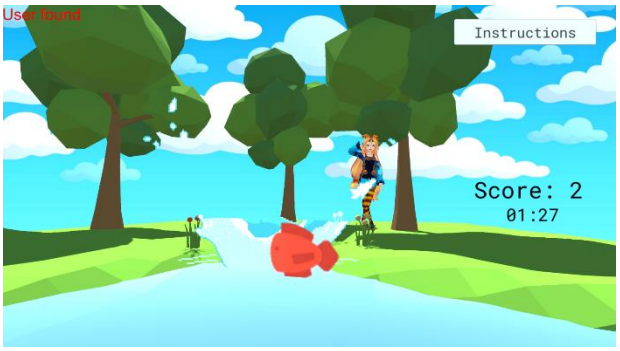
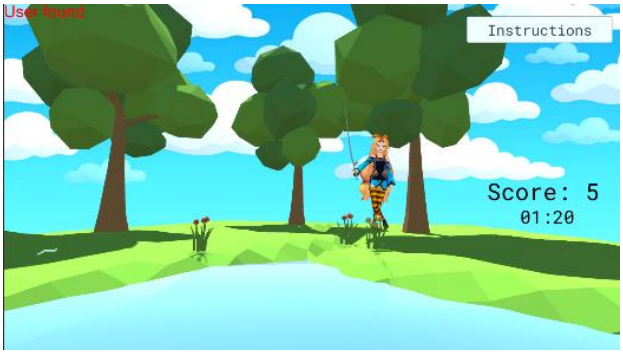
User Movement	Corresponding Avatar Movement
	
	

Table 9. ‘Absurd Fishing’ motion control.

The user is prompted to input the prescribed number of repetitions in the minigame (each fish caught translates to one repetition completed). If the user does not complete the exergame within the time limit, no XP is earned. However, the user can retry the exergame so that they may progress in the game.

To meet the requirement of maintaining user engagement, we decided to include:

- Fun, high-tempo background music to motivate the user. The user is given the option to alter the volume to their needs.
- Encouraging pop-up messages when the user successfully completes the prescribed exercise.
- Timer to prevent prolonged exergame gameplay if the user is unable to complete the prescribed exercise.

3.3 Data Logging and Access

3.3.1 Nuitrack SDK

We can select the two segments of skeleton we are interested in to calculate the angle between them.

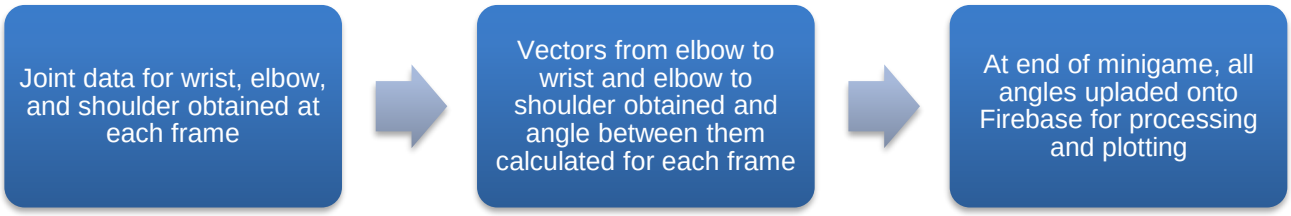


Figure 19. Flowchart showing how Nuitrack detects the angles of motion during gameplay

3.3.2 Feedback Page

When logging out of the game, the user can give feedback on their fatigue, pain and enjoyment levels on a 1-10 scale, in line with the product requirements.[10]

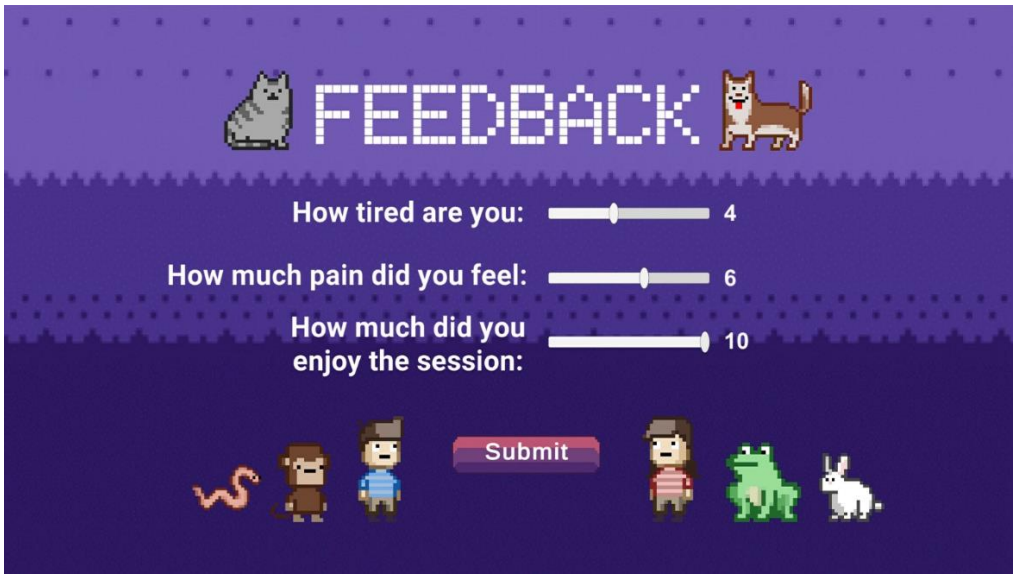


Figure 20. Feedback Page after the user ends the game

3.3.3 Firebase

Firebase is an online database on which user-specific information can be stored. The administrator can view and alter the full list of authorized users and new participants as they sign up, as well as access their passwords in case of login issues.

The data from our game is transferred onto a real-time database each time a user completes the minigame or saves the game. Data stored include:

- Username
- Physiotherapist's email
- Current scene
- Current in-game user position
- RPG character level

[10] PSD requirement 3

- Current XP
- Number of exercises completed
- Enjoyment, pain, and fatigue level from feedback
- Joint angles from the exergame

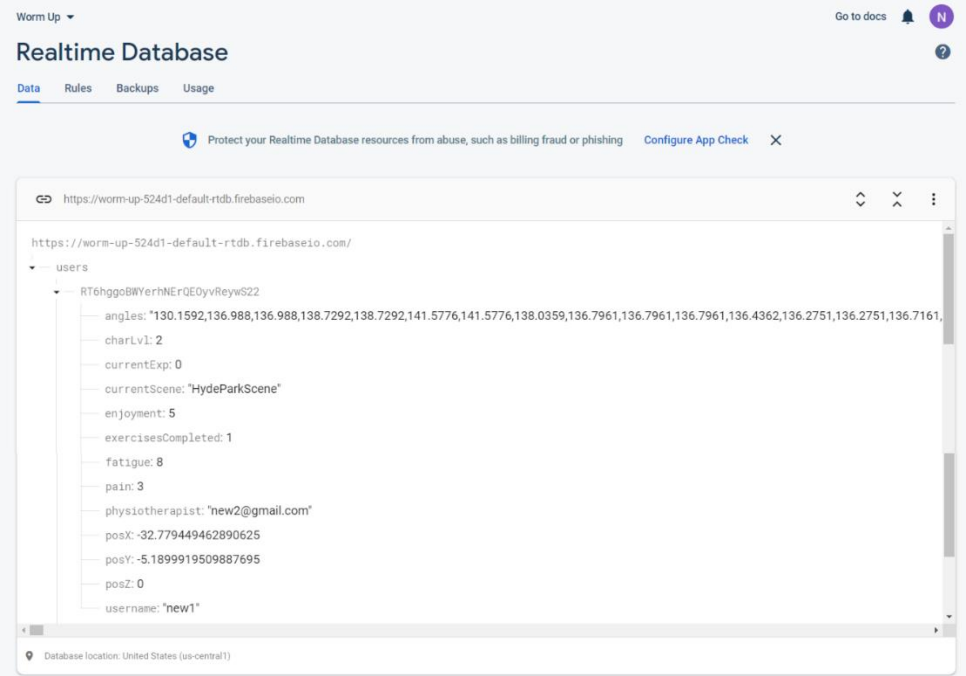


Figure 21. Firebase real-time database. Data recorded are stored in JSON tree format. The main branch divides into sub-branches corresponding to the name of each user, and each sub-branch divides further into the data values stored from each game.

3.3.4 Wix Website for Physiotherapists

Certified physiotherapists are granted permission to log into the Wix website to access the users' record. We used FLATLY [17] to automatically export the data for all users from Firebase into a CSV file stored on a OneDrive folder every 6 hours. A Python script then automatically generates plots of flexion angle against time, which is added to the Wix Website alongside the data from Firebase.

Figure 22. Patients record page

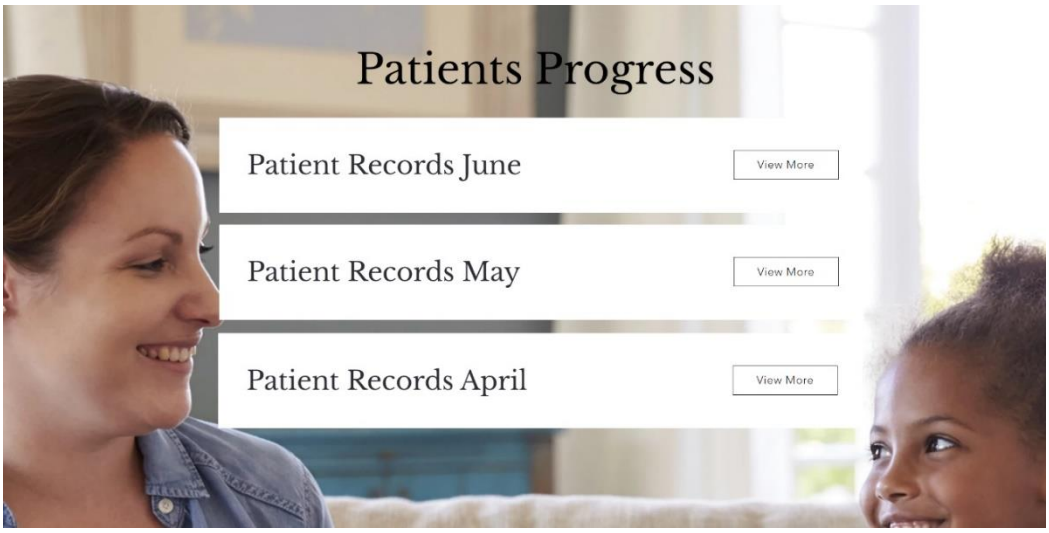


Figure 23. Patients Progress Menu

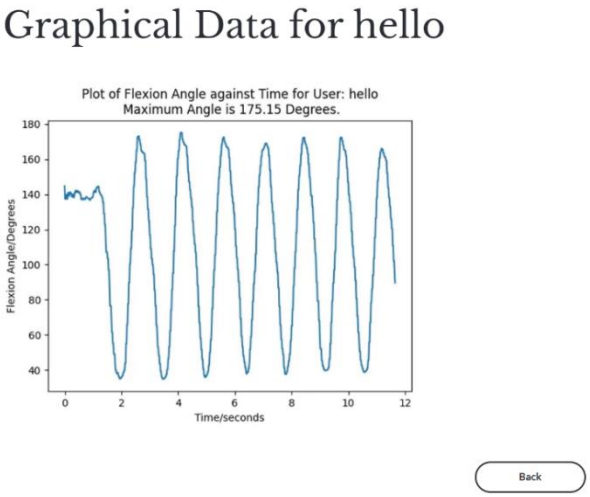


Figure 24. Graphical data for each user (Maximum flexion angle)

3.4 Hardware

There are no hardware elements to our design, however playing the game requires the 3D camera Orbbec Astra S, connected to a computer[11] on which the game will be played.

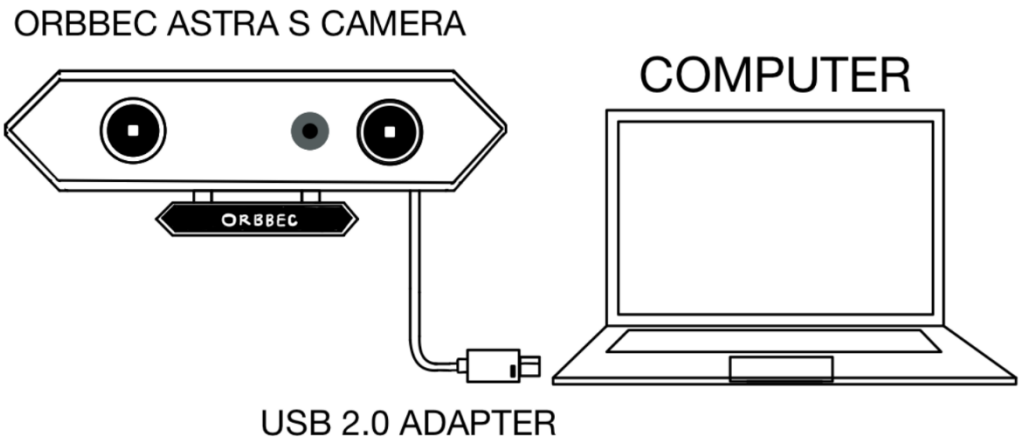


Figure 25. Connection between the Astra S camera and computer

[11] Either Windows or Mac works

4 Discussion

4.1 Evaluation of our design

4.1.1 Software Testing

4.1.1.1 Absurd Fishing

Software testing was segmented into two components: whether motions other than that expected would trigger the score count (repetition logging), and whether the angle of flexion captured remained consistent with user orientation (angle logging).

Experiment 1

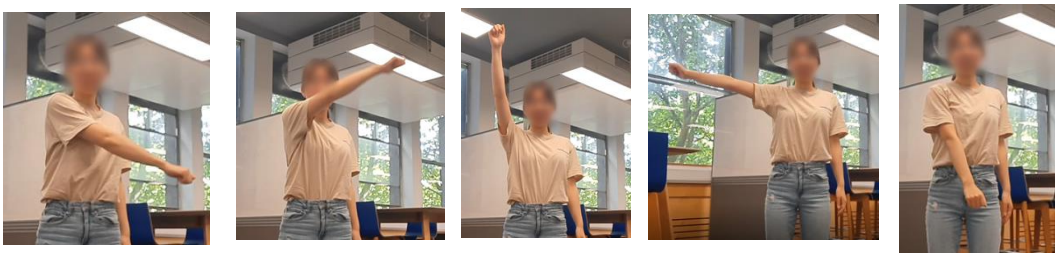
Hypothesis	Movements other than biceps flexion movement are performed will not cause repetition count to increase in the Absurd Fishing minigame.
Methods	1. Perform 20 windmill right arm circles. Note down the number of fish caught in the game. Compare both numbers obtained.  *Figure 26. Windmill right arm circle exercise* 2. Perform 20 repetitions of right arm bending exercise. Note down the number of fish caught in the game.  *Figure 27. Right arm bending exercise*
Results	No fish are caught in the Absurd Fishing minigame if we perform windmill circle exercise.
Discussions	We wanted to ensure that our motion capture model only responds to our target arm exercise. The results proved entirely consistent with our hypothesis, with no fish caught while incorrect movements are performed. This shows that our game is functioning as intended.

Table 10. Absurd Fishing game testing 1

Experiment 2

Hypothesis	Repetition count in the Absurd Fishing minigame will exactly match repetitions performed.
Methods	1. Perform 8 repetitions of right arm bending exercise (Figure 27). 2. Note down the number of fish caught. 3. Repeat step 1 and 2 ten times.
Results	For every bending movement performed, a fish is caught in the game. There were no notable inconsistencies between the number of biceps flexion performed and number of fishes caught in the game.
Discussion	The results proved entirely consistent with our hypothesis, with no irregularities noted throughout the repetitions. This shows that our game is functioning as intended.

Table 11. Absurd Fishing game testing 2

4.1.1.2 Nuitrack Model

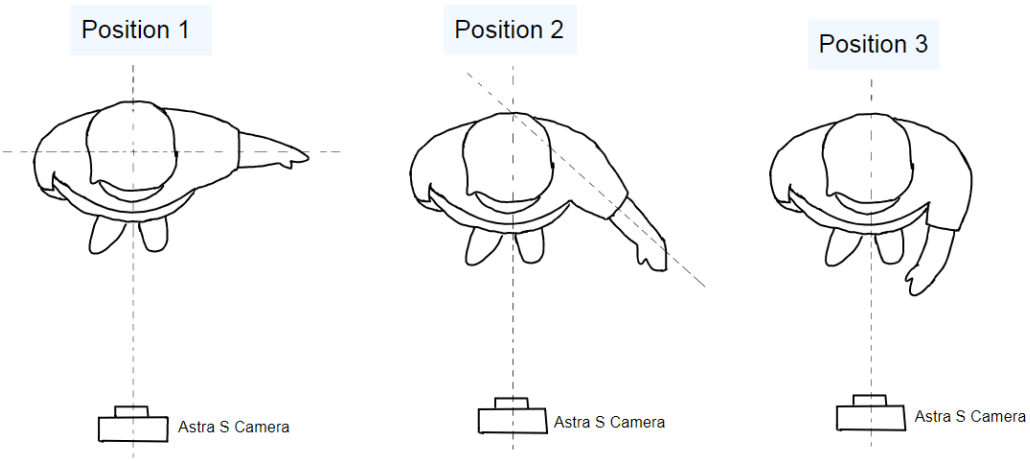
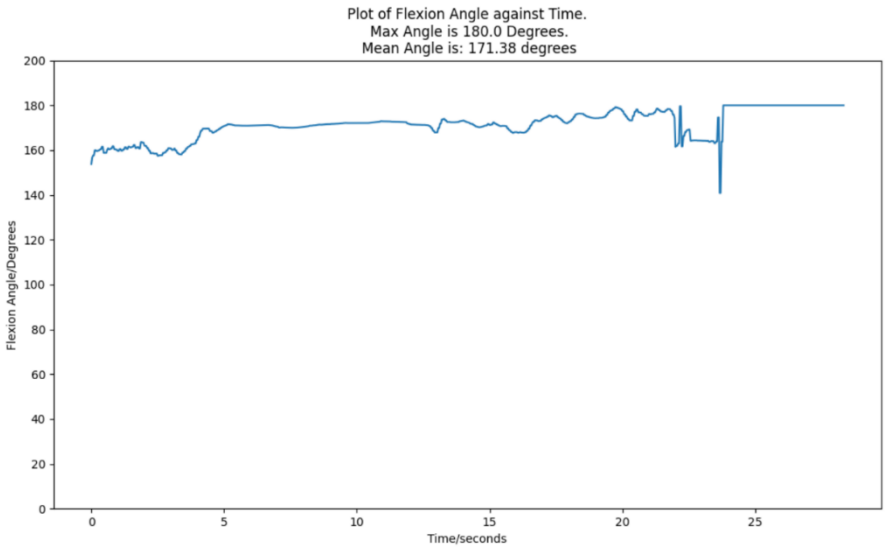
Hypotheses	When the user is standing parallel to the camera and performing the biceps flexion exercise, the angle detected by Nuitrack should be accurate and reasonable.
Methods	1. Straighten left arm and stand facing the camera (Position 1) for 10 seconds. 2. Slowly move to position 2 and 3, stopping at each position for 10 seconds. 3. Repeat steps 1, 2 and 3 with the right arm. 4. Plot the graph of flexion angles against the time, and find the mean angle measured.  *Figure 284. Top view for the orientation of the body with respect to the camera*
Results	The average angle measured is 171.38°. If the maximum angle of straightened arm is taken as 180°, the percentage differences for the angles measured using Nuitrack is 4.79%. 

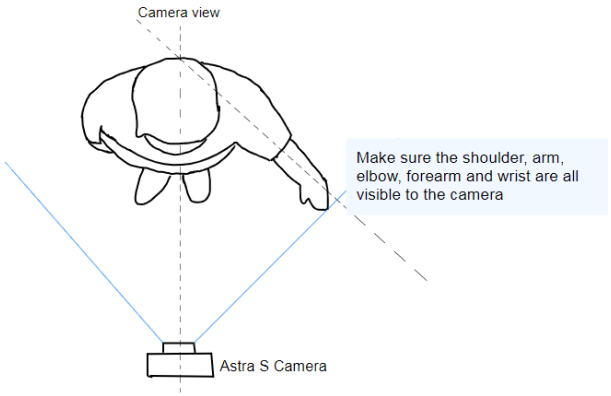
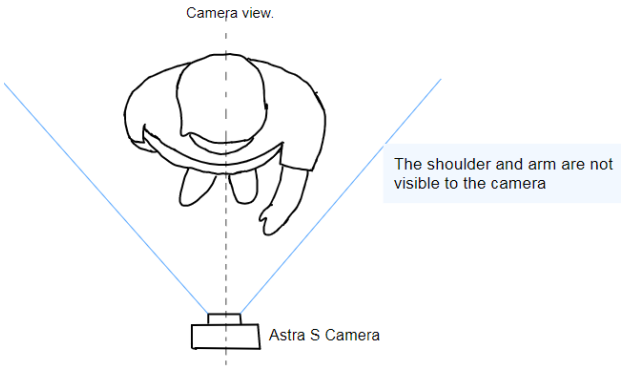
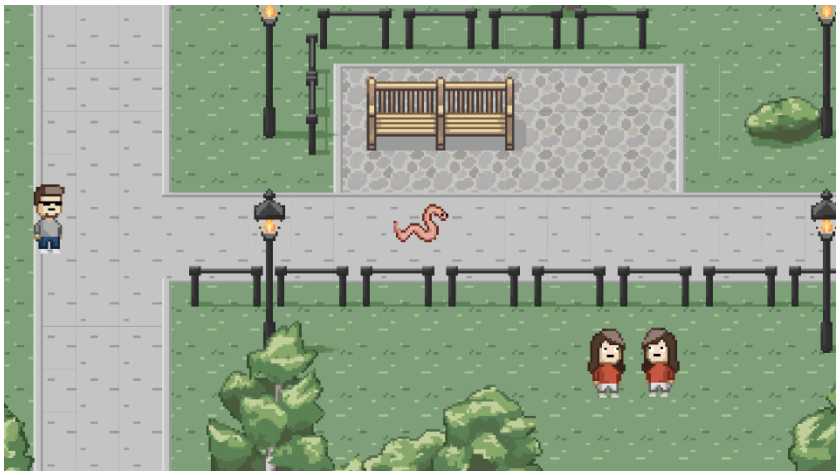
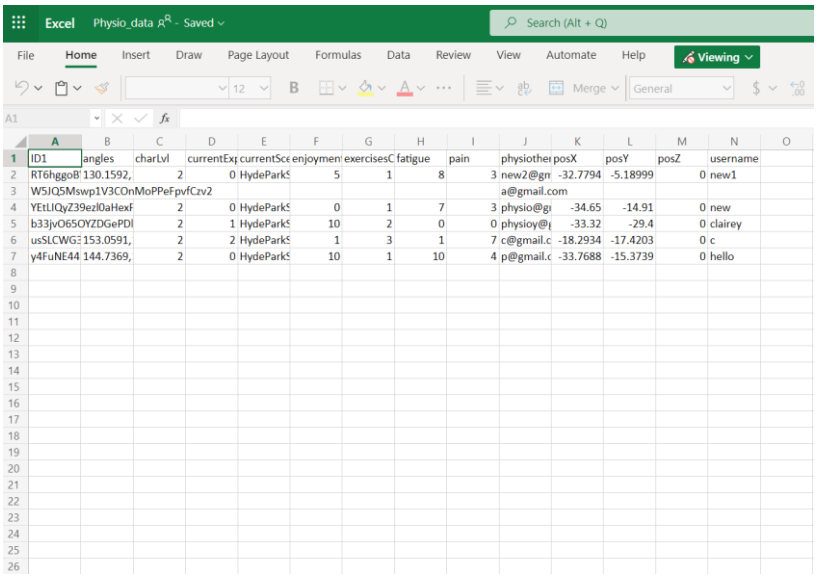
	Figure 29. Graph shows the angle of straightening left arm while turning the body to three distinct positions
Discussions	Our experiment aimed at ensuring that the Nuitrack model cosnsistently detects the joint angle accurately. The results showed a relatively low percentage error, consistent with our hypothesis and no irregularities were noted in Figure 29. However, the user is advised to perform biceps flexion exercises in optimal Nuitrack tracking position (Figure 30), so that our Nuitrack model is functioning properly. When taking data from this region, the percentage error was further decreased to 3.31%.  *Figure 30. Recommended position for the user to perform exercise*  *Figure 315. The user should not perform exercise as the wrist and forearm are blocking the camera view.*

Table 12. Nuitrack Model accuracy testing

4.1.1.3 Data Logging

Hypotheses	When the user saves and logs out of the game, all the in-game data as outlined in 3.3.3 should be uploaded onto Firebase's real-time database. Every 6 hours, an updated version of the database should be exported as a .csv file onto OneDrive.
Methods	1. Level up the user in-game by completing exercises 2. Move the user to a random coordinate on the map 3. Press the sign-out button and submit feedback information 4. Check on Firebase on whether all data are uploaded  *Figure 32. Character levelled up to a worm after completing one exercise, and moved to a random position on the map*
Results	All data required are uploaded successfully onto Firebase whenever the user presses the save button or signs out. When the user signs in again, the character is at the level and position when the user last saved the game. Every 6 hours, updated data from Firebase is found to be uploaded onto a .csv file on OneDrive.  *Figure 33. In-game data are immediately synced onto Firebase as soon as the user signs out*



ID1	angles	charLvl	currentExp	currentSce	enjoymen	exercisesC	fatigue	pain	physiother	posX	posY	posZ	username
RT6hggoB	130.1592,	2	0	HydeParkS	5	1	8	3	new2@gn	-32.7794	-5.18999	0	new1
W5JQ5Mswp1V3COnMoPPeFpvfCzv2									a@gmail.com				
YEtLIQyZ39ezl0aHexF		2	0	HydeParkS	0	1	7	3	physio@g	-34.65	-14.91	0	new
b33jvO65OYZDGePDI		2	1	HydeParkS	10	2	0	0	physioy@	-33.32	-29.4	0	clairey
usSLCWG3	153.0591,	2	2	HydeParkS	1	3	1	7	c@gmail.c	-18.2934	-17.4203	0	c
y4FuNE44	144.7369,	2	0	HydeParkS	10	1	10	4	p@gmail.c	-33.7688	-15.3739	0	hello

Figure 34. Firebase data are automatically uploaded onto OneDrive of a specific account as a .csv file

Discussions	Our experiment aimed at ensuring that in-game data are always synced onto Firebase's database every time the user finishes a session and uploaded every 6 hours onto OneDrive for physiotherapist access. The results proved consistent with our hypothesis, with no irregularities throughout repetitions.

Table 13. Firebase testing

4.1.2 User Feedback

Despite being unable to get in contact with a disabled-specialist school, we contacted two children to whom we described and showed our game concept. They were both intrigued and entertained by the storyline, so we continued in that direction.

4.1.3 Evaluation Matrix

Following our PSD, testing (section 4.1.1), Risk Analysis[12] and our user requirements (outlined in 1.2.1 and 2), an evaluation matrix was produced to assess the success of our project.

Requirements	Outcomes	Success?
Incorporates physiotherapy exercises	The absurd fishing minigame aims at getting the user to move and perform a specific set of repetitive movements. The game cannot be played if no movement is performed.	Yes
Motion tracking (3[13])	Users' movements are detected and tracked using the 3D camera, and it is used to control the game.	Yes

[12] Refer to Appendix B
[13] The numbers indicate the PSD requirement number

Data logging (3)	Users' data such as number of exercises completed, fatigue level, etc. are uploaded onto Firebase after each game therapy session.	Yes
Convenient platform for physiotherapists to access recorded data (4)	Physiotherapists can access the user's record after they complete the exergame through the Wix website after logging in.	Yes
User feedback (3)	There is a pop-up feedback system for the user to share their pain, fatigue and engagement level after each game session.	Yes
Quick and easy set-up (10)	3 minutes was spent to set up the hardware and log into the game.	Yes
Affordable (21)	Assuming the user has his own computer, the user would need to purchase an Astra S camera at the cost of £121, which is less than the limit of £2,500 stated in the PSD[14].	Yes
Light hardware (6)	The Astra S camera weighs 300g, which is below the 2kg limit in the PSD.	Yes
Game tailored to children (9)	The RPG is designed with cartoon pixel characters to appeal to children. The minigames are designed for children and do not contain any aspects that could be disturbing to them (loud noises, violent scenes, frightening pictures, etc.). The dialogs were kept simple and easy to follow while being entertaining.	Yes
Children can play the game independently, without the help from any supervisors (8)	We were unable to test our device due to limited time, however, we have ensured that our game has the following features so the children can play independently. • Simple language • Easy to navigate menu • Three clicks to start the game	Further user-testing required.
Enjoyable gameplay and interactive design (2, 9, A, F[15])	We were unable to test our final product on the children due to limited time, but we implemented: • Interesting RPG storyline • Fun, upbeat music • Rewards after completing exercises	Further user-testing required.
Short duration of games (D)	We were unable to test our device on the children due to limited time. Different children have different levels of concentration, and we need to record when they	Further user-testing required.

[14] Refer to Appendix E for definition.
[15] The letters indicate 1.2.1 requirement number

	become distracted or lose motivation while playing the game.	
User-specific therapy requirements	The physiotherapists will choose the number of repetitions for the exercise that the user is required to complete in a fixed timeframe.	Yes
Accurate collection of data (3)	The data recorded has an error margin of no more than 5%. In the Nuitrack software testing, the error margin was found to be 4.8%.	Yes
Data privacy (24)	The Firebase database is in “locked” mode to prevent unauthorized access. A link must be sent to the physiotherapists to access user’s record on the Wix website to again prevent unai without authorization.	Yes

Table 14. Evaluation Matrix

4.1.4 Future Improvements

From our evaluation matrix, our final design successfully met most of our objectives. With more development time, we would implement the following improvements:

	Improvements	**Outcomes**
Improvements to Game	Increase the options for background music so the user can select their preferred music choice	The ability to choose their preferred music will increase user engagement levels in the game.
	Design and update more minigames to the system	User will be able to play different games, allowing for a much greater range of treatment options and catering to a greater range of disabilities. For more abled users, these further increases diversity of game, increasing enjoyment.
	Add side quests to RPG	Allows the user to complete certain objectives without the need to perform exergames. This will add variety to the RPG gameplay and thus increase user engagement.
	Improve graphics and animations	Produces a more appealing game design that the user will feel more engaged with.

	Design more game scenes for the RPG storyline	User will be more engaged in the game as the gameplay and storyline will be more interesting and enticing. More scenes will also lengthen the playtime required to attain the human avatar, making it more suitable for users with longer-term disabilities.
	Allow further game personalization, i.e. the user will be able to use their avatar when playing the minigames	User will be more engaged in the game as they get more freedom to design their avatar.
	More pop-up encouraging messages during the game	Users will be motivated to continue playing the game and will not give up easily.
Improvements to Data Logging Platform	Fetch real-time data from firebase onto physiotherapist's one drive	When multiple exercises are performed, the data is not over-written.
	Set up a backend service that we securely control, and route all client access through that backend	Physiotherapists need to pass a Firebase Authentication token [18] to our endpoint so it can validate access using the Firebase Admin SDK.
	Upgrade the free Wix version to Premium to make the physiotherapist interface more professional	Custom domain, larger data storage space, no external ads from Wix

Table 15. Future design improvements and outcomes

4.2 Project Reflection

4.2.1 Team Core Values

Setting ground rules early, we prioritized effective communication, punctuality in meetings and prompt asking of support as needed, with a large emphasis on being encouraging and respectful to maintain a conducive environment. When designing our RPG storyline, we ensured that everyone's voices were heard equally as all of us generated two plot ideas before we narrowed down democratically.

4.2.2 Division of Work and Workflow

We split the group into subgroups to research disabilities and motion capture systems, based on interest in the topics. More team members were allocated to the Game Design team due to the volume and duration of the game's development process, in comparison to the Motion Capture and angle analysis teams. Our team structure was fluid and evolving, with team members pivoting to help others as their subprojects ended, such as in the BlazePose subgroup splitting to aid in the integration of the Orbbec camera with Nuitrack, developing a Firebase database, and a login page on Firebase.

Unable to work with John Chilton School as planned, we adopted a sequential Waterfall methodology [19] (Figure 30) by gathering requirements at the start of the project to create plans and resources.

4.2.3 Means of Communication

We met as a whole group weekly or biweekly, generally in person but remotely as needed. There were further subgroup meetings when more specificity was required. Prioritization of in-person meetings facilitated smoother and clearer communication. Meeting minutes were fastidiously recorded on OneNote, all individual work uploaded onto a shared OneDrive folder, and regular communication on the main WhatsApp group allowed every member to follow the progress of other subgroups for cross-collaboration. Usage of collaborative features of Google Collab, Google Docs, Canva and Unity greatly increased the integration of individuals' work.

4.2.4 Future Improvements

Despite an open and encouraging team dynamic, there are learning points for future projects. We could make weekly written bulletins of progress and challenges from each subgroup to concisely communicate progress and facilitate manpower redistribution. We would use an alternative platform called Slack in place of WhatsApp to capitalizing subchannel feature. Creating a written agenda prior to meetings would facilitate discussion and ensure preparedness. Usage of services such as When2meet would greatly facilitate arrangement of irregular meetings quickly accounting for each member's timetabling conflicts.

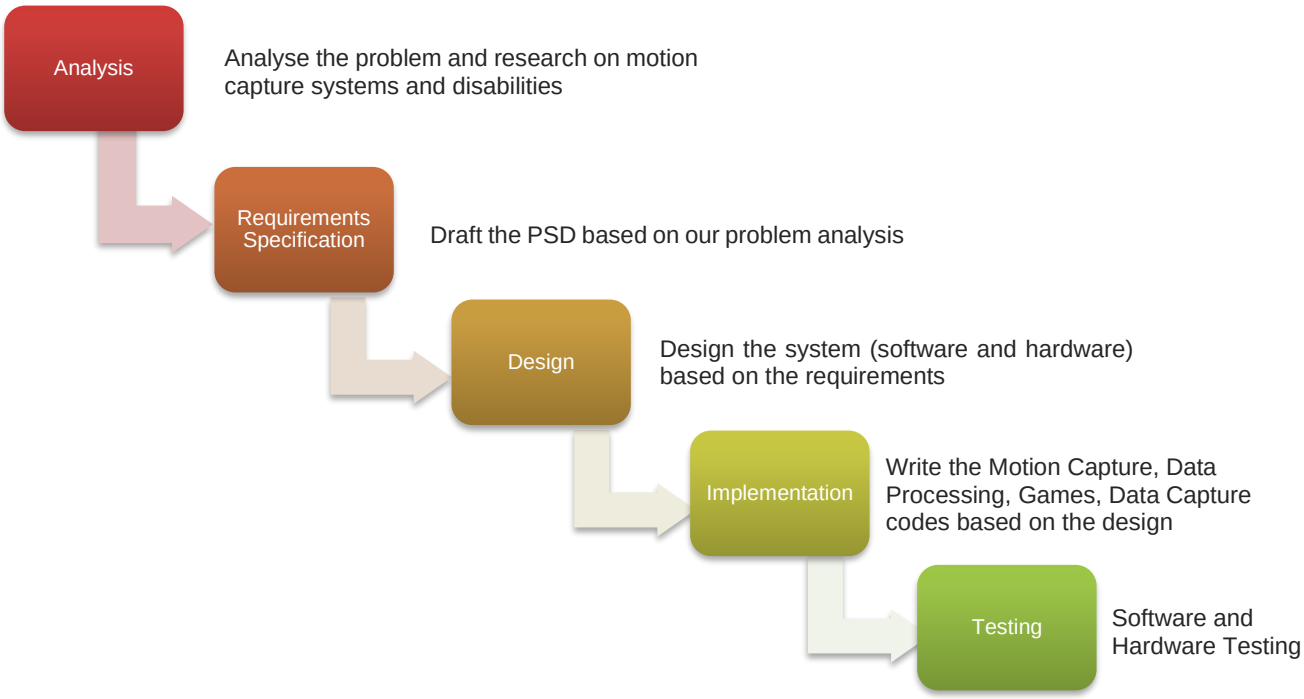


Figure 35. Waterfall methodology

5 Conclusion

Our project's main aims to both increase patient retention rates and out of session activity as well as provide insightful data to physiotherapists have largely been satisfied. The combination of classic RPG gameplay interwoven with a monitored minigame provided a good balance between entertainment, physical stimulation and progress tracking. As motion capture technology progresses, as well as game development engines becoming more accessible and cross compatible, there will be even more space for the growth of game-based home therapies. Current drawbacks of the design of limited minigames can be added to cater to a much larger range of disabilities. These technologies show a promising solution to challenges of out-of-session therapy, providing better monitoring and forecasting of patients, and allowing for earlier and more customized care.

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Appendix A – Project Management and Gantt Chart

Our team, supervised by Dr Ian Radcliffe, consists of 10 members. We were divided into sub teams, to work simultaneously on multiple aspects of our project. Everyone contributed to the PSD writing, final report writing, and poster design. The main roles for each member are as follow:

Arinjay Mishra

- Project manager
- MATLAB and Python code developer
- Nuitrack middleware research
- Angle data processing

Annie Szeto

- Sensors background research
- Unity research
- Game graphic designer and animator
- PSD writer

Claire Zhang

- Liaison with the supervisor and technician
- Minigame developer
- Sensors and motion capture system research
- Scribe
- Unity research

Emma Le Gousse

- Disabilities research
- Survey developer and liaison with external physiotherapists
- Unity research
- Poster editor
- PSD writer
- Report writer

Gloria Sun

- Disabilities research
- Liaison with external physiotherapists
- Liaison with the supervisor and technician
- Treasurer
- Game graphic designer
- RPG developer
- Login page developer
- Poster editor
- Firebase research and implementation

Helen Elmslie

- Disabilities and exergames researcher
- Scribe
- Unity research
- Minigame developer
- Poster editor
- Report writer

James Liu

- Sensors and motion capture system research
- Minigame developer
- Motion capture model developer
- Data logging platform developer

Nabeel Azuhar Mohammed

- Disabilities and exergames researcher
- RPG developer
- Interviewer
- Unity research
- Firebase research and implementation

Yui Harayama

- Sensors and motion capture system research
- Liaison with external physiotherapists
- Firestore research
- Data logging platform developer
- Motion capture model developer
- Report writer

Zhi Yan Hee

- Sensors and motion capture system research
- Firebase and Nuitrack research
- Motion capture model developer
- Report writer

Below is the Gantt chart we followed to complete our project:

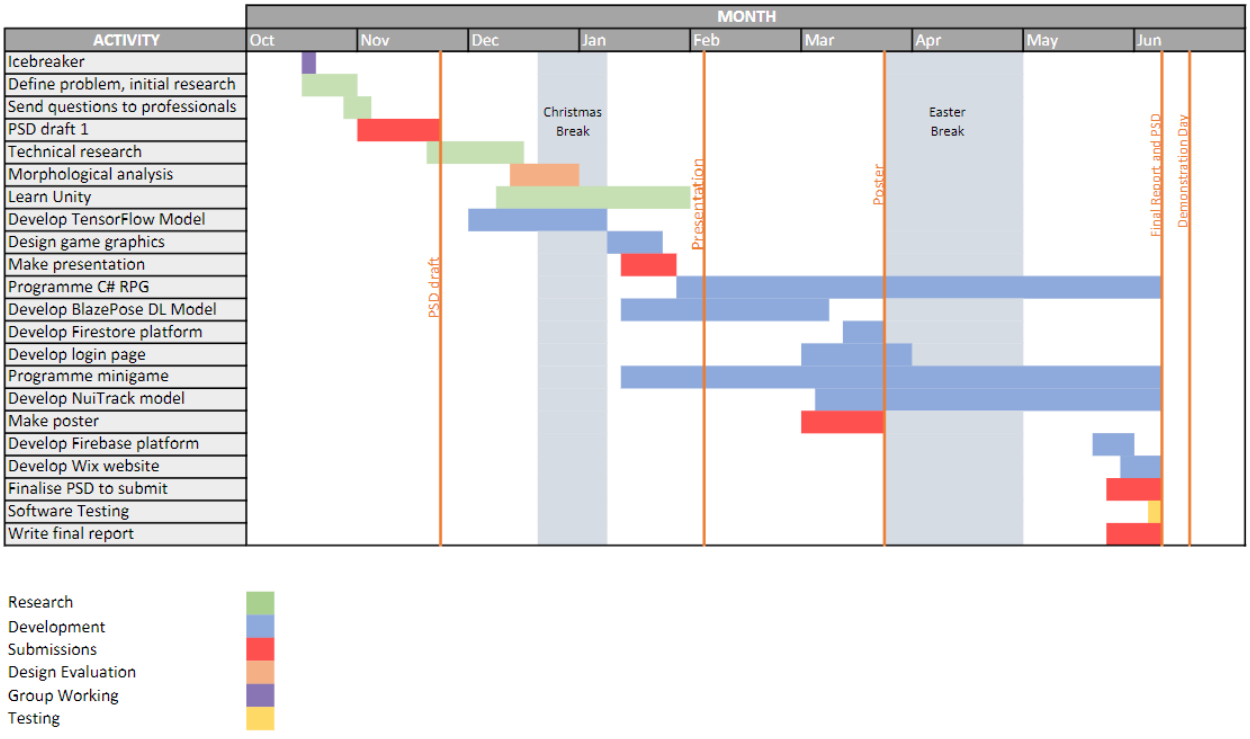

Figure 36. Gantt chart

Appendix B – Risk Management

Risk Analysis

Assembly	Failure & Effect	S1	O1	D1	RPN before	Preventing measures	S2	O2	D2	RPN after
Flashing lights from monitor screen	The game or screen may malfunction and exhibit rapid flashing lights, causing discomfort or perhaps triggering epilepsy due to the varying disabilities of the users,	6	2	3	**36**	Consult a photosensitive epilepsy expert to gauge whether the game would be harmful.	5	2	3	**30**
Motion Tracking	The user may accidentally hit any obstacles around them in the room when doing triceps extension exercise.	3	7	7	**147**	We would recommend having a free space of 2 m^2 around the user when playing to minimise the chances of contact with objects. Physiotherapist is encouraged to visit the place and provide advice on the size of the space. We would also recommend the presence of a supervising adult when children are playing to lower the risk occurrence and severity.	3	4	3	**36**
Excessive Gameplay	Users may get addicted to the game and excessively complete the exercises, which may lead to extreme fatigue and muscle injuries.	2	7	4	**56**	The physiotherapist can set a suitable timer for the user so that when the allocated physiotherapy session has ended, the game will automatically terminate.	1	2	3	**6**
Database Storage	Firebase may experience a failure or service disruption for some time where the user's data will no longer be saved. A bigger failure of the database may cause the loss of saved data. This can impact the progress tracking of each user.	1	2	3	**6**	Check and monitor the functionality of the servers over a period, such as 6 months, testing it with data overflow and high user traffic.	1	2	1	**2**

Assembly	Failure & Effect	S1	O1	D1	RPN before	Preventing measures	S2	O2	D2	RPN after
Loss of function of the gameplay	The camera may not be properly connected to the computer, which means the physiotherapy session may not be recorded.	1	4	2	**8**	A warning will pop up and the game cannot be played if the camera is not properly connected, so the user is aware of the issue. We will provide user manual for the user to connect the camera to the computer. We will also provide technical support if the camera is not compatible to the device used.	1	2	1	**2**
Misdiagnosis due to light interference	Too bright or too dark an environment may lead to deterioration of video graphic, and Nuitrack may not be able to detect some of the user's motion.	1	5	6	**30**	User is advised not to place the camera under bright light source. The user is advised not to play the game with light off. A warning is displayed on screen if the camera cannot detect the user. All detailed guidance will be provided in the user manual.	1	3	1	**3**

Table 16. Risk Analysis

Appendix C – Ethics

- **Respect for colleagues**

During the meetings, we ensured that everyone had a chance to voice their opinions and implemented a zero-tolerance approach to discrimination against anyone in our group. As our team came from different cultural backgrounds, we carefully reviewed our opinions to avoid unconscious bias. We distributed the work evenly, and constantly reviewed our progress. Members of the team were always welcome to choose which work they wanted to be involved in. Support and help for those who may be struggling were always offered in our group chats and during our in-person group meetings.

- **Social responsibilities**

Our product aim is to make the at home physiotherapy session more enjoyable, rather than the typical prescribed physiotherapy exercises. The product aims to encourage the users to follow their physiotherapy exercises plans, and to improve the rehabilitation progress. We adapted our product such that users can avoid overexercising and extreme physical and psychological fatigue.

- **Non-discrimination**

As our project is targeting children with disabilities, we have researched and understood the user's needs thoroughly. We made sure to use inclusive language when referring to our users.

Everyone can play the games, regardless of sex, race, ethnicity. We have designed different levels of difficulty for our game to cater for our users with different severity of disabilities.

- **Legality and respect of Intellectual Property (IP)**

During our product development phase, we ensured to give credit to any sources of inspiration and reference the resources we have used using IEEE style (References). We ensure that we have not used any copyrighted background music or other's work to be included as part of our product. For example, we did not copy directly the BlazePose Python code from the sources, however, we learnt and modified the code so that it can be implemented in our product. In addition, none of our product was made for commercial purposes: we in no way intended to gain monetary profit off our ideas, or anyone else's.

- **Confidentiality**

Our product involves handling of user's data, and this recorded data should not be accessible to anyone without authorization. In accordance with the General Data Protection Regulation, only the patient and any other entity such as the physiotherapist to whom the patient has given a clear consent to the use of health data can access and process health data. Our product includes a privacy policy in the terms and conditions that elucidates to the user that video data from the exercises will be stored and processed, as well as that the processed data will be sent to physiotherapists for analysis.

Appendix D – Bill of Materials

This is the total amount of money we spent whilst doing our project.

Item	Quantity	Supplier	Date of Purchase	Use	Cost (£)
A. Orbbec Persee Camera	1	Orbbec	19/01/2022	Motion tracking device	239.99
B. Body Tracking SDK	1	Orbbec	19/01/2022	Motion Tracking	74.99
C. Shipping fees for A and B	1	Orbbec	19/01/2022	-	89.57
D. Orbbec Astra S Camera	1	Orbbec	01/03/2022	Motion tracking device	121.78
E. Shipping fees for D	1	Orbbec	01/03/2022		75.09
F. RPG Course	1	Udemy	15/03/2022	To learn how to develop the RPG	23.00
				Total	624.42

Table 17. Bill of materials for the whole project

Our user would need to purchase the device below to play the game.

Item	Quantity	Supplier	Use	Cost (£)
Astra S Camera	1	Orbbec	Motion Tracking	121.78
Game subscription	1	-	Gamified Physiotherapy	30.00
			Total	151.78

Table 18. Bill of materials for the user wishing to use our projects

Appendix E – Nomenclature

Note: The abbreviations and terminology listed below are written in the order in which they occur:

RPG – Role-playing game, type of game in which players assume the roles of characters in a fictional story

XP – Experience of the player in-game

RGB Camera - Red Green Blue Camera: camera equipped with a standard CMOS sensor which captures coloured images of persons and objects

ROM – Range of Motion: Measures the distance and direction that a joint can move: E.g. The normal ROM for full extension and flexion of the elbow is 0-180°. (cite)

FPS – Frames per Second, frequency at which consecutive images are captured/displayed.

AWS – Amazon Web Services, division of Amazon that provides cloud computing platform and APIs. It is constituted of 3 main products: virtual machine service, cloud storage service and storage system

NUI – Natural User Interface, system for human-computer interaction that allows interface interaction using touch, voice, gestures. Eg. Voice assistants (Siri, Alexandra)

API - Application Programming Interface, software interface that connects two applications, computers. The API masks internal details of a system and only makes visible the portions relevant to the programmer.

GHUM – Generative 3D Human Upper Model

SDK – Software Development Kit, package of software development tools and programs for a specific platform, that facilitates the building of applications. It typically includes a compiler, code samples, documentation, debugger and testing tools.

UI – User Interface, point where human-computer interactions occur.

NPC – Non-Player Character, game character that is not controlled by a player

CSV - Comma-Separated Values, type of file that uses comma to separate values. Data is saved in a table

PSD - Product Specification Document, document that helps represent all the expected requirements for a product. In our case, the PSD has been defined during the Requirements Specification step of the Waterfall methodology.

Appendix F – Survey

We disseminated the following survey on social media and received a total of 43 responses. Out of the 30 individuals who responded that they only partially did or did not complete the prescribed physiotherapy exercises, 21 answered that they got bored after a certain time and 8 answered that they were too busy or forgot.

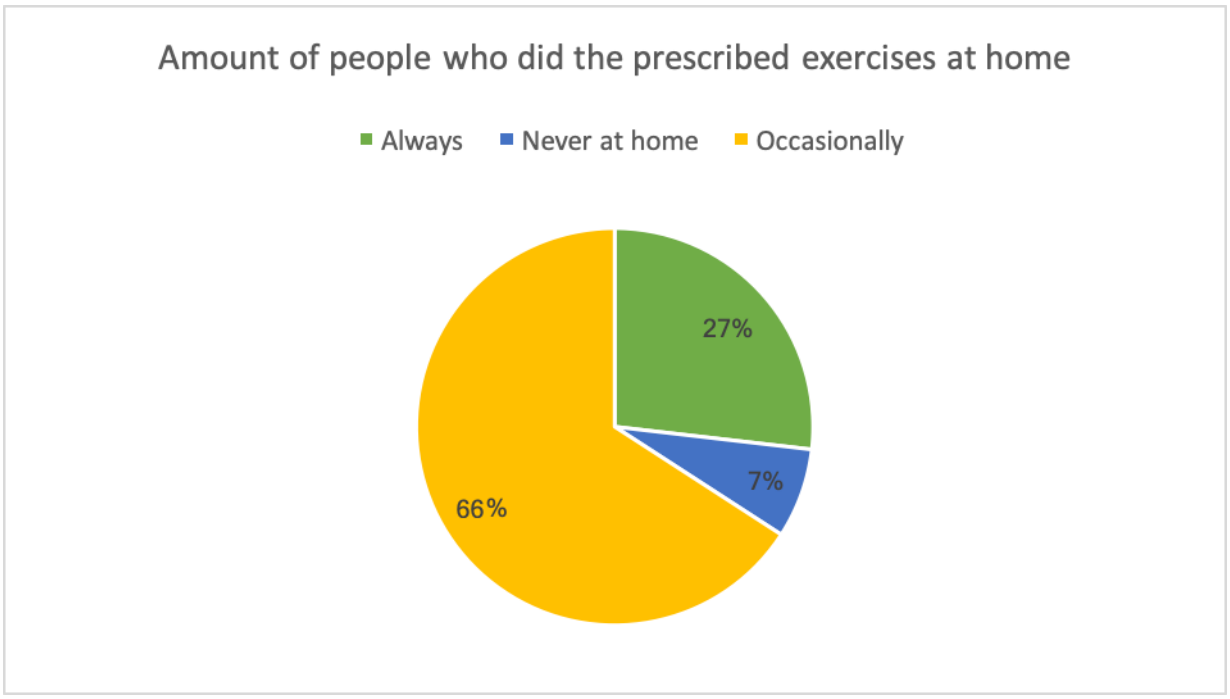

Figure 37. Pie chart shows amount of people who did the prescribed exercises at home

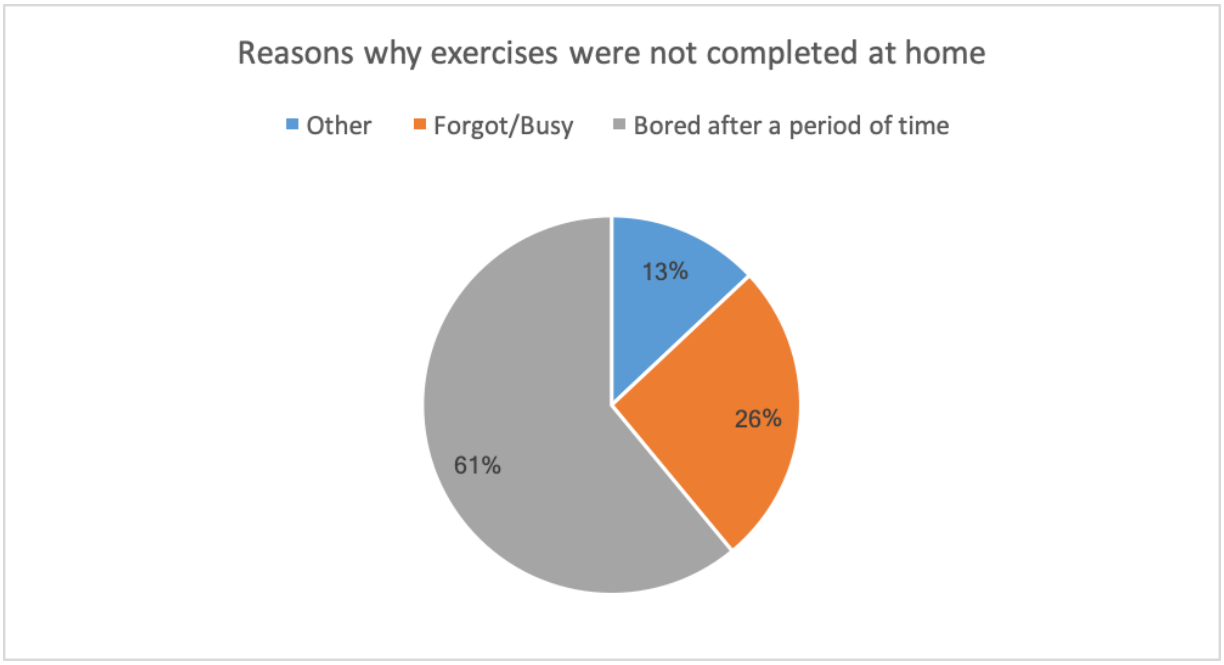

Figure 38. Pie chart showing the percentage for the reasons why exercises were not completed at home

Appendix G – Morphological Analysis

We generated our game concept by brainstorming ideas for the requirements of the game. To do this, we conducted a morphological analysis, and through consideration of necessary features and how this could be implemented in the game, decided by the user requirements, we generated 3 possible game idea concepts.

Key	
■	Concept 1
▲	Concept 2
●	Concept 3

Feature	Means					
Exercise	Minigames in a story ■	Non-related minigames	Character control ▲ ●			
Game Reward	Currency ■	Skins/ collectible items ●	Level ups/ experience system ▲			
Game Type	Shooter ●	RPG ■	Arcade	Platform ▲		
Dimensions	2D ■ ▲	3D ●				
Console	Laptop ■	PC ●	Xbox One ▲ Kinect	Wii	Nintendo Switch	
Controls	Keyboard ■	Mouse ■	Controller	Hand Gestures ●	Hand Gestures with others ▲	Voice control
Motion Detector	In built camera ▲	External camera ■	Wearable sensors ●			
Data Logging	Firebase ● ■	MongoDB ▲				

Table 19. Morphological Analysis: Game Idea Brainstorm

After having 3 chosen game ideas, we evaluated each concept using a decision matrix, by scoring each against the weighted, most important user requirement

Requirements	Weighting	Concept 1		Concept 2		Concept 3	
Engaging	5	5	25	4	20	4	20
Simple UI	4	4	16	5	20	3	12
Appropriate amount/type of exercise	5	5	25	3	15	2	10
Accuracy of results	3	3	9	3	9	5	15
Ease of data logging	3	3	9	4	12	4	12
Cost	3	3	9	5	15	1	3
TOTAL			93		91		72

Table 20. Decision Matrix used to decide on our final RPG concept

As concept 1 scored the highest, this was our chosen concept that we would develop.

We generated the storyline for the RPG by brainstorming ideas as a group and ranking by preference. Each of the team members were required to contribute at least one RPG idea. Then, each of us voted for the idea that we liked the most in the excel sheet. We each had 3 votes, ranking our preference from 1 to 3, where 3 is the most preferred idea. The highest score was to be our chosen RPG storyline. Details are shown in Table 21*Table* .

Put a '1' under your name to vote for a certain RPG idea. 3 votes ONLY.

Idea number	RPG Idea	Votes										Total Votes
		Arinjay	Helen	Gloria	Claire	Annie	James	Zhi Yan	Emma	Nabeel	Yui	
1	The player is provided with an empty landscape and the objective is to build the nicest neighbourhood. Player will complete physio prescribed exercises to earn currency which can be used to build improvements or speed up building time. Player can compare their world with friends for further gameplaying incentive											0
2	The player controls a character in a pokemon esque world where they have to complete battles with NPCs to become stronger. The player will then compete against gym leaders as well to become the world champion. The battles will be completed by performing the physio prescribed exercises				1		1					2
3	The player will control a racing car. The player is required to complete a set of prescribed movements shown on the screen in order to speed up the car. The more accurate the movements is, the faster the car will go. The game can be multiplayer or single player, and the best record is being saved and placed on the leaderboard!	1	2									3
4	The player will be in a game(mario or total wipeout style) where he has to get over obstacles in a course to win points and pass levels.Before each obstacle they would have to perform a prescribed physiotherapy exercise and depending on how well/how long they did it for they will have more power and complete the exercise therfore winning more points. They need a certain amount of points to pass levels and with each level they can change their character or the world they are playing in a bit.		3	1	2	3		1			3	13
5	Drum game. The user has to match the drum rythm (speed increasing or more complicated actions with higher difficulty) OR complete a set of exercises to get the chance to play											0
6	The character is a fighter cat who explores a forest world and encounters various random animals. The currency in this world is fish and the cat gets sent on quests. Minigame: fishing - extend elbow by stretching tricep to throw the fishing rod and bend again to bring it back	2	1				2					5
7	Balloon pop game. The user controls an on-screen target where the task is to pop the balloon of a specific colour. To do this, they must flex and extend their elbow (exercise prescribed by the physio.). This encourages accuracy, as they collect points in the form of stars (displayed onscreen) and lose stars if they pop a balloon of the wrong colour. The user can progress to the next level once having collected all their stars. More challenging levels might involve having a moving background (vs static) and the chance to 'unlock' different avatars (to replace the target), with the exercise becoming progressively difficult, i.e. user needing greater elbow extension to pop the balloon for further levels.							3				3
8	The player controls a character in a world and go on quests to fight battles against monsters (lore related). Gameplay wouldn't be an open-world rpg, so there will be a set path players must travel on in between cutscenes/dialogue. Exercises must be done to complete attacks to fight. To advance the story they must level up to the required level by completing sidequests (as to lengthen the story content so that it could cover the period of physio). Something similar to what ring fit adventure has.							2	1	2		5
9	...Where's my body? Protagonist slips into a coma and his soul slips out, game is played as his ghost. The ghost tries to repossess his body but is not strong enough yet, must progress through lesser bodies first: e.g worm --> frog --> turtle --> etc. ---> human. Easy to manipulate length of the game			3	3	1	3		2	3	1	16
10	Post apocalyptic mario and sonic at olympic games + hunger games type. Overlords have taken over earth and everyone must compete in olympic games/ sports to appease the overlords. The protagonist must try to win the games to gain freedom/ win for humanity. Could also be like a gladiator format but with sports to give storyline more longevity. An example game would be hurdles race, with patient having to do high knees. Could have non olympic sports like bowling as well. Rhythmic dancing could have sequences of moves.	3		2		2			3	1	2	13
11	Imperial student going into campus and getting their degree by fighting professors											0
												60

Table 21. Table showing how we vote to obtain our final RPG storyline

Appendix H – PEGI 7 Assessment Form [20]

Rating	Question	Content Descriptor	Yes/No
12	Moving images that encourage and/or teach the use of games of chance that are played/carried out as a traditional means of gambling(only answer 'yes' to this question if a 'yes' answer has been given to any of questions		No
12	Depictions of realistic looking violence towards fantasy characters		No
12	Depictions of non-realistic looking violence towards human-like or animal-like characters		No
12	Depictions of realistic looking violence of a minor nature on a human-like or animal-like character that does not result in any obvious injury or harm		No
12	Words or activities that amount to obvious sexual innuendo or explicit sexual descriptions or images or sexual posturing		No
12	Mild swearing and/or offensive language		No
7	Depictions of non-realistic violence towards fantasy characters		No

7	Depictions of non-detailed and non-realistic violence towards non detailed human-like characters		No
7	Depictions of non-realistic violence of a minor nature towards a human like or animal-like character		No
7	Depictions of implied violence to humans where the actual violence is not shown		No
7	Depictions of non-realistic violence set in a child-friendly setting or context.		No
7	Pictures or sounds likely to be scary or frightening to young children		No

Table 22. PEGI 7 Assessment Form

Appendix I – Animation Design Process

Figure 39. Breakdown of the animation of the characters

To appeal to younger audiences, the characters are designed to be animals. The walking and Idle animations of every character were hand drawn on Procreate, (e.g. as shown in Figure 39 - walk cycle sprite sheet) and exported as PNG files, which then could be uploaded directly onto Unity as animations.

Appendix J – Product Specification Document

No.	Aspect	Objective	Specification	Test Method
1	Functionality and Performance	**Maintaining engagement of the patient in out-of-session physiotherapy**	Achieve a high user retention rate of 65%[1] as a metric of user engagement.	Monitor and document the user retention rate, a common Key Performance Index for user engagement[2,3], thereby measuring whether the patients are meeting the necessary weekly targets prescribed by the physiotherapists. Frequency and duration of user sessions will be tracked over a month, for 10 users, with cohort retention rate being calculated as percentage of users keeping to their prescribed schedules for the testing period.[4]
2		**Enjoyable gameplay and interactive design**	Games must be entertaining enough for users to stay motivated in their exercise routines continuously and play the games as prescribed.	Prior to product release, collect game engagement feedback from 10 users, playing different games: Rating out of 10 before and after each test session along with qualitative feedback, to gauge how users feel.[5]
3		**Accurate collection of relevant data**	The device must be able to accurately obtain measures of Range of Motion (RoM), flexion and extension angles of joints, as well as record users' self-recorded values for fatigue and engagement[6]. The data collected for motion must have a percentage error of less than 5% across the different measures compared to those measured by the physiotherapist. *Limit on RoM: for flexion/extension: 0-180 degrees	Test the device alongside the measures taken by physiotherapist's, calculating the percentage error across the different measures for a sample size of 30 sessions. Compare repetition-counting by software with video footage of the session.
4		**Convenient platform for physiotherapists to prescribe exercises**	The device must provide the physiotherapist with an intuitive interface to select the exercises, frequency, volume, and intensity to best suit the user.	Task a physiotherapist with prescribing an exercise routine of 6 exercises for 10 users on the platform and rating their experience on a scale from 1 to 10 (wherein 10 stands for immediate understanding of interface upon interaction) along with written feedback. Minimum mean result – 8/10. Furthermore, the system must be optimized such that the physiotherapists are able to prescribe the exercises within 8 'clicks'[7] on the interface.
5		**Convenient platform for physiotherapists to access recorded data**	The device must supply an intuitive platform to access user's data (exercise metrics) from their previous sessions.	For data access, task a physiotherapist with accessing a user's data from 10 different dates on the platform and rating their experience on a scale from 1 to 10 along with written feedback.
6	Size and Weight	**Fit within an average household room**	The window for movement that the device will capture should take no more than a 2.5m by 2.5m[8] square, so that the entire body, including arm span fits in frame whilst staying in range.	Measure length, width, and height of detection region of device.
7		**Weight**	As the device is to be set up, it should weigh less than 2kg[9], so that the users are able to transport the device as necessary.	Measure weight of device
8		**Dimensions**	Maximum size: 40cm x 35cm x 16cm (l x w x h)[10], so that it is convenient to put away and store.	Measure length, width, and height of the device
9		**User Interface (UI) should be straightforward and clear enough to be used without supervision of parents/guardians**	Simple language should be used and the process of setting-up should be clear and concise. Gameplay in turn should not require high-level inference skills.	Collect game feedback from 30 users, rating their experience on a scale from 1 to 10, with 10 corresponding to extreme ease in use of the interface, with a minimum average of 8/10. There should be a maximum of 5 'clicks'[7] to start the game (including calibration) which does not allow the user to be put off before playing.

10	**Usability, Interface and Ergonomics**	**Set-up procedure should be straightforward and quick while ensuring accuracy in measurement**	In order to ensure accurate data management and prevent misdiagnosis based on incorrect readings, accurate setup is vital. A fast and simple setup procedure thus in turn minimises the opportunity for such errors to occur. Ensuring being in the camera frame and logging into the game should take less than 5 minutes, as an average physiotherapy session length is 30 minutes to an hour[11], and it would be discouraging to start after longer.	Test setting up with a sample of 30 people and measure how long it takes for exact session set-up and calculate the average.
11		**The device should function in most households, regardless of location or season**	The device must function across a range of temperatures that may be typical of a household, and the range of 0-40 degrees[12,13] as well as humidity ranging from 40% to 75%.[14,15]	Test the device in a lab room and slowly increase and decrease the temperatures, and then humidity to the maximum and minimum of the ranges. Check if the device is still working in these conditions for a sample size of 10.
12	**Environmental**	**The device should be resistant to splashes, such as liquids and bodily fluids (sweat & tears)**	The device should achieve an IP54 rating of dust and splash resistance.	Test if the device is working under IP54 conditions[16], with a sample size of 10. Test by exposing the prototypes to a fluctuating spray for 10 minutes and by showering dust onto them and seeing if it enters any parts where it ends up harming the functionality after 8 hours.
13		**The device should perform under the various lighting conditions that may be expected in households**	The device should be able to support the designated permissible percentage errors for a range of luminosities; 20 to 1000 lux[17]depending on the amount of sun outside and how big the windows are (the natural lighting is also often compensated by artificial lighting) that may be expected in a household. The device should further be able to supply a prompt if ambient light conditions are insufficient to record data effectively.	Test a sample of 10 prototypes within the range of 20 to 1000 lux to decide if device supports maximum percentage errors of measurements. Test if the device supplies the prompt that the surroundings are too dim or too bright when the lighting level falls outside functional range.
14		**The device should be durable enough to undergo transportation requirements**	The device should be durable enough to withstand normal parameters of rough handling.	Conduct a 2m drop test of the device in its packaging, and alone to simulate a household accident and examine the device damages (powering, data capturing, data entry). Test on concrete, wooden floors, carpet and grass. Repeat 10 times.
15	**Portability**	**Epilepsy and Photosensitivity Triggers**	Gameplay should avoid flashing images flickering faster than 3 times per second especially if they are red[18] but, if necessary, include an early and clear warning prior to displaying such components.	Download a highly qualified software to perform epilepsy tests on the game in accordance with the guidelines on flashing and spatial patterns
16	**Safety & Security**	**Child Friendly Games**	Games' content should be suitable for users (7-19 years old) and not contain violent scenes but can have some implied or non-realistic violence.	To cater for the lowest age range (7), verify that the games satisfy the PEGI 7 requirements[19]
17		**Product Should Not Incentivize Overtraining**	Repetition count for each exercise should be at the number prescribed by the physiotherapist and users should not be excessively fatigued or in pain after a usage session.	Set a maximum repetition count at the beginning of each exergame equal to that prescribed by the physiotherapist. Additionally, at the end of each session, user should input a score of pain and fatigue corresponding to the standard Visual Analogue Scale of pain and fatigue they are familiar with from in-clinic sessions.[5]
18		**Long-Term Use Electronic Device**	The device should function for at least three years while maintaining the accuracy of device performance outlined earlier.	Subject the prototype to Accelerated Life Testing by subjecting it to an excessive amount of stress, strain, temperature, and pressure. Then check that measurements are accurate and if the error margins are the same.

19	Life, Reliability and Maintenance	**Database and Server Maintenance**	Servers of the game must be maintained over time to prevent data overflow and handle user volume.	Check and monitor the functionality of the servers over a period, such as 2 months, testing it with data overflow and high user traffic.
20		**Maintenance of Device**	The device should be able to handle any software patches and if any updates are performed, then all the devices new and old should immediately be brought up to date.[20]	Test 3 updates of varying size (from minor changes to version updates) to check if they load on devices already logged into the game.
21		**Price-Accessible at a Household Level**	Should be sold at a price point that does not compromise quality of materials while maintaining a profit margin for distribution costs. On the market existing games are available from £2.5k[21], the cost of our product must stay below that amount so that it can be competitive on the market.	Check cost of materials and assembly and ensure price does not exceed 175% of the cost and that it is less than £2.5k.
22	Cost	**Clear instructions and safety guidelines**	The product should be shipped with an information booklet clearly and thoroughly demarcating the usage parameters and safety guidelines necessary for correct usage of the product.	Collect feedback from 30 users to see how easy it is for them to understand the instructions with a 1-10 rating system.
23	Legal and Regulatory	**Intellectual Property Rights**	The device should follow industry copyright standards and existing Intellectual Property guidelines, both for the physical product and the gameplay.	Adhere to this UK intellectual property guidelines[22] and check existing patent database for potential infringement.
24		**Privacy**	Users recorded data and footage of sessions should not be accessible to anyone without authorization. The product should follow the GDPR[23] the protection law focusing on data protection, security, and accountability.	Ensure strong cybersecurity to prevent hacking such as two factor authentication and limiting access to private data. Data should not be accessible if another user logs in and tries to access the data. Have a data privacy policy for the user, physiotherapist, and the employees.

Appendix K – Instructions Sheets for ‘Worm Up’ and ‘Absurd Fishing’

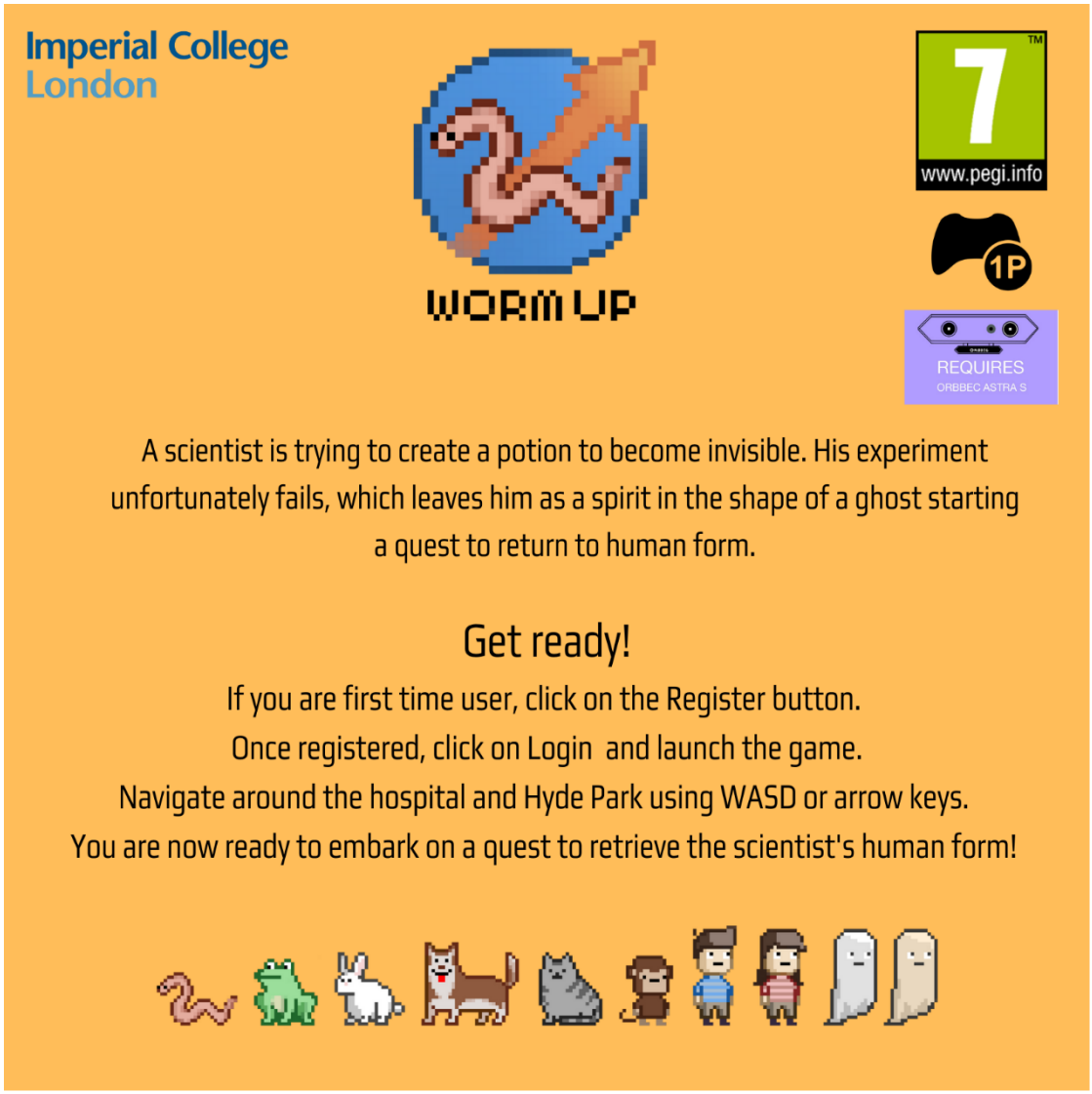

Figure 40. Instructions Sheet for Worm Up RPG

Figure 41. Instructions Sheet for Absurd Fishing minigame