EXPLORING THE TECHNOLOGICAL BENEFITS OF VR IN PHYSICAL FITNESS

by

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ABSTRACT

NEELESH MUNGOLI. Exploring the Technological Benefits of VR in Physical Fitness.
(Under the direction of DR. AIDONG LU)

In the contemporary world, we can find a plethora of fitness solutions ranging from personal training to mobile application-based training. However, any given solution fails to provide a balance between the benefits of personal training and the cost efficiency of web and mobile-based solutions.

To contribute to this topic, we conducted an extensive survey for this project. Our research included a survey of 45 people to gather their feedback on the adaptability of VR. The survey results indicated that first responders and millennials would be among the early adopters of VR technology. Secondly, we reviewed ongoing research in the field of VR. Lastly, we looked into the ten most popular commercial applications for personal training on different platforms and assessed the features they offered.

The VR Gym we developed consists of around 20 exercises categorized by body parts such as back, legs, arms, and chest. The user's workout data is recorded and can be used to replay the user's history.

Keywords: virtual trainer, VR.

ACKNOWLEDGMENTS

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CHAPTER 1: INTRODUCTION

For many decades now, personal training has been embraced by people. Studies have confirmed [13] the benefits of personal training, such as offering faster and better results, reducing the chances of injury, and overcoming plateaus. Studies on devices such as HTC Vive and Kinect have indicated the potential of these platforms to improve fitness [10].

Games such as beat saber and boxVR are very popular with the masses, but the availability of full-body motion tracking in VR has enabled games such as VRchat to gain a considerable following. The major offerings of platforms such as VRchat are hyper-realistic environments and the ability to play as a character.

A personal trainer tends to provide more personalized feedback as compared to the feedback provided by current applications on devices like the Microsoft Kinect and Nintendo Wii.

We created a VR gym game prototype. Some of the features of our game are: i) About 20 exercises categorized by back, arms, legs, and chest. ii) The user's motion data is recorded during the workout and can be used to replay the user's action.

CHAPTER 2: SURVEY

In this chapter, we review the related work on VR/AR technology for creating virtual environments, virtual training, and interactions in VR. We survey the current most popular commercial applications on different platforms.

2.1 Survey of Research Papers

We review the related work on virtual training and its efficiency and look into the benefits of the virtual environment for training.

2.1.1 Virtual Training in AR/VR

This section describes related work in the field of VR and AR. Previous research projects have explored multiple facets of virtual training. Some of the works have a virtual environment setting with different devices like Oculus, Vive, and Hololens. A study of these papers has been useful in understanding VR and AR capabilities for virtual training.

Virtual training [10] extends the use of a virtual environment for hand hygiene. The prototype system developed using a virtual environment gives feedback about microorganism transmission among healthcare workers. Different parts of the environment, such as the patient's behavior, are varied for better training.

While still in its early stages, immersive environments have attracted the interest of many researchers. The systems developed utilizing the virtual and physical space. CAVE [12] provides the user with a virtual environment consisting of 3D projections on the walls of a room, floor, and ceiling to provide an immersive environment. It is used to provide people with a simulation of training in an offshore oil platform with multiple procedures.

VR is more suitable for training when compared to desktop-based solutions. For example, VR techniques were used to train medical students and novice surgeons to perform biopsies [30], which was followed by an evaluation study to test the effectiveness of this approach.

Jin et al. [24] presented a system that utilizes the skeleton tracking capability of Microsoft Kinect to create a system that provides real-time feedback for different data tasks and interactions, including personal training. Also, Hoang et al. [19] showed a similar virtual trainer for rehabilitation.

Furthermore,Yildiz et al. [32] presents a VR training model to integrate with a virtual and physical factory, which has been shown to have significant potential for efficient training in the industry. According to our knowledge, we are among the early efforts for developing virtual trainers for motion analysis in VR.

2.1.2 Interactions in VR trainer

Augmented reality(AR) and virtual reality(VR) are used to create virtual environments, allowing users to interact with other objects in real time [5] [14] [20].

We found three techniques for VR interactions to be especially valuable. The first technique uses a GUI based trainer [5] to restore proper breathing in patients with damage to their respiratory system. The user data is obtained from the pulse monitor attached to the patients is used to provide feedback and instructions to improve their lung capacity.

The second technique [31] presents an immersive visualization approach for investigating complex medical procedures. The final technique [4] proposed for endoscopy uses foot control instead of hands for some of the equipment, thereby replacing the need for a second doctor. The user study discussed the validity of the new procedure using a virtual environment. Overall, Some advantages of this technique have been demonstrated for intrusive procedures such as endoscopy.

Specifically related to the immersive environment, several recent studies have been performed, and the results are still mixed. Esmaeili et al. [14] focuses on creating a virtual environment to train users for various activities such as sports, martial arts, playing instruments, and acting. The authors compare the immersive training to traditional methods such as using 2D videos in a user study. It showed that immersive environments are more effective for certain tasks.

Recently, virtual collaboration among multiple users has been identified as one of the challenges [20]. Some advantages of immersive environments have been demonstrated, especially favorable to address spatial constraints and replicate the actions that are generally observed in other human interactions. Also, [22] and [23] supports the use of a virtual environment for the development of training simulations. Our work also provides users with an exercise history for analyzing and review.

2.1.3 Effectiveness of training in VR

VR creates sensory experiences that may include sight, touch, and hearing. VR allows the users to train in realtime under various scenarios [34]. A similar system [18] for Endotracheal Intubation replicates the real physical setup of the procedure and can be used to improve user interfaces and design choices [34]. Furthermore, [39] [17] compare training in VR for baseball and golf against traditional methods. Overall, Some advantages of immersive training have been demonstrated, especially favorable for sports training.

Studies of performance in VR using the recent HMDs [27] , have shown no difference with expensive cave-style environments and in alleviating boredom, fear, and obtain a more immersive training experience. A similar system [33] aims at using virtual reality to create a fitness application. The system provides features to keep the user motivated and monitor the training history. The user's motion is captured using Microsoft Kinect and displayed in virtual reality with the help of Oculus Rift. Our system has similar methods to assist training in VR.

2.1.4 Virtual applications for training

Kouris et al. [25] presented a system to help older adults suffering from balance disorders. The system uses an AR headset to monitors the person's activity throughout a day and provides the user with a real-time virtual 3D augmented reality avatar that is projected in front of him and provides real-time guidance for the correct exercise execution.

A similar system [36] proposes training for medical procedures such as thoracentesis, lumbar puncture, bone-marrow puncture. The user trains in a 3D virtual scene, and his action data is put into the database for analysis. Moreover, [16] suggests the use of virtual environments for a variety of purposes, such as cognitive training in the elderly. Nguyen et al. [29] and Vaughan et al. [35] propose VR applications for disaster response and recovery.

Similarly, Chang et al. [9] developed a system for virtually training gynecology students. The training modules identified key challenges and opportunities, followed by a user study evaluating conventional methods using LCD with virtual training using HMD.

The system [37] highlights a training system followed by a user study to determine the improvements based on the legacy training procedures. The system compared the user centric approach to adaptive training, where the style of training dynamically changed based on the user's performance. Overall, Some advantages of adaptive systems have been demonstrated.

Additionally, Clifford et al. [11] compares the use of virtual environments in training Air Attack Supervisor (AAS) pilots in terms of stress, which is comparable with radio-only exercises. Yu et al. [26] and Jin et al. [38] propose similar results for health training and cockpit simulation. Our work also provides immersive virtual environments for VR training.

2.2 Application Survey

This section describes the state of the most popular applications on different platforms such as the App Store and Google Play Store. The applications are primarily divided into weight training, cardiovascular training, and calorie tracking categories. We survey the features they offer.

Table 1: Application categories

Index	Applications	Feature	Missing Features
Weight Training	7	Personalized exercises	Users data not tracked
Cardiovascular	2	Workout tracking	Immersive Environment
Calorie Tracking	1	Calorie tracking	User data not tracked

2.2.1 Weight training applications

JEFIT, which is among the popular training applications, provides users with exercises and instructions in the form of animations and videos. The application lets the user track the number of sets and repetitions for each exercise and comprehensively track their workouts. A similar application **Stronglift 5 X 5** provides the user with exercises and weights that they should be lifting based on their fitness goals. The new users are asked to enter their lifting statistics at signup and the application progressively increases the weights they should be lifting every week to develop better strength and conditioning.

Skimble recommends exercises based on the programs designed by fitness trainers. Users can enter the specific body parts to train and get exercise suggestions. They can select training programs from numerous certified trainers and sync their calendars with trainers to track their progress. Similarly, **Fitness Builder** provides its users with a large number of instructional videos and live streams from personal trainers and helps them build custom fitness and meal plans.

GAIN provides 350+ exercises to the user for different programs like calisthenics and strength training. This application is primarily used by the trainers to track their client's workout schedules and calendars. Additionally, **Nike Training Club** provides a rewards-based system for the users, where they can unlock exclusive workout sessions and medals.

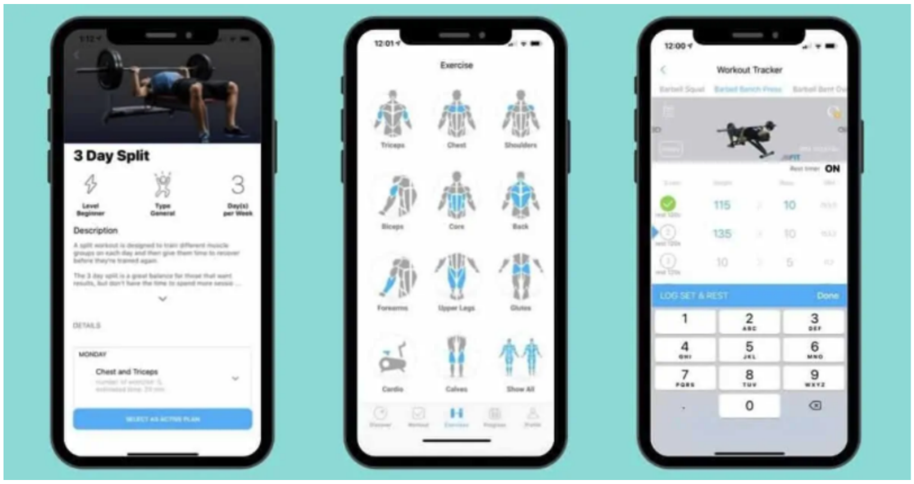

Figure 1: JEFIT Application

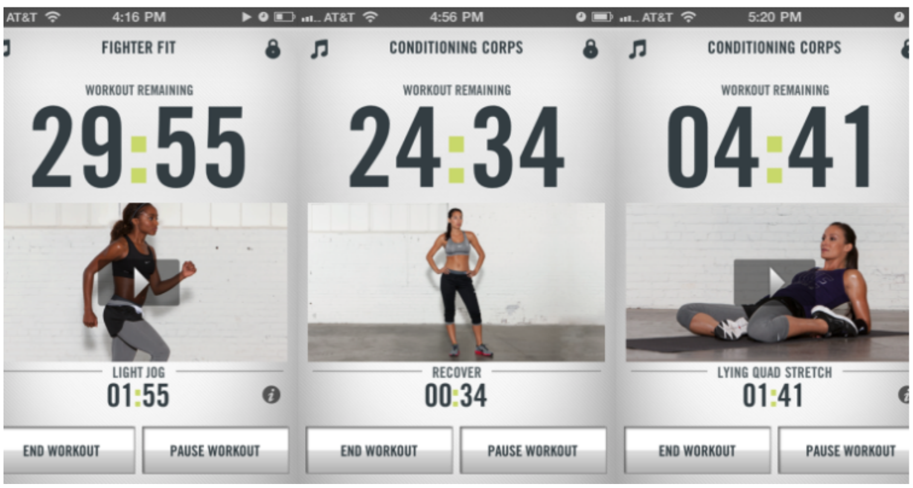

Figure 2: Nike Training Club Application

2.2.2 Cardiovascular applications

CardioTrainer is a popular fitness application that focuses on running. It allows the user to compete with one another and track their running statistics such as distance covered and pace. A similar application **Zombies, Run** provides a post-apocalyptic version of the world, where the users run from the zombies to survive, creating an engaging experience. It also tracks user data, such as the distance covered and calories burnt.

Nike+ Running is a dedicated running application available as a smartphone and smartwatch application. It tracks user data like heart rate(smartwatches only), distance traveled, pace, and calories burnt. It has different running modules such as beginner, amateur, and professional and allows sharing your running data in platforms like Facebook.

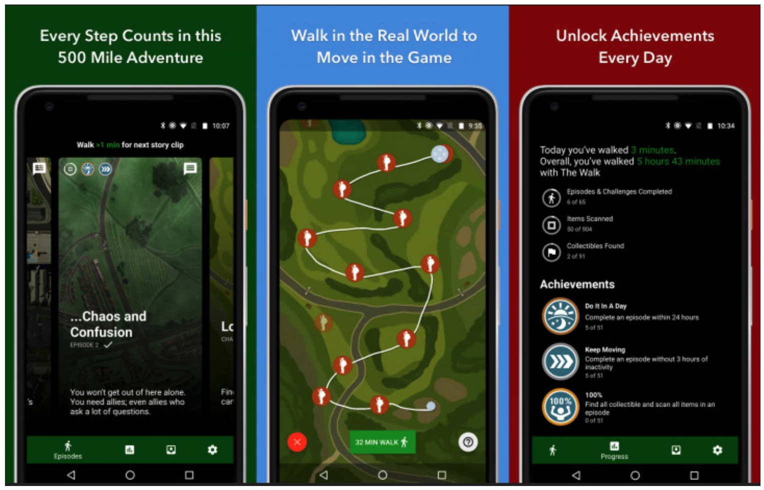

Figure 3: Zombie Run Application

Figure 4: Nike+ Running Application

2.2.3 Calorie tracking applications

My fitness pal is an application designed to help the user build meal plans by tracking calorie intake. The pro version also allows tracking of nutrients and planning workouts.

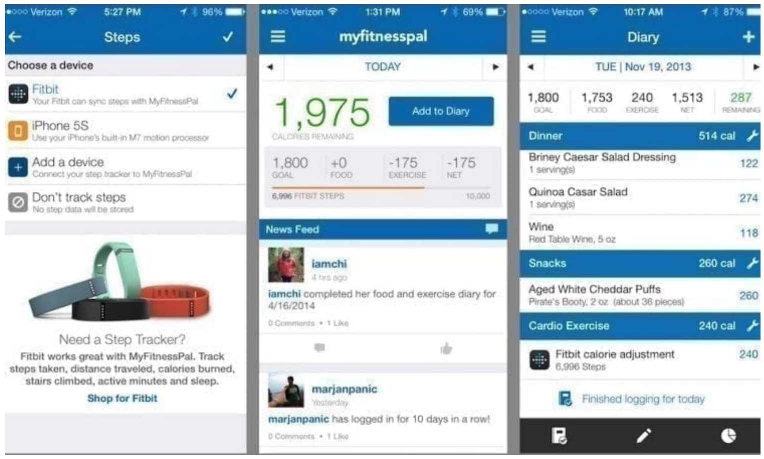

Figure 5: My Fitness Pal Application

2.3 Survey of current state of VR in the industry

2.3.1 VR/AR for Sports

This section describes the state of virtual reality in the sports industry. NFL teams are using virtual reality to train their players in gameplay using an immersive environment. NBA is using VR to improve shooting and playoff skills among players. We survey the effects VR training might have on the sports industry.

2.3.1.1 American Football

Virtual reality has become immensely popular in the NFL with teams and college programs. Dallas Cowboys, New England Patriots, and colleges like Auburn University and Clemson University are using VR technology to create a realistic game like conditions for training. Also, VR headset eye tracking data is being used to detect early signs of concussion in football players.

Figure 6: VR in NFL

2.3.1.2 NASCAR

NASCAR is using VR to train amateur and professional drivers. The immersive and realistic nature of the environment is used to train drivers for long endurance races. It is also being used to provide fans with pre-race events and 360 videos, drawing many people towards the game.

Figure 7: VR in NASCAR

2.3.1.3 Soccer and Basketball

Major League teams are using VR to train the players by providing them with realistic game experiences, which helps to make their training more efficient using immersive environments. VR is also being used to allow fans to interact with their favorite players virtually. Similarly, NBA teams are using VR to train players in different scenarios. Teams such as Lakers and Bucks are using VR to teach different strategies and playoffs.

2.3.2 VR/AR for Rehab and Recovery

A million people in the United States suffer from stroke and other traumatic injuries each year. These injuries require some rehab and recovery. The current estimation puts around 12 million people in the rehab system. These individuals go to physical therapy for the treatment of a disease or an injury. There can be different reasons for rehab ranging from muscle soreness to recovering from post-surgery complications.

The rehabilitation community is actively looking for intuitive and cheaper ways to provide people with rehab, and VR is one of the newer areas that a lot of new companies are exploring.

Figure 8: VR for Rehab and Recovery

Companies like neuro-rehab are using VR devices such as the Oculus Quest to provide realtime feedback and immersive environments to the people undergoing therapy. They use various VR simulations such as grocery shopping and walking to make the rehab process immersive and add a sense of engagement. Different scenarios can be built onto the VR environment and modified based on the requirements. The affordability of headsets like the Oculus Quest has opened up the possibilities for using virtual reality. The doctors can access their patient's data and closely observe their performance, which can lead to quick feedback and, ultimately, better recovery. This builds the case for the effectiveness of VR for physical therapy.

CHAPTER 3: VR ADOPTION SURVEY

This section describes our survey to assess the adaptability of VR. Researchers have traversed different approaches to virtual training using devices like Oculus, Vive. Our survey consisted of interviewing around 45 people to assess the situation of VR adaptability for personal and commercial purposes.

3.1 Week One Customer Survey

In week one of our survey, we aimed to evaluate the customers belonging to the working class and gym owners about the acceptance of VR. We interviewed a total of 11 people consisting of 6 working-class people and 5 gym owners and trainers, to establish the current state of VR adaptability for personal and commercial purposes. Our questionnaire consisted of asking the working-class people about their current fitness regime. Also, we interviewed gym trainers and owners to get their opinions on the adoption of technologies in the health and fitness industry.

- Questionnaire for the personal use of VR
  - What is your current fitness regime?
  - What are your fitness goals?
  - What prevented you from achieving these goals?
  - How knowledgable are you about VR?

  - How willing are you to incorporate VR into your fitness regime?

- Questionnaire for the commercial use of VR
  - How knowledgable are you about VR?
  - How willing are you to incorporate VR into your fitness regime?
  - How willing are you to integrate VR into your business?

- Adaptability of VR for personal use response
  - Availability of time and motivation are the significant factors preventing people from achieving their fitness goals.
  - Acceptance of VR from working-class people is high, and they want to adopt new technologies into their lifestyle.
  - Working class people were self-decision makers. Their friends and families were the main recommenders for new technologies.

- Adaptability of VR for commercial use response
  - Gyms have a high acceptance of new technologies.
  - Gym trainers were the prominent influencers for new technologies, and gym members were among the decision-makers to adopt new technology.

The conclusion derived from week one of the survey put the adoption of VR high among the working class and gym owners. Gym owners were needed to be interviewed further to get a better idea about the adoption of technologies.

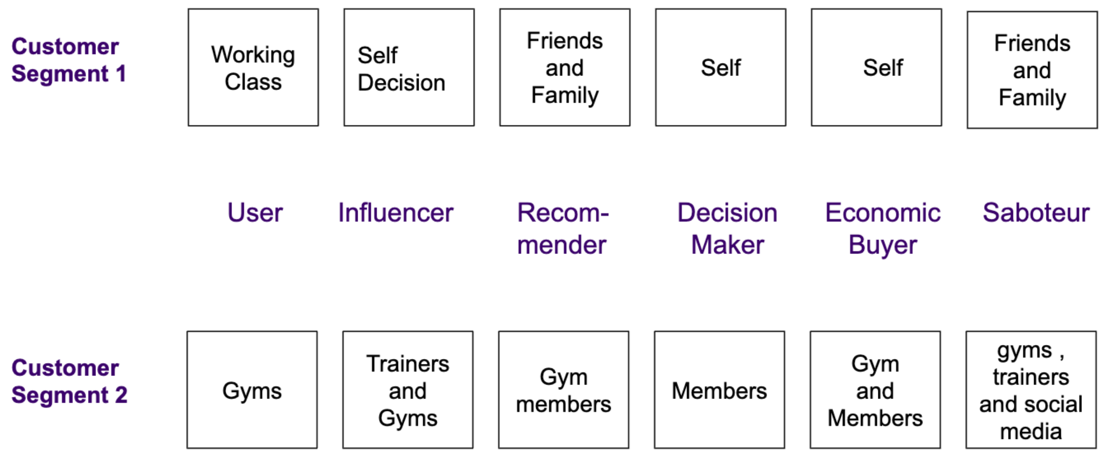

Figure 9: Customer Ecosystem

3.2 Week Two Customer Survey

In week two of our survey, we aimed at further mapping our customer ecosystem. We interviewed 5 students from UNC Charlotte and 3 firefighters. We intended to develop a generalized idea of fitness solutions used by students to achieve their fitness goals. We also surveyed firefighters from the training academy about the current training methods and how they could incorporate the new technologies.

- Questionnaire for UNC students
  - What are the current technologies you are using for health and fitness?
  - What do you think about personal training?
  - Do you own a VR headset or plan on purchasing one?
  - What is holding you back from achieving your fitness goals?
  - What do you think about our solution?

- Questionnaire for firefighters
  - What are the current technologies used for training?
  - Do you have a VR headset? If yes, then do you incorporate it into training?
  - What part of the training can benefit from our solution?
- Adaptability of VR for students response
  - Most of the students used YouTube or Instagram or got help from their friends regarding fitness.
  - They used fitness apps such as MyFitnessPal or Nike+ to achieve their goals.
  - The factors that prevented them from achieving their fitness goals were lack of motivation, time, food choices.
  - Students had a positive response to our solution. They had a few questions such as the pricing of the solution.
- Adaptability of VR for firefighters response
  - Acceptance of VR from firefighters is high, and they want to adopt new technologies into their training.
  - They had questions about the initial setup cost.

The conclusion derived from week two of the survey was that students are pliant to newer technologies, and firefighters are open to incorporating new technologies in their workout.

3.3 Week Three Customer Survey

Based on our interviews in week one and week two, we determined that gym owners and millennials would be the early adopters of VR Technology. We interviewed fitness chains and gym customers to arrive at the problems our solution addresses and the customer segments it targets. Based on these responses and third week questionnaire, we were able to discover the value propositions(problems our solution might solve).

- Questionnaire for week three
  - Factors that prevent people from achieving fitness goals?
  - Have you opted for personal training?
  - Reasons why people are not interested in personal training?
  - How important is having fun in fitness?
  - How do you deal with the changing needs of customers?
- Week three questionnaire response
  - Time and money are of the utmost importance to people.
  - Gyms are optimistic about adapting to new technologies for fitness classes and martial arts.
  - Cost is a significant factor that prevents people from enrolling for personal training.
  - Businesses are willing to adopt new technology (metabolic training newest addition to gyms).

  – Coming up with new workouts and techniques are big challenges for businesses.

The conclusion derived from week three survey is that our solution can help traditional gym customers save time by providing flexibility for working out from home and reducing the travel time to and from the gym. Additionally, it can help save money by eliminating the need for personal training. It can also help customers learn new fitness techniques such as Yoga, Olympic lifts, and CrossFit.

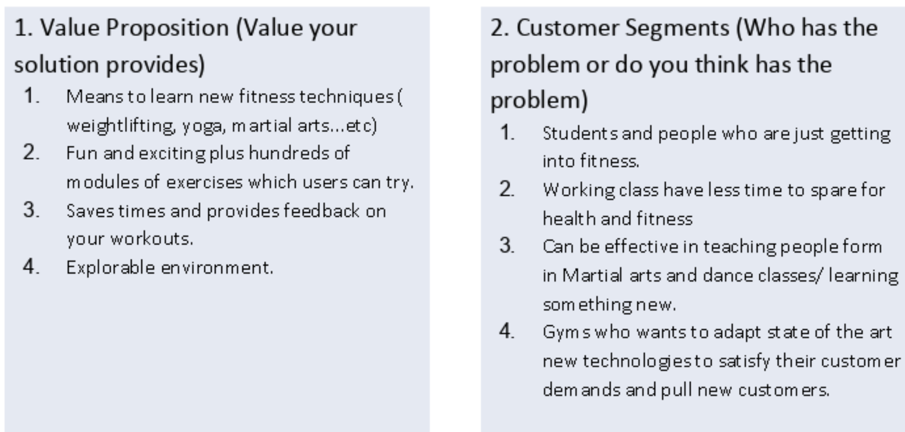

Figure 10: Value Proposition Week Three

3.4 Week Four Customer Survey

In week four of our survey, we aimed at expanding our target customer base. We interviewed 10 more people between the ages of 30 and 52. We were able to get a better idea of how the people were able to incorporate fitness into their lives. Further, we were able to device the current problems people have regarding their current fitness solutions and how our solution can help them.

- Questionnaire for week three

  – How much does personal training cost?

  - Have you opted for personal training?
  - Are you interested in learning new fitness techniques?

- Problem with current fitness solutions
  - Personal training session cost somewhere between 50-100 USD.
  - Learning new techniques are difficult, and training classes might not be the best solution.

- Gains our solution can provide
  - Save people time and money.
  - Proper training where people can learn at their own pace.

Based on our value proposition, week four of our survey concluded that people between the ages of 13 and 30 could use VR training to learn new fitness techniques such as martial arts, weight lifting, and yoga. Our solution can also help people learn new techniques at their own pace from the comfort of their homes.

3.5 Weeks Five and Six Customer Survey

In weeks five and six of our survey, we aimed at comparing the adoption of VR technology by different sections of society. We interviewed 12 more people, pushing our total respondents to 45.

- Questionnaire for week five and six
  - How valuable is saving time and money for you?

- Rank the top two things that prevent you from achieving fitness goals?
- What are your likes and dislikes about our solution?
- Reasons why people are not interested in personal training?
- Reasons why people are behind in achieving fitness goals?
- What are your likes and dislikes about our solution?

- Week five and six questionnaire response
  - Money is a significant factor that prevents people from signing up for personal training.
  - Coming up with new workouts and techniques is a big challenge for businesses.
  - Businesses want to adopt new technologies, but we cannot be sure until we interview upper management.
  - All the respondents gave positive reviews about the solution; however, we don't know that for sure and require further questioning.

After the combined interview of 45 people, we were able to conclude that for businesses, gyms are the early adopters, and they can easily implement the new system. Millennials are the main source of adoption for personal use. The other source of VR training's adoption would be the first responders, such as firefighters and police. VR Training can save both time and resources, which can lead to faster adoption of new training environments.

The conclusion derived from week five and six surveys is that acceptance of VR among firefighters and police is high. First responders are adopting VR and AR technologies for training purposes. Secondly, millennials would be the biggest adopters of our solution, amounting to up to 58 percent. Lastly, fitness centers are looking to adopt new technologies to provide new techniques and workouts for their customer base.

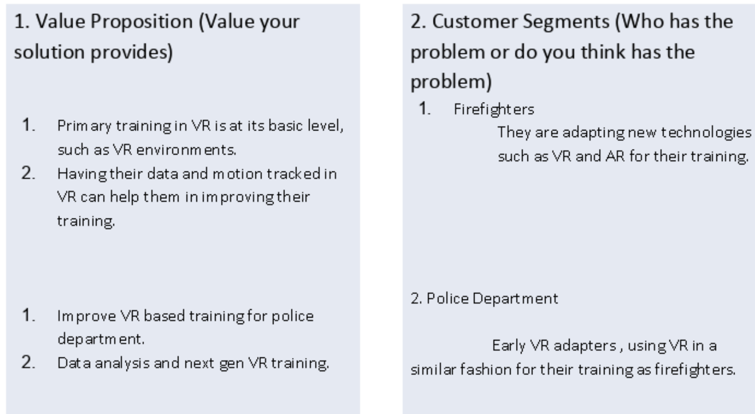

Figure 11: Findings for First Responders

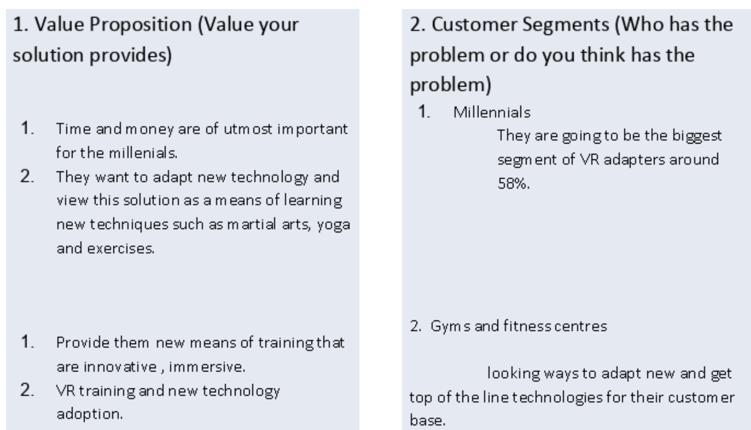

Figure 12: Findings for Businesses and Millenials

CHAPTER 4: IMPLEMENTATION OF THE PROTOTYPE SYSTEM

This thesis focuses on creating a virtual environment for training using Unity. A scene in Unity is where we have the world setup. Similar to a class with different functions, a scene in Unity has gameobjects that form different components of it. These gameobjects can be arranged in either 2D or 3D since we are creating a virtual environment; we choose a 3D arrangement to provide an immersive environment. The Unity product hierarchy consists of objects inside a scene. These objects can be players, buildings, and other things like GameManagers. Each object has a transform component that represents its position, rotation. In the next few sections, we look at the implementation of our prototype system.

4.1 VR GYM Setup

The project demonstrates how virtual environments can be used for training. Also, as mentioned earlier, this thesis focuses on creating an immersive environment since we were among the early efforts for developing a virtual gym, we had to build some of our prefabs and gameobjects using Blender. The assets we needed for creating a basic gym were barbells, dumbbells, benches, treadmills, punching bags, other gym equipment such as pull-up bars, dip bars, and a boxing ring. Some of these assets were made from scratch, and others were imported from the Unity store.

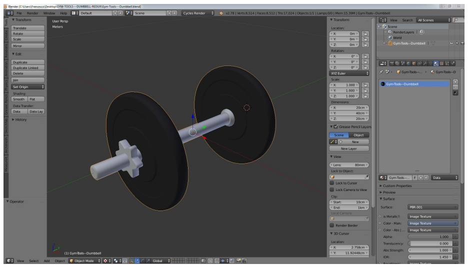

Figure 13: Asset Creation in Blender

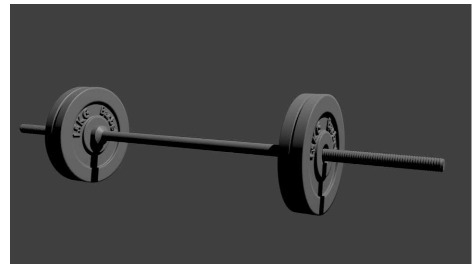

Figure 14: Barbell Creation in Blender

Figure 15: Gym Setup

Figure 16: Boxing Gym

Figure 17: Gym Environment

Cassola et al. [8] presents a virtual gym for elderly people. We followed a similar setting for our VR gym. One of the users said: ”gym looked realistic, the lighting was adequate, and gave a perception of openness”. This re-enforces the claims of [8] that well-designed spaces can have a positive effect on the user.

4.2 Gym Trainer Setup

In a user study, Donne et al. [13] mention personal training to be beneficial. The results proved that people that were given personal training had more progress than their training counterpart who did not receive any personal training. Thus for our project, we wanted to provide the user with some of the benefits of personal training.

In the VR Gym, there are two types of coaches

- Primary Coach
- Secondary Coach

The primary coach function is to guide the user through the exercise. This was backed up by a user study [15], which stated that having a virtual training partner facilitates the user to have the motivation and work towards goals. The other feature of the primary coach is to keep the user in sync with the exercise session.

Figure 18: Primary and Secondary Coaches Setup

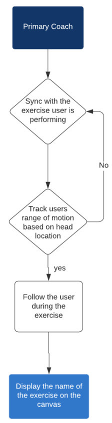

Figure 19: Main Coach Workflow

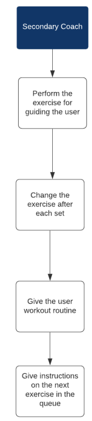

Figure 20: Secondary Coach Workflow

The secondary coaches have two views. The first one is the linear view, and the second one is the lateral view that gives the side view of the coach. The secondary coach gives the exercise instructions to the users. This was helpful to observe complex movements such as jumping jacks and side laterals, and it may be beneficial for other exercises.

The two coaches are interdependent. This means the primary coach check the user's range of motion, and the secondary coach provides exercise instructions to the user. In a popular VR game, instruction for the next step is given by a 2D picture, which may cause confusion. Therefore one of the aims of this project was to have a simplified UI to give instructions to the user.

In order to make the gym realistic, we designed AI to emulate a public gym. The two AI in the scene perform their exercises and walk around the gym.

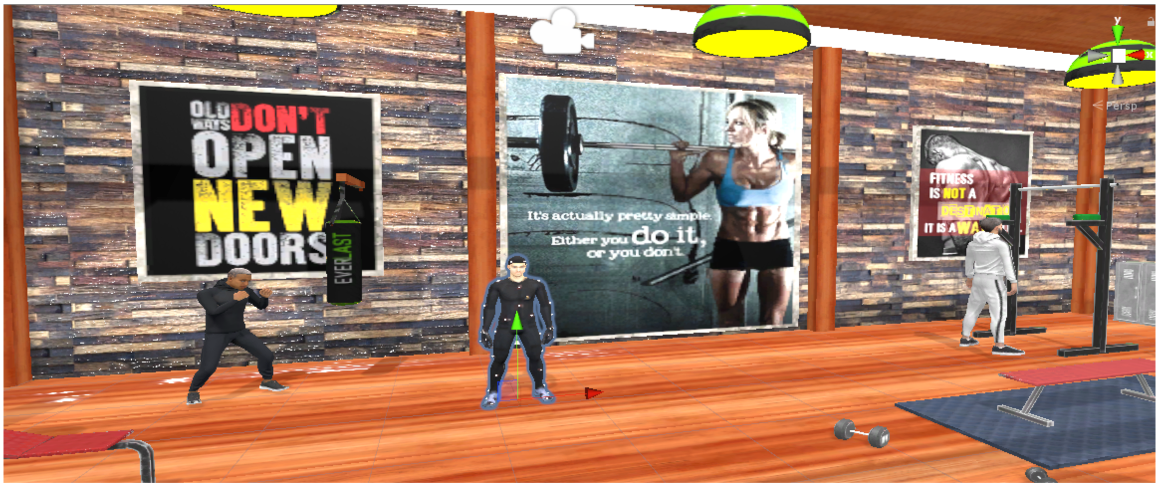

Figure 21: AI in VR Gym

4.3 Motion Capture in VR

Motion tracking is the process of transposing your movement from real life to a digital VR avatar. As the paper [10] suggests using a virtual controller gives the users sense of immersion in the virtual environment, we looked into two preferred ways to track motion.

- Optical tracking
  - Image capture used to track motion. Eg. Optitrack motion capture.
- Non- optical tracking
  - Sensors attached to the body used to track motion. Eg. Vive motion trackers.

Conventional optical tracking methods use cameras and markers with high reflectivities. There are certain disadvantages to this method. The multiple cameras may track single dots as two separate dots, which may lead to incorrect data tracking. Optical motion tracking is not popular with the consumers owing to the cost associated with such a system. A small setup of Optitrack with 24 cameras may cost between 150,000 and 300,000 dollars.

Figure 22: Lighthouse Trackers SteamVR

Microsoft Kinect is among the popular motion capture devices for Xbox 360 and Xbox One. Jin et al. [24] use motion capture from Kinect to build their virtual trainer. The precision of such devices is questionable in the motion tracking industry. Similarly, AR devices such as Leap Motion create scans of the user's hand in high resolution, which allows the digitized version of their hands to be visible in VR when wearing the HMD.

The lighthouse tracking system that is used by SteamVR is compatible with devices such as Vive, Steam gear. The lighthouse system uses laser-based tracking, which offers precise tracking of the VR sensors in our virtual gym. The VR trackers contain electromechanical sensors such as accelerometers and gyroscopes. The gyroscope measures the rotation(360 degrees), and the accelerometer measures the movement along the XYZ axes.

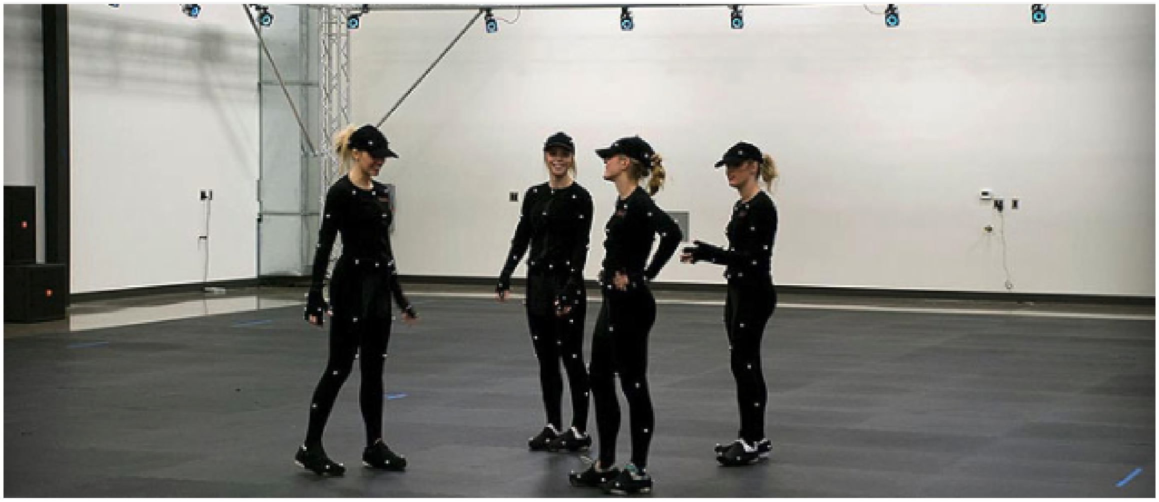

Figure 23: Optitrack Motion Capture

The accuracy of the lighthouse sensors and the ease of development in the VR platform made it our preferred sensors for motion capture. The tracking systems use electromechanical tracking and run at 1000 Hz. The accelerometers track the acceleration. Integral of the acceleration gives us the velocity, which in terms gives us the position of the object we need to track. These devices contain an array of IR photodiodes, which measures the time between the IR flashing, and gives us the position in the room.

- Lighthouse Advantages
  - Accurate tracking.
  - Doesn't require a computer or connection.
- Lighthouse Disadvantages
  - Expensive.
  - Reflective surface causes glitches.

4.4 Skeleton Reconstruction

After selecting the tracker for motion capture, the next step was to translate the motion data captured from the sensors to the VR avatar. For this translation, we use the IK algorithm from [21] [28]. The algorithm in [21] uses a three-point IK to get the position of the virtual avatar's joints.

- Three Point IK algorithm:
  - IK problem is the calculation of the angles and positions of the joints in between the two endpoints. E.g., In order to calculate the position of the elbow when the positions of the wrist and the shoulder are given. Most of the time an IK problem has more than one solution.
  - A three-point IK is IK with three joints. This has only one solution to the angle.
  - If the positions of the ankle and the hip are known (tracked), there's only one solution for the knee angle, as shown in the figure.

To check the accuracy of the IK algorithm, we use another program Mocap VR [28]. This motion-capture technique uses Unity Mecanim IK to translate the motion-captured from the sensors to the movement of VR avatar.

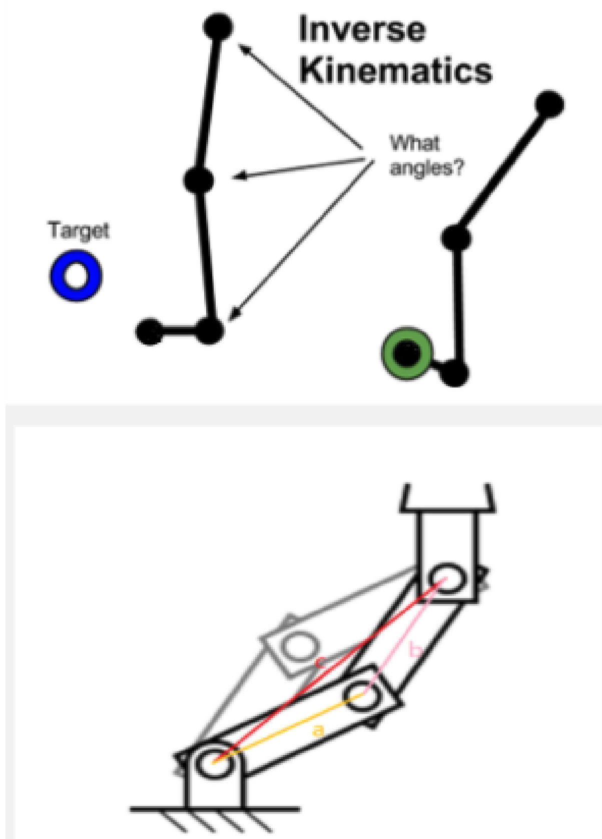

Figure 24: Three Point IK

4.5 Three Point IK vs Mechanim IK

In our project, we used both of these motion captures to translate the data from sensors to VR avatar and compare the two algorithms.

- Three-point IK
  - It supports an array of 6 vive sensors (3 body sensors + 2 hand sensors + HMD).
  - The data collected is assigned to the inverse kinematic algorithm that syncs the person's movement with avatar in VR.

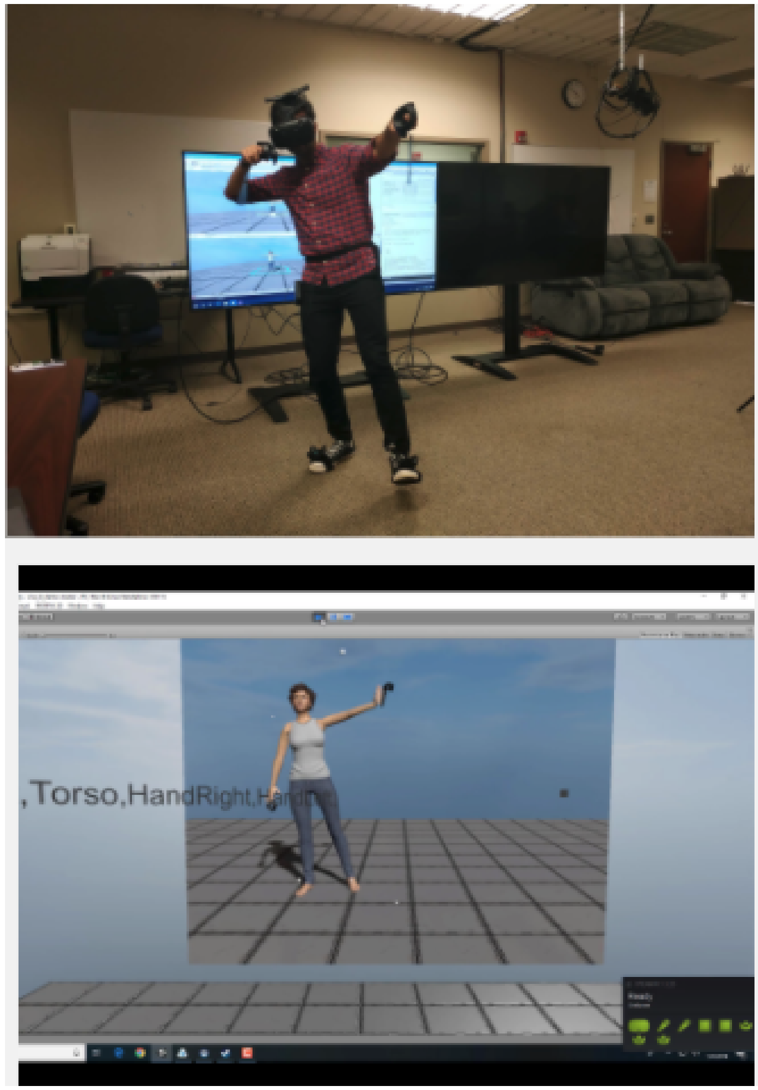

Figure 25: Three Point IK motion capture

This algorithm was reasonably accurate for most of the actions except for the hand movement. Hands have a relatively extensive range of motion, and the algorithm's prediction of the elbow joint was not very accurate in our testing.

- Mocap VR

  - It supports an array of 10 vive sensors (7 body sensors + 2 hand sensors + HMD).

– The data collected is assigned to Unity's Mechanim IK algorithm that syncs the person's movement with its avatar in VR.

Mechanim Ik supports up to 10 sensors on parts such as hips, elbows, feet, and knees. It was more accurate than Three-Point Ik [21], which had a couple of anomalies for hand movement. Mocap VR had better motion tracking hand movements were fairly more accurate that the three-point IK discussed earlier.

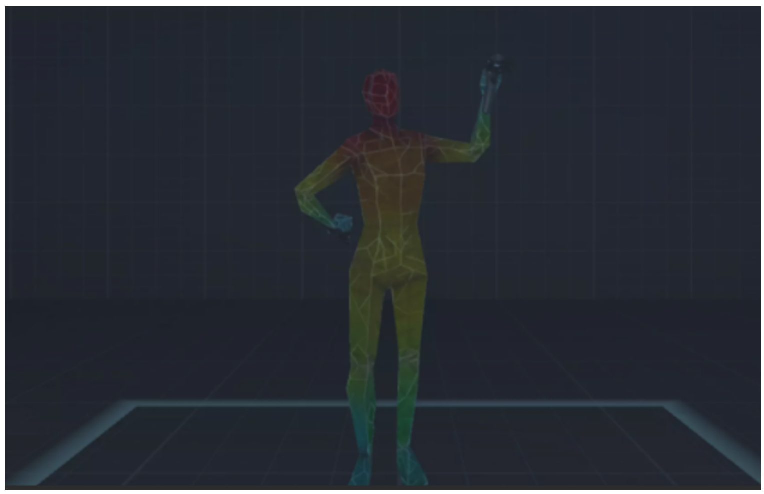

Figure 26: Mocap VR motion capture

4.6 Body Tracking and Reconstruction

After designing the virtual gym and skeleton reconstruction, the next step was to introduce the recording of history data and replay it in VR. The VR avatar used in our system consisted of 122 body parts and joints(game objects). To record the game data, we created a script that records the data from each of these joints, such as rotational and positional data. It was written to a data file that can be used to replay history.

```
public class writingdatacombination : MonoBehaviour
{
    Transform[] array;
    List<string> Body_position = new List<string>();

    public GameObject avatar;
    // Start is called before the first frame update
    0 references
    void Start()
    {
        array = avatar.gameObject.GetComponentsInChildren<Transform>(); //getting the components all the transform components

    }

    // Update is called once per frame
    0 references
    void Update()
    {
        // StartCoroutine("RecordData");
        string path = "Assets/Pistol_squat.txt";
        if (!File.Exists(path))
        {
            File.WriteAllText(path, "");
        }

        for (int i = 0; i < array.Length; i++)
        {
            Transform x = array [i];
            string content = (x.position.x + "," + x.position.y + "," + x.position.z + "," + x.rotation.x + "," + x.rotation.y + "," + x.rotation.z + "," + x.rotation.w + "\n");

            Body_position.Add(content);

        }

        foreach (var item in Body_position)
        {
            File.AppendAllText(path, item);
        }
```

Figure 27: Writing Data to a File

```
0,0,0,0,0,0,1
6.697029E-06,0.9511754,-2.74007E-05,0.03332172,0.03219694,0.00233921,0.9989232
-0.09604775,0.9178585,0.003970452,-0.03676152,-0.08058355,-0.07575196,0.9931852
-0.1604076,0.5056607,0.02370293,0.03083936,-0.1268225,-0.08995384,0.9873569
-0.2218278,0.1220333,-0.02840306,0.0001629926,-0.1318904,-0.001218179,0.9912636
-0.2420041,9.799004E-05,0.05193922,0.0003794469,-0.1319014,5.047955E-05,0.991263
-0.2752143,8.34465E-07,0.1745201,0.0003794469,-0.1319014,5.047955E-05,0.991263
0.09622665,0.9191724,-0.008393298,-0.03944704,0.1104443,0.07311871,0.9904038
0.1591816,0.5067827,0.01185394,0.009165222,0.1007764,0.09273124,0.9905359
0.2262909,0.1220765,-0.02212999,0.0001859814,0.1056296,0.001750649,0.9944041
0.245902,0.0001526475,0.05836952,0.0005958378,0.1056585,-6.329757E-05,0.9944023
0.2725578,4.172325E-07,0.1825406,0.0005958378,0.1056585,-6.329757E-05,0.9944023
0.000790373,1.042185,0.02183188,0.03481535,0.02944504,0.002409439,0.998957
0.0002434837,1.204444,0.0315118,0.03931563,0.0245608,0.003395103,0.9989192
-0.00105582,1.341428,0.02938049,0.04378689,0.01966114,0.0044337,0.9988376
-0.06467933,1.445565,0.002941179,0.06675541,0.1134701,0.09237715,0.9869827
-0.184973,1.412381,0.01000161,0.2101898,0.1628591,0.5967788,0.7570683
-0.2499444,1.143245,0.008815867,0.1419543,0.2467141,0.6165822,0.7340352
-0.2828123,0.8714113,0.06097905,0.1618694,0.2569935,0.6672952,0.6800516
-0.2657181,0.7698824,0.09218804,0.2342394,0.1888636,0.7865804,0.539216
-0.2485844,0.7178992,0.08304169,0.2989634,0.1022655,0.8973504,0.3080997
-0.2271732,0.6970747,0.06698373,0.3275433,0.04458459,0.9313328,0.1527972
-0.2087048,0.6892293,0.05207177,0.3275433,0.04458459,0.9313328,0.1527972
-0.2804355,0.7674702,0.07498506,0.2690684,0.163978,0.7833152,0.5358462
-0.264163,0.7137359,0.06074829,0.3382042,0.03762584,0.9125222,0.226949
-0.2393505,0.6974112,0.03846316,0.3575585,-0.0359075,0.9323714,0.03932504
-0.2223026,0.6963152,0.02306286,0.3575585,-0.0359075,0.9323714,0.03932504
-0.303838,0.7685663,0.03686998,0.3131915,0.08662759,0.856619,0.4007628
-0.2860963,0.74133,0.01969662,0.3456876,-0.0007020482,0.9197239,0.1860328
-0.2666481,0.7317235,0.001812973,0.3525147,-0.0326259,0.9293482,0.1047909
-0.2454925,0.726742,-0.01738666,0.3525147,-0.0326259,0.9293482,0.1047909
-0.2931957,0.7670783,0.05551681,0.2852712,0.1451361,0.8235595,0.4683012
-0.2714895,0.7205679,0.03733308,0.3415472,0.036337,0.9179287,0.1985759
-0.2459492,0.7061095,0.01458598,0.3613515,-0.04158067,0.931502,-0.0007624013
-0.2311722,0.7067388,0.001123291,0.3613515,-0.04158067,0.931502,-0.0007624013
-0.2572319,0.8495675,0.07586881,0.07945723,0.3140287,0.5530881,0.7675718
-0.2362699,0.8151032,0.0961275,0.3151906,0.2172799,0.4404544,0.812062
-0.2290335,0.7639183,0.09922834,0.3261299,0.248055,0.4090065,0.8153661
-0.2258956,0.734572,0.1014525,0.3261299,0.248055,0.4090065,0.8153661
-0.0037731,1.483466,-0.001797849,-0.06659798,0.03013323,-0.01722612,0.997176
-0.001877987,1.527676,0.001562658,-0.06659798,0.03013323,-0.01722612,0.997176
-0.000120639,1.568693,0.004665992,0.0217463,0.0004061386,0.002106698,0.9997613
-0.0009602539,1.776941,0.06198071,0.0217463,0.0004061386,0.002106698,0.9997613
-0.0003802973,1.629064,0.05146649,0.0217463,0.0004061386,0.002106698,0.9997613
-1.425035E-06,1.563551,0.1399419,0.0217463,0.0004061386,0.002106698,0.9997613
5.922013E-05,1.543749,0.1078518,0.0217463,0.0004061386,0.002106698,0.9997613
-0.0001977037,1.593558,0.09643291,0.0217463,0.0004061386,0.002106698,0.9997613
-0.0001844264,1.593257,0.1130945,0.0217463,0.0004061386,0.002106698,0.9997613
-0.0001545948,1.588359,0.1257405,0.0217463,0.0004061386,0.002106698,0.9997613
-0.02920298,1.611272,0.1365735,0.0217463,0.0004061386,0.002106698,0.9997613
-0.06904779,1.655496,0.04169857,0.0217463,0.0004061386,0.002106698,0.9997613
-0.03141282,1.660485,0.1231796,0.0217463,0.0004061386,0.002106698,0.9997613
-0.03141282,1.660485,0.1231796,0.0217463,0.0004061386,0.002106698,0.9997613
-0.03141282,1.660485,0.1231796,0.0217463,0.0004061386,0.002106698,0.9997613
```

Figure 28: History Data written on a File

Once we have the motion data in a file, the history replay script takes the data from the file and assigns it to the avatar on every frame, which recreates the user's motion history.

```
void FixedUpdate()
{
    timesincebeginning += Time.deltaTime;

    int seconds = Convert.ToInt32(timesincebeginning % 60) ;

    Debug.Log(seconds);

    if (Time.fixedTime >= timeToGo)
    {
        for (int i = 0; i < array.Length; i++)
        {
            if (i + scale < lines.Length)
            {
                readTxt(i + scale, array[i]);


            }



        }

        scale += array.Length;
        timeToGo = Time.fixedTime + 0.1f;

    }

}
```

Figure 29: Script for Reading Datafile

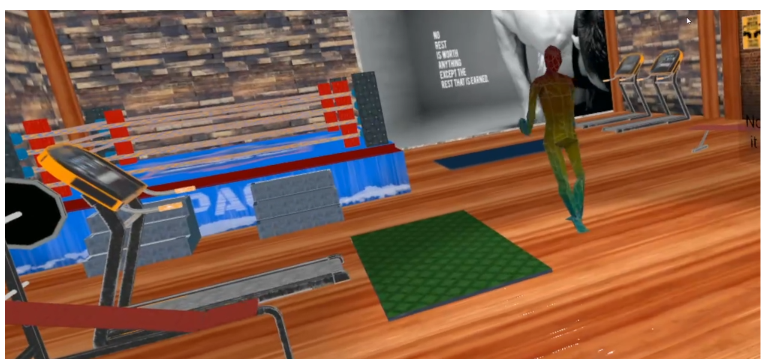

Figure 30: Seeing your history in VR

4.7 VR Game

As pointed out by Bian et al., there are many aspects to be looked at [7] while designing a VR game. Similarly, Cassola et al. [6] in the game for firefighter training, design a comparable easy to explore environment. In our game, we incorporated similar features to make the environment easily explorable. The canvas displayed in the VR environment allows the user to choose the specific menu items, and the type of exercise they want to perform. Further, users can select the body part they want to train. The native steam laser pointer inspired the design for the VR pointer. These pointers were modified to interact with the canvas and select the menu items.

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.EventSystems;
0 references
public class Pointer : MonoBehaviour
{

    public float m_defaultLength = 5.0f;

    public GameObject m_Dot;

    public VRInputModule m_inputmodule;

    private LineRenderer m_Linerenderer = null;
    0 references
    private void Awake()
    {
        m_Linerenderer = GetComponent<LineRenderer>();
    }
    0 references
    private void Update()
    {
        UpdateLine();
    }

    1 reference
    private void UpdateLine()
    {
        PointerEventData data = m_inputmodule.GetData();

        float targetLength = data.pointerCurrentRaycast.distance == 0 ? m_defaultLength : data.pointerCurrentRaycast.distance;

        RaycastHit hit = CreateRaycast(targetLength);

        Vector3 endPosition = transform.position + (transform.forward * targetLength);

        if(hit.collider != null)
            endPosition = hit.point;


        m_Dot.transform.position = endPosition;

        m_Linerenderer.SetPosition(0, transform.position);
        m_Linerenderer.SetPosition(1, endPosition);

    }

    1 reference
    private RaycastHit CreateRaycast(float length)
    {
        RaycastHit hit;
        Ray ray = new Ray(transform.position, transform.forward);
        Physics.Raycast(ray, out hit, m_defaultLength);
        return hit;
    }
```

Figure 31: Pointer for Canvas

Upon entering the game, the user is asked to select a workout in the main window of the game. In the secondary menu, the user can select exercises focussed on particular body parts such as the chest, arms, back, legs, or can select random exercises. Each category has 5 exercises and the random category groups any 5 exercises. The system has inbuilt exercises such as curls, air squats, pistol squats.

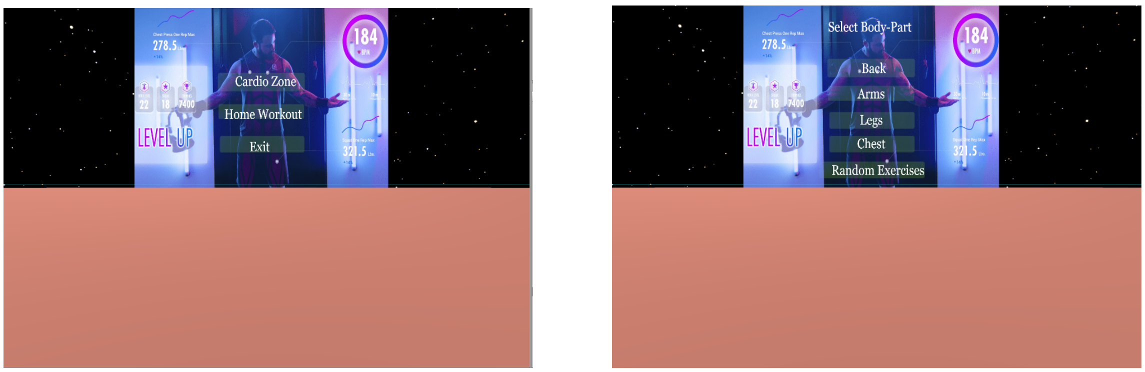

Figure 32: Main VR menu

Once the user selects the exercise, the next step is to calibrate with VR avatar. The final version of our game utilizes [28] for motion capture. This supports up to 7 VR sensors along with the hand sensors and HMD for precise tracking. The user can press the menu button on the controller to recalibrate a VR avatar in case the calibration is not perfect.

Figure 33: Calibrating with VR avatar

Figure 34: Recalibration with VR avatar

Once the calibration is complete, the primary and secondary trainer guides the user for various exercises. The primary trainer follows the user's range of motion to keep user motivated. The secondary trainer shows various exercises to the user. It uses both linear and lateral views to give the user instructions regarding the next set of exercises. For example, in the pictures below, the primary trainer follows the user's range of motion, and the secondary trainer gives instructions for the various exercises such as kettlebell swings, overhead squats, and pistol squats.

Figure 35: Overhead Squat

Figure 36: Kettlebell Swing

Figure 37: Pistol Squat

In the screenshots below, the user can be seen performing an air squat. The air squat is a three step exercise. The first part of the squat is the upright position this is the starting position of the squat, the second part of the squat is when the user gets into the squat stance, and the third part is where the user is in the lowest part of the squat having the thigh parallel to the ground. The primary trainer follows the user throughout range of motion to keep the user motivated.

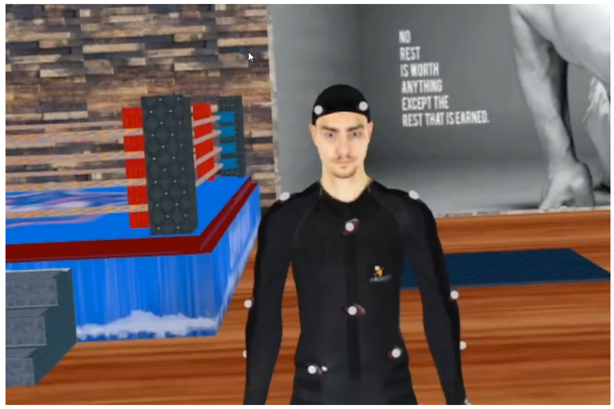

Figure 38: Air squat range of motion - Upright

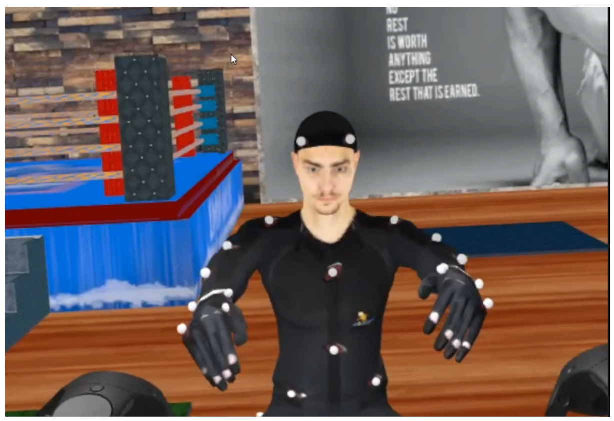

Figure 39: Air squat range of motion - Mid

Figure 40: Air squat range of motion - Low

4.8 Exercise Statistics

One of the fitness applications essential features is to track the calories consumed by the user during the workout session. Our game has a fixed number of repetitions for every exercise. We designed an algorithm that predicts the average calories consumed in a workout session. In our finding, the exercises in our list, such as squats, hand raises, and jumping jacks, burn an average of 3 to 5 calories based on a person's body weight, as pointed out by [2] [1] [3]. The algorithm required further testing for the measure of its accuracy.

Let us assume the user selects the leg exercise. Leg exercise module consists of pistol squats, air squats, kettlebell swing, jump squat, and overhead squat. The total time for the session was around 10 minutes.

Average calories burnt = 4 calories/minute(pistol and air squats)

Average calories burnt = 3 calories/minute(kettlebell swing and overhead squat)

Average calories burnt = 5 calories/minute(jump squat)

Time for the session = 4 minutes(pistol and air squats)

Time for the session = 4 minutes(kettlebell swing and overhead squat)

Time for the session = 2 minutes(jump squat)

Average calorie burnt for the session = 4*4 + 4*3 + 5*2 = 38 calories

Calories burnt per minute = 38/10 = 3.8 calories

Calories burnt per hour = 3.8 * 60 = 228 calories

Figure 41: Final Screen Counting Calories

CHAPTER 5: CONCLUSION AND FUTURE WORK

The game that we developed uses Unity and SteamVR to provide an immersive virtual reality experience. The application can provide an immersive training experience to its users with the ability to choose exercises based on specific body parts. The application also stores user motion data in a file that can be used to replay user motion history. The project uses VR sensors and devices like Vive, which shows that it is pretty easy to develop virtual training environments. The use of SteamVR makes the project portable to Vive, Steam gear, and many other VR devices.

The benefits of VR cannot be unseen. The technology is new and exciting for the users, and real-world use cases of virtual reality are expanding across various industries such as entertainment, fitness, military, etc. The introduction of new devices, such as oculus with low hardware cost, enabled developers to explore the field easily. Looking from a personal standpoint, it had been a great experience to learn Unity. VR is visually appealing to its users and we can use machine learning and AI to add more capabilities to the application as needed. This project also emphasized collecting motion data that can be utilized by different devices. It enables the system to be similar across devices running on SteamVR, which is a crucial part of developing apps that supports multiple devices.

In the future, apart from improvements on the trainer feedback. I want to make the virtual trainers capable of providing real time assessment to the users based on the exercises. Also, I would like to see virtual training spread to different fields, such as sports medicine, basketball. In our case, training in VR is just the beginning. As the devices in the future get smaller and more efficient, the sensors should be on par with the dedicated hardware such as Optitrack to track the human body.

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