Effectiveness and efficiency of Table Tennis serve training in Virtual Reality and skill transfer to the real world

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Abstract

The fast-paced game of table tennis is used in the current study to examine skill transfer from virtual reality (VR) sports training to the real world. The concept behind VR instruction is that the knowledge and experiences gained translate to the outside world. In certain application areas, such as VR sports training, there is a dearth of evidence to support this assertion.

Negative transfer can occasionally occur when the virtual environment does not adequately replicate the task utilized for training, even though the positive transfer is the expected result of virtual training. Users may experience abnormal movements due to consistency issues in a virtual training environment, which could negatively affect how well they accomplish the activity in the real world.

In this study, a group of participants gets trained in VR to serve in table tennis. Their performance has been continuously measured and studied if their skill in real-time is improved after the training.

Moreover, this study has been conducted for novice players with almost zero experience in playing table tennis. Moreover, if users are convenient in handling VR devices, that means if they do not get any VR sickness, then this study is quite valuable for the new player.

This work contributes to the limited but growing body of research demonstrating the real-world application of VR sports training. In the current study, we found that real-world table tennis serves performance significantly increased after VR training through all performance measures.

Acknowledgments

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Chapter 1 Introduction

Recent advancements have opened up the potential for virtual reality (VR) gaming in motion sensors, graphics, multimodal display technologies, and interactivity, which enable seamless, immersive experiences in highly interactive synthetic worlds. VR develops beyond the connected technology to take the user(s) into the tale's heart, experiencing it in the first person, ranging from exciting adventures to peaceful, passive immersion. VR was invented in the 1980s, but its trials began in the mid-1960s. When most people think of virtual reality, they think of "games" and "movies." If we look into the first definition of VR, it says, "*A 21st-century art form that will weave together the three great 20th-century arts*." Ivan Sutherland invented the first head-mounted display device for immersive simulation applications in 1968, with the support of his pupils, notably Bob Sproull[01]. VR is utilized for various applications, and it has shown to be a game changer in various disciplines of study.

Because of the enchantment of VR, serious games, like those used in education and training, become an exciting experience that helps players acquire new abilities and advance their competence[30]. VR gaming is now used by the real estate, automotive, advertising, and tourism sectors to reach new audiences or engage customers in fresh, exciting experiences.

Nowadays, more people are using virtual reality as a training tool; it is becoming more common. VR is a virtual reality environment (or VE) in which users can interact with items and navigate as if they were in a real environment. VR technology has sparked interest for application in circumstances where real-world training is challenging to organize, unsafe, or prohibitive. Training programs for surgeons[14], firefighters[13], and pilots[16], for example, are taking advantage of the realism and flexibility that VR provides. Transferring abilities and experiences to the actual world is a significant assumption of VR training[01]. However, little study has tested this assumption in particular application areas, such as VR sports training. Although numerous studies have been conducted on other sports such as basketball, baseball, football[08], and so on, this thesis will concentrate primarily on the Table Tennis serve area. VR enables people to train and learn various things or sports for which they do not have the resources or access without interfering with or hurting their real life or future[01].

Furthermore, when it comes to sports training on VR, there are several benefits:

1. It allows individuals to exercise without having access to the essential athletic environment (such as a downhill skiing slope or several training partners) (e.g., football).
2. By actively implementing VR into sports training, users may keep track of their progress and performance data.
3. Virtual reality technology is adaptable and gives users much freedom to design and manage virtual worlds in various ways.

These benefits offer a massive window of opportunity for using evidence-based methods to boost training results. According to evidence-based training research, such as the challenge point framework, people learn best when regularly challenged. By methodically modifying the difficulty level depending on the user's skill, variation may be added to training with ease to integrate this study into a virtual environment.

Evidence-based training research, such as the challenge point framework, indicates that individuals learn their skills best when they are regularly challenged. Integrating this research into a virtual environment is simple by including diversity in training and systematically modifying the difficulty level depending on the user's aptitude. For instance, when medical students utilized a VR training simulator to learn how to dissect a gallbladder, they could complete the job 29 percent quicker and with six times fewer mistakes than non-VR-taught students [14]. Bliss et al. [13] discovered that VR teaching firefighters in real-world spatial navigation might be just as effective as conventional approaches, while Carlson et al. [35] discovered that VR training enhanced performance on a real-world assembly assignment.

However, Kozak et al. [36] and other researchers discovered that there was no transfer of training from virtual reality to the actual world when utilizing a pick-and-place device. These contradictory findings demonstrate the need for more studies transferring VR training to the real world. These benefits present a tremendous opportunity to use evidence-based techniques to generate more considerable performance gains from training.

Despite these encouraging results, it remains to be seen whether VR can have a real-world impact before it can be widely embraced as a tool for sports training. The fast-paced game of table tennis was used in this study to examine the effects of VR training on the outside environment. In comparison to no training, it was predicted that VR table tennis training would significantly improve real-world performance and serving accuracy.

1.1 Academic and Societal Relevance

For various reasons, this study effort is both valuable and vital. The study was carried out solely to improve the service techniques of new players who had never or just seldom played Table Tennis in their lives with or without the help of VR. An application has been built with Unity's help to improve the players' serving abilities, and we saw a significant change and improvement in the real-time game of all participants. We also tested the transfer of VR skills to real-life skills. Numerous examples of VR training have resulted in positive real-world effects. By nature, table tennis is a sport that requires open skills. Sports that require players to react in a dynamic, unexpected, and fast-paced environment are known as open-skill sports[11]. typically involving the opponent's presence (e.g., table tennis, football, boxing, Etc.).

Specifically, table tennis requires flexibility in quick decision-making, fast interceptive, and visual attention actions in response to an interactive opponent [12]. It is critical to think about how the training environment can arrange to maximize the possibilities for improvement. We tailored the atmosphere to help participants improve their serving techniques.

There have been numerous studies on VR training in Table Tennis. As a result, we did this study to add to the field's knowledge. We expanded on prior studies' information and attempted to eliminate their shortcomings. Our study focused on improving the serve technique of the participants and transferring VR skills into the real world. VR training has a beneficial and long-term impact on the participants. Their target skills dramatically improve. New technological advancements have dramatically improved our ability to create immersive virtual reality experiences. There are numerous variants of interactive tools and initiatives that strive for the best level of immersion. Because participants' motions are tracked, VR sports training allows users to study and repeat them until they have polished their technique. VR sports training games are available throughout the sports spectrum to help users develop their skills while having fun. As a result, our research concluded that VR training could help us improve our skills without needing a coach, opponent, set-up, or sporting equipment.

1.2 Thesis Outline

This thesis is organized as follows: I provide a general overview of virtual reality and the study in the first chapter. The next chapter will provide a brief review of prior studies pertinent to the current investigation and a discussion of the first experiment that was carried out to test the viability of VR training for table tennis. I have also included a few other games where a comparative analysis was done. The application design for both the real-life session and the VR training session is covered in the following chapter. Additionally, I have described the mini-game to the participants that they were required to play before their VR training to understand all the Virtual Environment components.

In chapter four, I go into great detail about how I put everything into practice while doing the study. Following the subjects mentioned earlier, descriptions of user experimentation and real-world and virtual user training have been given. These explanations start with the technology and equipment and essential participant information. The experiment's goal, sample participants, pilot user study, apparatus results, and software used for real-world and virtual reality training are listed in next chapter five. After that, I added a succinct description of the experiment.

Chapter 6 wraps up the performance study of each target both individually and collectively after implementation. Each target's analysis is explained with graphs. After the performance analysis, I provided my study's limitations and recommendations for people who want to conduct additional research on the subject after the conclusion. The next chapter includes limitations and the future direction of the study.

Finally, I wrapped my thesis in chapter eight by providing a succinct yet thorough review of the research project. A bibliography is included at the end. Consequently, this is my thesis' complete outline.

Chapter 2 Literature Review

Before carrying out the tests, it was initially essential to evaluate the knowledge that earlier studies had already produced about the related topic. As a result, I will briefly examine earlier studies that I believe are pertinent to my study issue in this chapter and identify the gaps that exist in empirical knowledge. I will start by going over earlier research on VR in sports. Then talk about the earlier study in connection to subsequent research of a similar nature. After that, I will offer a succinct summary of the key issues discussed in this chapter.

Significant advances in virtual reality (VR) technology have occurred over the previous decade, particularly in developing 3D and 360° virtual worlds. Athletic training has evolved. Thanks to technological advancements and training efficiency advances, athletes are bigger, stronger, and faster than ever. Virtual reality training for athletes is not the only application for such technology. Companies and programs such as Basic Science's Anatomic Visualizer, Japan's "3D Human Atlas," and others are assisting students by leveraging virtual reality to provide excellent methods to examine and access the human body. Advances in this technology aid in the education of future practitioners and medical emergency[17] staff and prevent injury to individuals who volunteer to be practiced on.

The sports sector is now fully utilizing Virtual Reality in training. VR technology impacts physiological data collection, recognizing and enhancing sensorimotor abilities, simulating competitive and environmental circumstances where reaction time is crucial, and developing skill acquisition[02]. Despite the rise in usage in sports, it is still not apparent how much VR training tools can be used to aid in the motor learning of intricate actions[15]. Prior VR research has focused more on realizing performances than teaching physical skills. Virtual reality is being employed in a wide range of sports, including soccer, football[08], basketball, golf, cycling, skiing, tennis, and more. Coaches use the performance analysis approach to examine and divide athletic movements into subunits to develop athletes' performance. Improved performance data (such as physical demands and technical components of a sport) better provide coaches and trainers with information about their athletes' skills, motions, and physical traits.

VR sports training allows players, athletes, and fitness enthusiasts to practice whenever and wherever they want. While we will not be doing away with courts, fields, gyms, and ice rinks for good, VR can improve live-action play and practice. Because users' motions are tracked, VR sports training allows users to study and repeat them until they have polished their technique. A Virtual Reality sports environment allows players to speed up their training program even at home, allowing them to run infinite reps in the most realistic environment imaginable, so they can perform at their utmost best when it truly matters. Several types of studies on sports training via VR have previously been undertaken.

Athletes in sports such as football, volleyball, badminton, Etc., have already begun practicing VR due to its numerous benefits, and the findings of such studies have never disappointed. Although, Several studies examined the application of VR in sports [41]. Remarkably, there has been a satisfactory response to the presumption that the acquired knowledge, abilities, and experiences may be applied to actual situations. A rise in performance was noted following VR training sessions for activities including juggling [42], karate [26], throwing darts [03], and baseball batting [35].

Few researchers have examined how well VR training may be designed to learn complicated sensorimotor skills in the real world effectively or how the quality of visual perceptual cues in VR relates to realistic situations [37]. Different measuring techniques, such as eye-tracking [38], EEG [39], and motion capture systems accomplishing whole-body visualization (WB), have been integrated into or paired with VR applications to achieve more realistic VR training [40]. These methods are required to increase the number of physical movements translated into virtual sporting events [41]. There are still discrepancies in perception and the use of VR-adapted abilities in real-world situations [38]. Therefore, research into how VR training recommendations or ideas should be developed to lead to a successful transfer to reality is required.

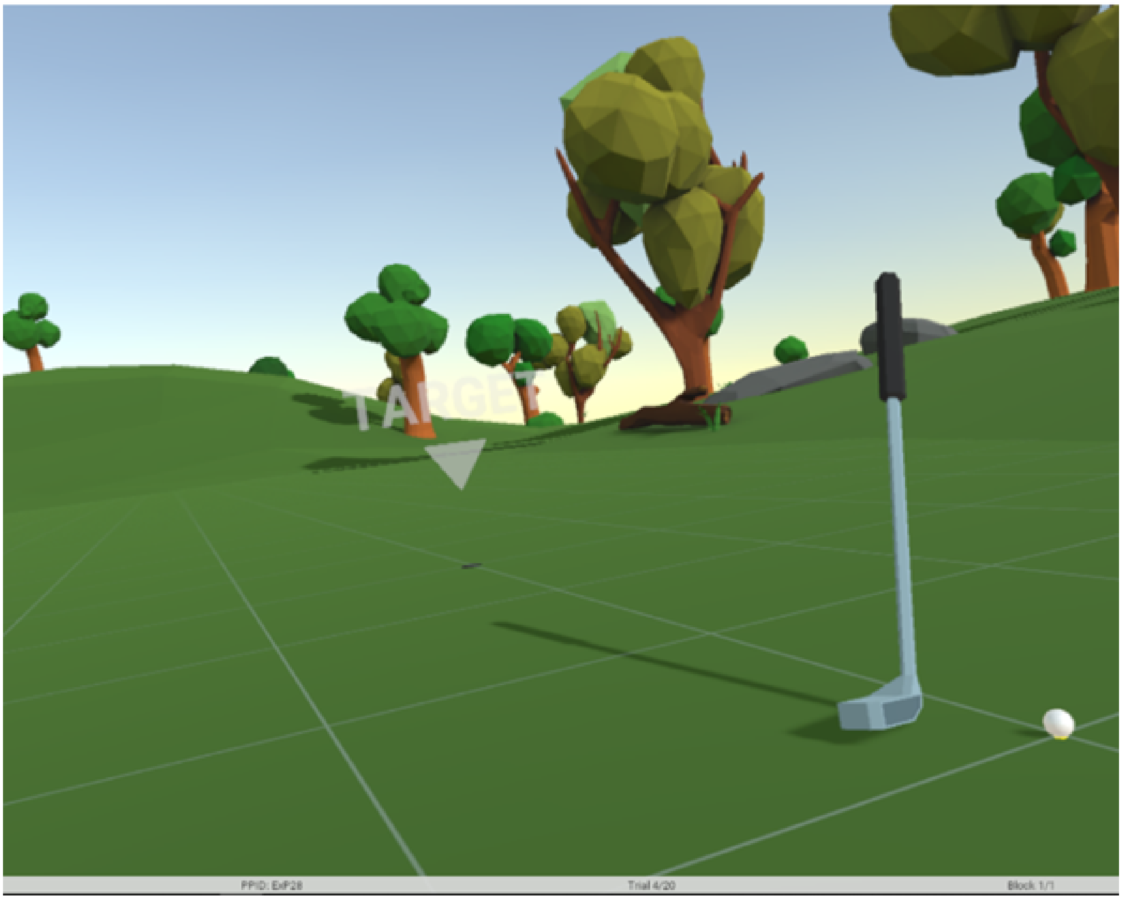
To date, there have been numerous types of research and studies on sports training via VR. For instance, Tennis studies have created virtual environments with an interaction between an immersed subject and a virtual humanoid (Molet et al., 1999; Noser, Pandzic, Capin, Thalmann, & Thalmann, 1997). Similarly, research has been done in football, motorsports, rowing, Etc., to enhance and study one or more skill sets in the users. According to research on the development of free-throw shooting skills in basketball (Covaci et al., 2012), as well as in cricket batting (Dhawan, Cummins, Spratford, Dressing, & Craig, 2016), VR can help athletes train. Athletes can benefit from virtual reality training. VR simulation has also been utilized as a standardized setting to study perception-action coupling in situations such as duels between two players in handball or rugby or the viewpoint of a soccer goalkeeper, as well as a ski jump training simulator. VR has also been used to teach complicated motor tasks such as juggling and the perceptual abilities required to accomplish complex motor tasks [02].

Virtual Characters (VC) and Virtual Environments (VE) are included in the VR training. Physical and social relationships with opponents or teammates, coaches, officials, or auditors illustrate the importance of other VCs in sports. VR athlete training was a significant step forward for coaches. Many studies on many people have previously been undertaken to examine the effects and benefits of VR training. With beneficial findings, people have successfully researched sports such as basketball, football, baseball, and tennis. Technical demands for powerful hardware and software and human demands for user adoption of VR are sport-specific requirements. Thus, to achieve functional fidelity, immersion, and interactivity, technical demands such as realistic rendering and the reduction of latencies (time delays between user action and VR adaptation) and human demands such as the reduction of cybersickness and the implementation of a natural sports setting where sports-specific behavior is allowed and can be analyzed are essential [04].

2.1 VR Training in Golf:

Even though earlier research has shown the best practices for creating VR training tools for athletes, Only a few studies have been conducted to determine how representative training environments are before they are used. However, Harris et al. [23] made an unusual exception to test the fidelity of a VR golf putting simulator by

(a) evaluating professional and amateur golfers in VR and real-world settings (action fidelity measure),
(b) determining the perceptual and cognitive demands of the golf simulation using a self-report measure of task load (functionality measure), and
(c) contrasting the perceived distance to the hole in VR and real-world settings (functionality measure)...

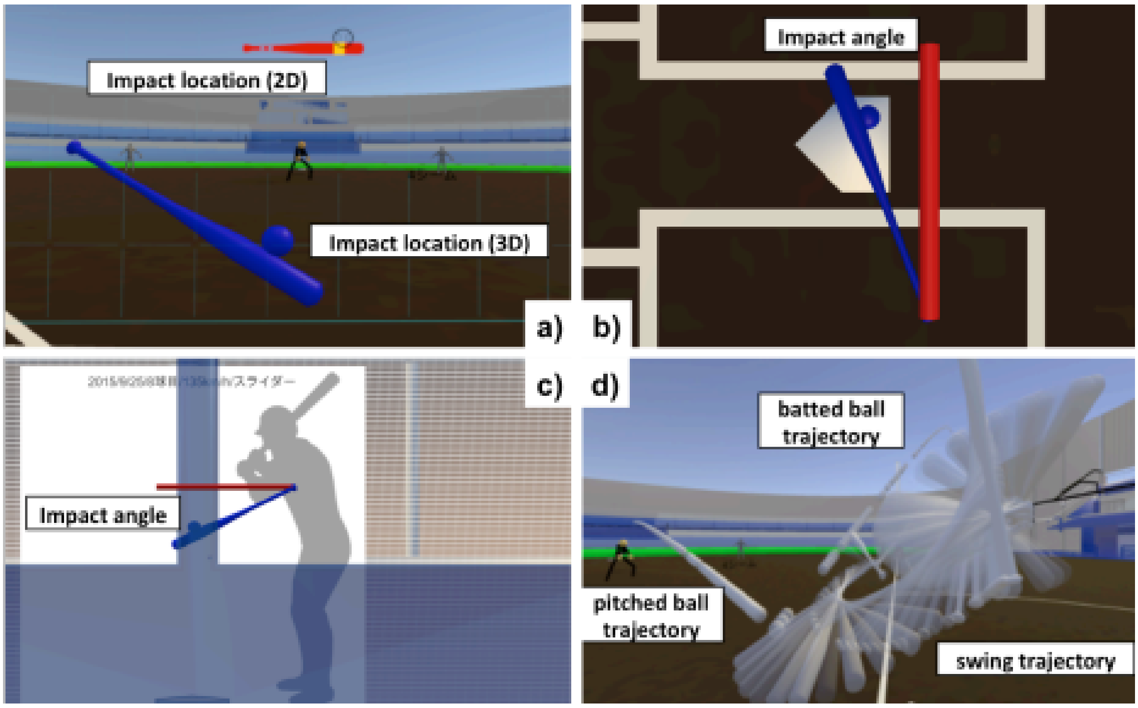


[Figure 2.1: The VR putting task in golf]

The simulation generated work demands equivalent to actual putting, demonstrating that it successfully discriminated against experts from novice golfers. Moreover, a feeling of presence was evaluated, which is the perception of being in a virtual reality environment and is considered to be a mental state that emerges from the integration of information from several senses [22]. According to the results, participants experienced a remarkable presence despite significant participant variability [37]. Nevertheless, this work offers a helpful illustration of how to evaluate and confirm the representativeness of VR settings in sports.

2.2 VR Training in Baseball:

A study conducted by a group of people on baseball athletes, and this is what they concluded: "From the pre-practice to the post-practice sessions, four of the five subjects improved their liner ball striking performance by two to three more liners. The VR-based training approach appears to be successful for these disciplines. On the other hand, subject 4's linear ball count decreased, most likely due to an inability to adjust to the novel VR-based training strategy." These findings indicate that VR training aided practically every participant in improving their swinging abilities. However, the loss in swing quality from one of the respondents demonstrated that if a person cannot acclimate to VR, they have no advantage in utilizing it. Overall, VR instruction benefited baseball training, and the real-world skill transfer also worked well [07].



[Figure 2.2: Swing Information: a) impact location, b) impact angle (top view), c) impact angle (front view), d) swing/ball trajectory]

For the VR group, all subjects received the four pieces of swing information shown in the Figure following every swing during the practice portion. The participants in this study can evaluate their swing data to modify their subsequent swings' timing, pace, or impact angle. This swing data includes -

a) the precise position of the bat-ball impact,
b) the angle of the bat-ball impact (top and front views), and c) the bat swing and ball trajectories.

2.3 VR Training in Basketball:

Haifu Li conducted a study on VR training for basketball, with the focus point being an increase in the concentration of players. The focus of training is one of the critical factors that affect athletes to complete training goals better. Festered devices detected that the athletes' brains were in a higher state of concentration during the VR intervention. The average initial value of the control group was 54.7units, the average experimental value was 56.2units, and the concentration only increased by 1.4 units. This demonstrates that virtual reality training can increase athletes' focus. Throughout the experiment, the concentration of the VR group was constantly greater and fluctuated less than that of the control group. In sports, psychological skills are equally important as physical skills. Therefore, this paper proves that concentration or focus can also be increased with the help of VR. Here, one unit value refers to the Fourier transform of a micro voltage value recorded by EEG equipment yielding a reading between 0 and 100) [09].

Group	Initial Value	Test Value
VR Group	53.9	59.6
Contrast Group	54.7	56.2

[Table 2.3: Comparison of EG values]

As shown in table 2.3, the concentration barely increased by 1.4 units from the control group's average initial value of 54.7 to the experimental group's average initial value of 56.2. This table demonstrates how VR training might help athletes focus better. In conclusion, VR technology does help team members focus during fixed-point shooting instruction, so the training effect is proportional to the concentration data.

2.4 VR Training in Badminton:

After doing a study on VR training on badminton players, a group of people discovered: Understanding essentials and mastering the technique, repeated practice and correcting posture, teamwork, mutual support, and encouraging motivation and learning were all improved by the VR-based badminton teaching method. As a result, VR can be utilized to educate social skills and develop their talents in a fun way that does not put them under too much strain. "Learning" refers to the clash between the students' need to enjoy their session and the teacher's goal to educate during class [10].

Course timetable

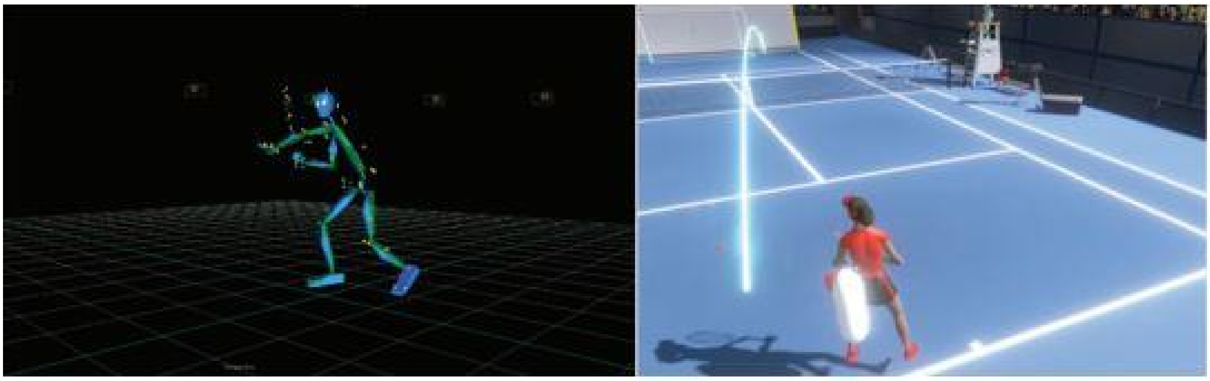
Unit	Session	Learning Content	Process	Dates	Technology	Time
To Know about VR	1	Introduction to VR, tablet, and badminton forehand serve	1.Be familiar with the device 2.Trying to experience badminton service	03/09/2018-05/09	Projection equipment	10 minutes
Between virtuality and reality	2	The virtual and actual practice I	1.Watch the VR video I 2.Take rackets and practice I 3.Watch the video again I	06/09/2018-07/09	Tablet/VR glasses	15 minutes
	3	The virtual and actual practice II	1.Watch the VR video II 2.Take rackets and practice II 3.Watch the video again II	10/09/2018-12/09	Tablet/VR glasses	15 minutes
Tran sform virtuality into realit	4	Record the real ME	1.Actual practice 2.Shoot the action with tablets	13/09/2018-14/09	Tablet/VR glasses	15 minutes
	5	Know myself through VR	1.Watch their own videos I 2.Discuss the differences of actions	17/09/2018-19/09	Tablet/VR glasses	15 minutes
	6	I'm the serving pro	1.Watch their own videos II 2.Actual practice	20/09/2018-21/09	Tablet/VR glasses	15 minutes
Level up in reality	7	forehand serve competition I/game	1.Serve competition I 2.Play game	24/09/2018-26/09	No use	0 minutes
	8	Badminton cognitive test/ forehand serve	1.Cognitive test 2.Serve competition II	27/09/2018-28/09	platform	10 minutes

[Table 2.4: Course Timetable]

Table 2.4 shows the four smaller units that made up the eight classes. The forehand serving unit had eight sessions spread across four weeks. The sampling strategy used in this study has no bearing on the reliability of the qualitative research, which is concerned with the "relationship" of a connection or the consistency of the relationship between the research findings and the study's objectives, participants, methods, or circumstances.

2.5 VR Training in Tennis:

The use of virtual reality has gained popularity in developing perceptual-cognitive abilities in sports. The real-world environment's contextual data and movement patterns must be replicated for VR training to mirror real-world tennis play. Therefore, it is essential to evaluate VR's representativeness before putting skill training treatments into practice. The researcher created a virtual reality tennis setting to determine its representativeness and confirm its usage. Tennis players' movement patterns in virtual reality and the actual world were compared. Participants typically adopted the same stance for groundstrokes in VR as in the real-world setting[24]. Users reported an intense sensation of presence in VR, which is demonstrated by criteria including high levels of engagement, ecological validity, and spatial presence. It concludes that Tennis VR adequately captures the game of tennis. Our discussion focuses on the possibility of skill transfer and the chance for perceptual-cognitive skill training [24].



[Figure 2.5- The marker trajectory models and visuals are created into a humanoid figure in the left image]

The marker trajectory models and visuals are created into a humanoid figure in the left image. In this instance, the humanoid strikes the ground with a forehand motion. An example of a ball trajectory collected using Hawkeye and integrated into the VR environment is shown on the right (note the light blue arch). Notably, the bright blue arch depicting the ball's flight path is eliminated when playing a match.

2.6 VR Training in Table Tennis:

According to Michalski et al. [34], players dramatically improved their real-world table tennis performance after completing just VR training. Since a representative version of real-world tennis was created, it is possible to infer that there is a favorable performance transfer effect from VR-adapted abilities in the actual world [33]. Virtual reality simulators are intended to help users successfully transfer their newly learned abilities to the real world. However, their validity and fidelity must be investigated before they can be used as practical training tools [32].

Understanding the potential integration of VR applications into sports scenarios is made more accessible by the foundation of the research stated above. Summarizing the information, we can notice specific gaps in the conceptual design for VR sports interventions. According to specific research, there is a lack of application of newly acquired talent in the workplace. Within the VR environment, a performance improvement was frequently noticeable, yet the application to the real world is not taken into account. Although studies are comparing various technologies in aiding the development of complicated motor skills, a lot has changed in terms of the opportunities brought forth by new gadgets and their software advancement.

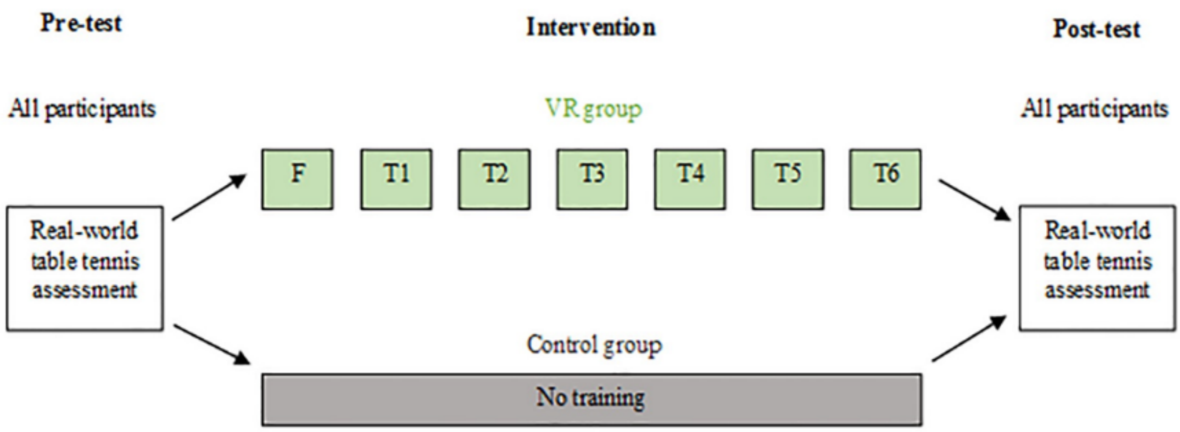
In sports training, visual feedback of one's performance compared to the best is frequently favored since it allows players to recognize and remedy flaws [31]. The authors discussed the advantages of visual feedback on motor learning in many sports but cautioned against adopting it immediately into coaches' learning strategies because research does not consistently support the most effective use of visual feedback.

Additionally, they talked about visual feedback about the athletes' level because even little performance gains may help an athlete reach their potential [31]. There are several sorts of visual input that are taken into consideration. Videos of professionals performing or executing movements can be shown to athletes to help them visualize fundamental movement patterns. It is commonly used in conjunction with the idea that persistent visual input from one's own body results in much higher visuomotor task accuracy than tasks that are not persistent [29]. This presentation may be why the supply of visual feedback could not yet be established as a critical instrument. In order to gain feedback on their performances or improved moves, the athletes were frequently just shown movies rather than being in a completely immersive environment where they could freely choose the views to ensure a three-dimensional image. We believe VR has a vast potential to meet these needs since it allows for the first-person perception of realistic training settings.

Table tennis is an open-skills sport by nature. Open skill sports are where competitors are present, and the setting is constantly changing, unexpected, and fast-paced [28]. (e.g., football, table tennis, boxing, Etc.). Table tennis specifically calls for rapid decision-making, flexible visual attention, and quick interceptive behaviors in response to an interactive opponent. Contrarily, closed-skill sports (like golf, cycling, darts, Etc.) take place in a predictable, broadly consistent, and self-paced environment [28]. The findings from Todorov and colleagues [27] support that training in a virtual environment might enhance closed table tennis abilities (target accuracy). While some research suggests that fundamental closed abilities may be learned in virtual reality and transferred to the real world [28], it is uncertain if complicated open skills, which are crucial in sports like table tennis, can be learned in virtual reality.

In order to maximize the chance for progress, it is vital to think carefully about how the training circumstances might be set up. Gray [25] recently investigated transfer in virtual reality baseball training. A comparison was made between a group that practiced batting repeatedly in the real world, a group that practiced batting repeatedly in a virtual environment, and a group that practiced batting repeatedly while receiving adaptive training in a virtual environment. In contrast to both groups receiving merely repetitive repetition, Gray [25] showed that real-world performance significantly increased when training was adaptive (tuned to the amount of success during training). Adaptive training is predicated on the assumption that a certain quantity of information is required for learning to take place, and this amount changes depending on the individual's skill level and the complexity of the job being trained. Perhaps the purpose of VR training is not to replicate traditional classroom instruction but to incorporate evidence-based practice concepts (such as adaptive training), which are challenging to incorporate into traditional classroom instruction.

The fast-paced game of table tennis was used in the current study to examine the impact of VR training on real-world performance. As opposed to no training, it was predicted that VR table tennis training would significantly improve real-world performance (serving and rallying) on both quantitative aspects (the number of rallies without errors and serving accuracy) and overall aspects of skill quality (ball height, technique, consistency, coordination, and strength)[34].



[Fig 2.6 Outline of study design. There were two participant groups: VR group and control group. All participants underwent a pre- and post-assessment. Participants in the VR group completed a familiarization (F) session followed by six VR training sessions (T1-T6).]

2.7 Conclusion

Several important topics were raised during this literature assessment. This study explains how a VR training system for a specific table tennis skill is built and evaluated. We investigated various virtual world aspects that aid training, such as visual signals. Virtual reality allows athletes to practice in real settings by connecting to a machine. The data collected is so realistic that one can compare one's results and perfect his technique. Coaches have typically utilized video sessions for training their players for future matches or showing them their mistakes. However, virtual reality can reveal much more: it allows us to analyze and optimize an athlete's performance to previously imagined levels. It enables us to picture a game before playing it - not on TV but the field of play. Using data from player movements and previously evaluated opposing team moves, players can observe all tactical possibilities and face a simulated opponent days before the game, thanks to the 3D simulator.

Chapter 3 Application Design

In this chapter, we will discuss the application design in VR and set up in real-time.

3.1 Real Time:

3.1.1 Purpose

Real-time training in table tennis was to familiarize the participants with the game's equipment and rules. It was critical because all of the participants had never or very occasionally played table tennis. The second reason is to assess real-life skill transfer following VR training to confirm that the VR instruction genuinely assists participants in improving their skills.

3.1.2 Implementation

For the real-time study, we have used a standard table. The table's playing surface is 2.74m long and 1.525m wide, and it is 76cm above the floor. The playing surface does not include the tabletop's vertical sides. When a typical ball is dropped from a height of 30cm onto the playing surface, it produces a uniform bounce of around 23cm[18]. The playing surface is green in color. Each 2.74m edge has a white side line 2cm wide, and each 1.525m edge has a white end line 2cm wide.

[Figure 3.1- Real Table tennis]

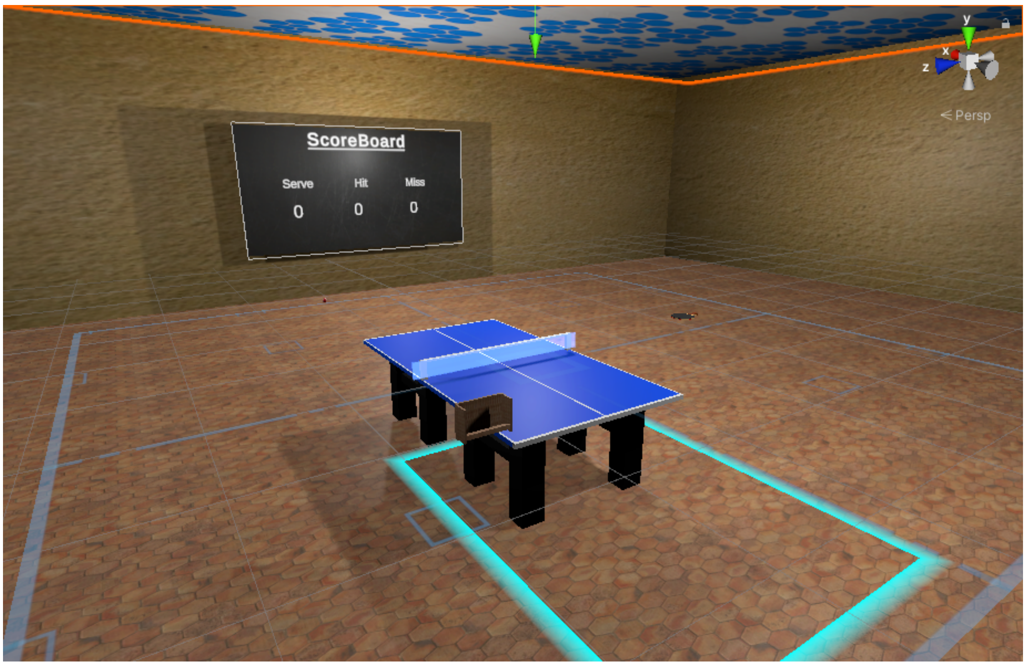
The playing table tennis area is divided into two equal courts by a vertical net that runs parallel to the end lines. The net is 6 inches in height (15.25cm). The net was supported at both ends and did not touch the playing surface area. The table on the opponent's side is divided into nine equal pieces. The participants were then instructed to hit the designated, and the target was randomly proposed to the participants. Each target received 40 attempts, for a total of 360 attempts. They were scored on a hit-or-miss basis.

3.2 In VR:

In the VR training, real-world table tennis performance was evaluated before and after the intervention period. Real-world table tennis was considered when creating the VR table tennis model. In virtual mode, this enables the players to experience real-world table tennis. We have created a virtual environment as close as a real-life experience.

3.2.1 Environment

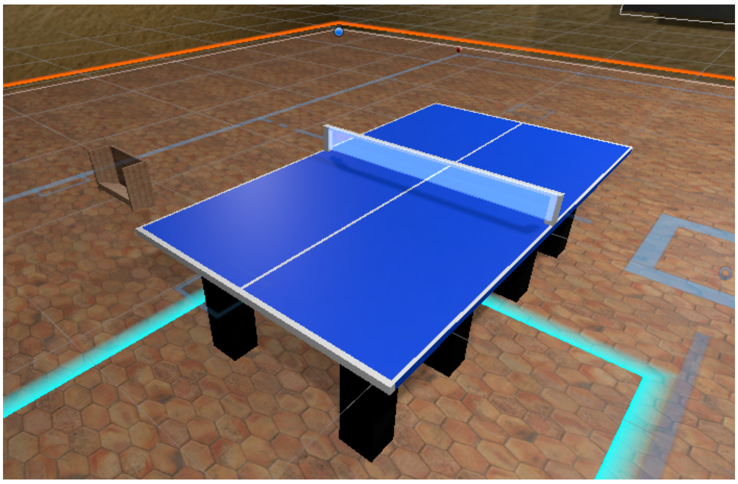
The virtual setting of the table tennis game was very close to that of a typical indoor game. The environment included a room, a scoreboard, a table tennis table, a paddle, a table tennis ball, a basket, and a net.



[Figure 3.2.1- Virtual Environment]

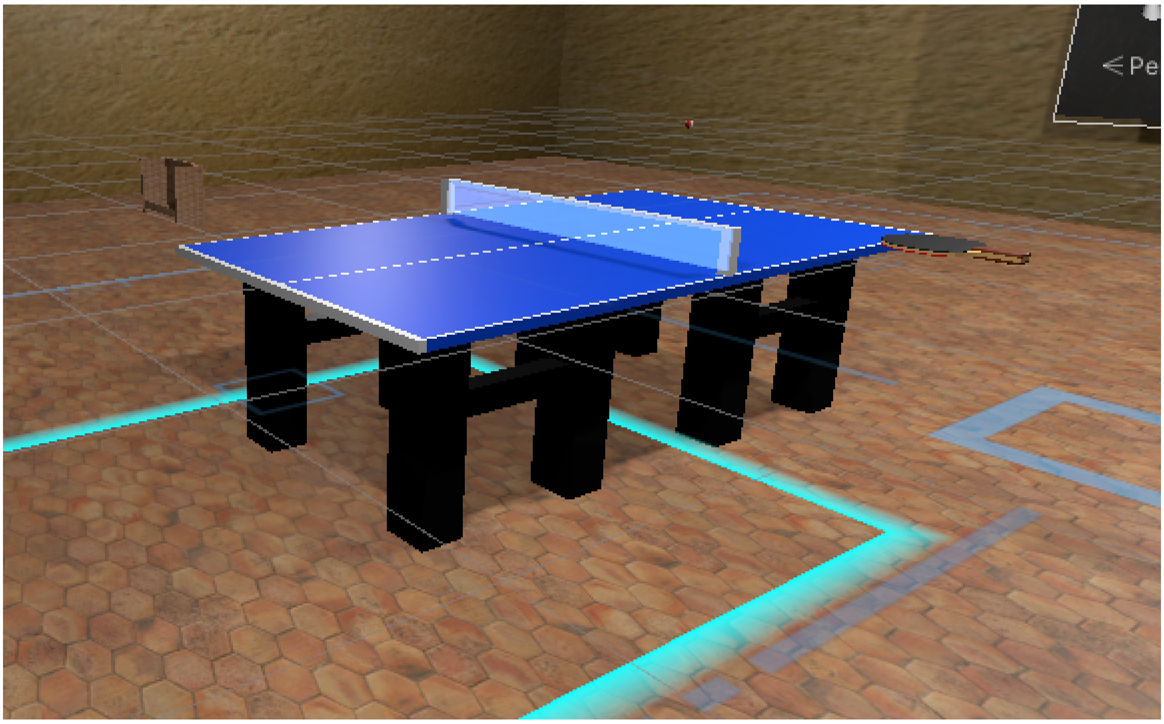
3.2.2 Table

The dimensions of the Table Tennis table were similar to that of a real Table Tennis table. We tried to keep the VR table as precise as possible. Nathan Dewell created the Low-Poly Table Tennis Set asset, which was imported from the unity asset store for free. Low poly 3d models provide faster load times because texturing is often does not need.



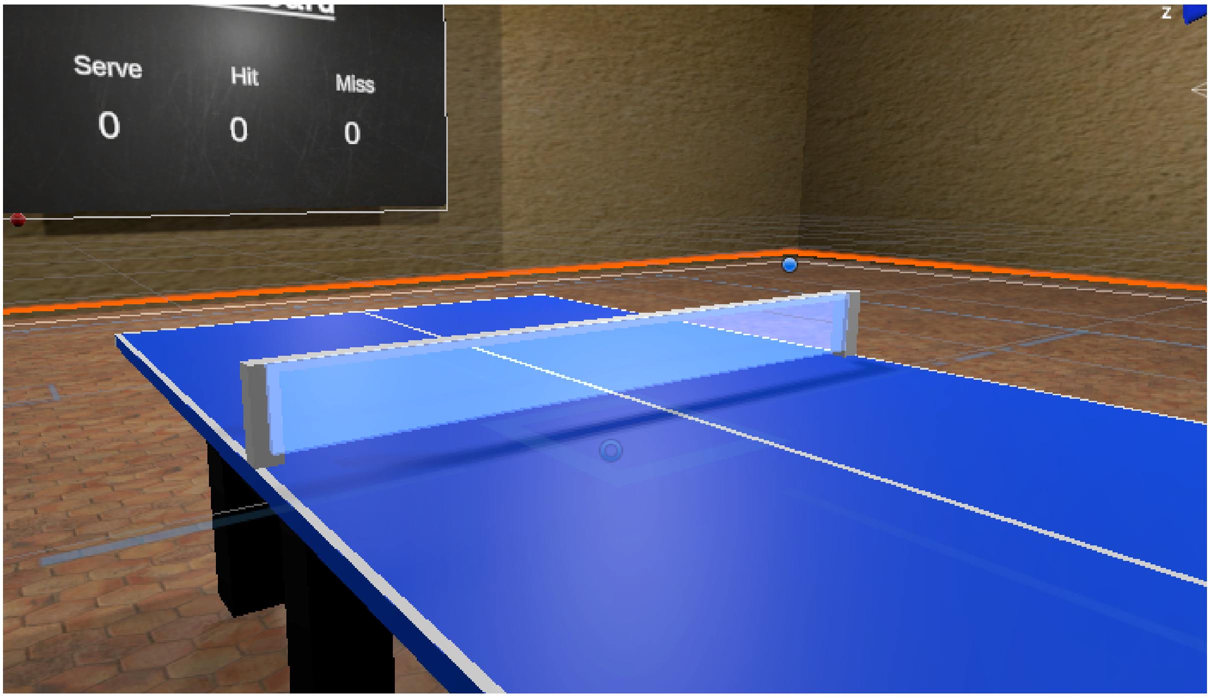
[Figure 3.2.2.1- Table]

The table height is kept according to user convenience, which is close to 76cm in real-time, so the user does not feel any difference from real life.



[Figure 3.2.2.2- Table height]

The table tennis net is used as a barrier, but it should not make it more likely for a player to get a good point. In order to avoid just rolling over onto the receiver's side, a ball that hits the top of the TT net should bounce forward or fall back. In VR, we have also created a semi-transparent net.



[Figure 3.2.2.3- Table net]

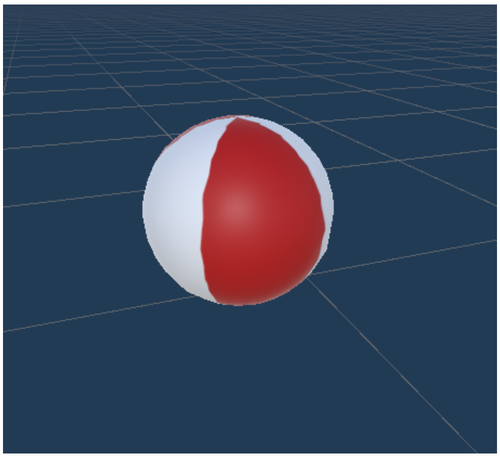
3.2.3 Table Tennis Paddle

Paddlers are table tennis rackets featuring a blade and a handle wrapped with a rubber sponge for better grip in the real world. In VR user, one of the controllers turns into a paddle, and another one participants can see as an HTC controller.

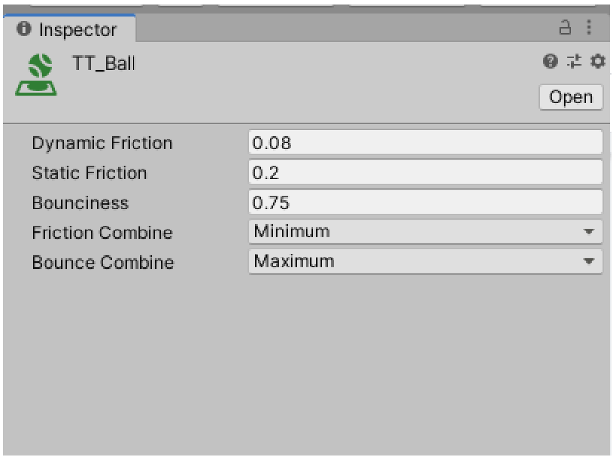
[Figure 3.2.3.1- Paddle]

3.2.4 Table Tennis Ball

The table tennis ball was spherical with a diameter of 40 millimeters and a mass of 2.7 grams (1.57 in). The ball had a bounciness of 0.75[18]. Similarly, we have added a physics material to the ball and adjusted the bounciness accordingly.

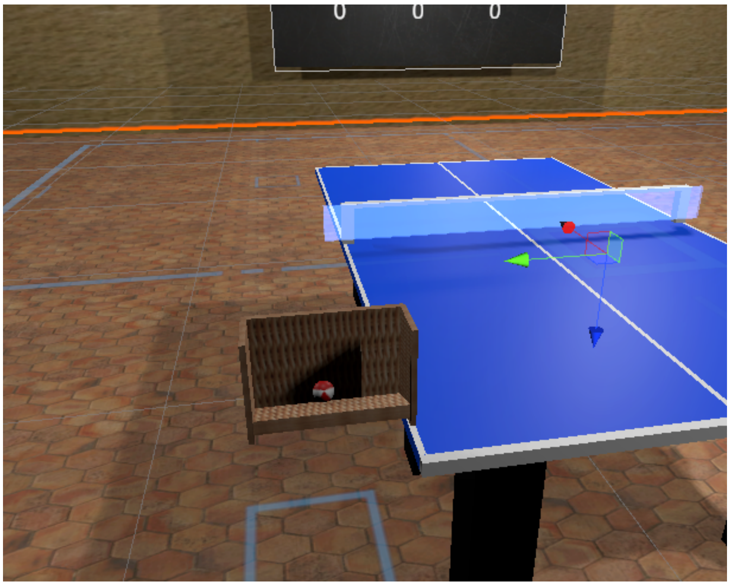


[Figure 3.2.4.1- TT Ball]



[Figure 3.2.4.2- Ball Bounciness]

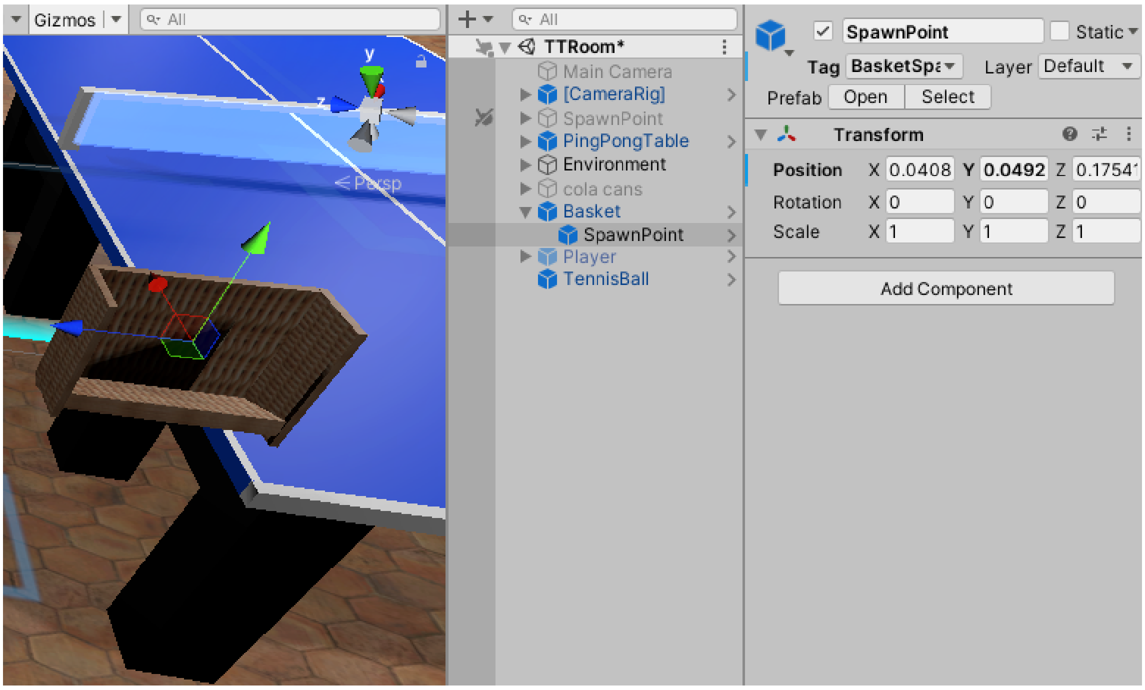
3.2.5 Basket



[Figure 3.2.5.1- TT Basket]

When the ball falls off the table, a user cannot physically go and pick it up in the VE. As a result, a basket was near the player's side of the table. When the ball hits the ground, it is destroyed automatically and spawned into the basket, where the player can pick it up with the help of the controller and continue the practice.

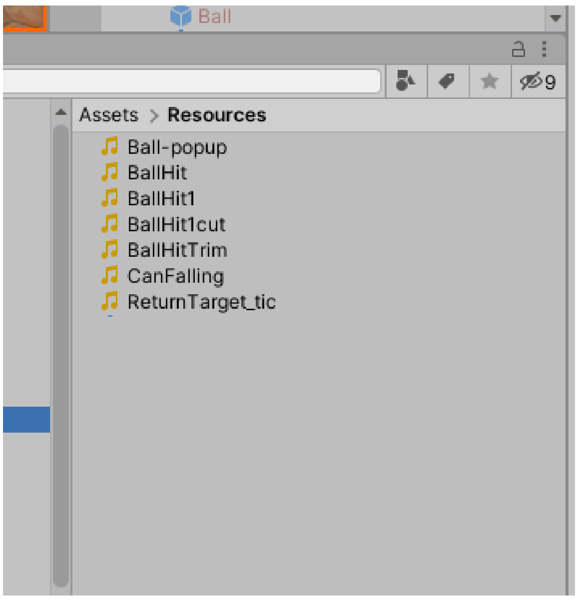
(a) **Spawn Point:** The spawn point has been placed just above the basket so that ball will always fall into the basket.



[Figure 3.2.5.2- Basket Spawn Point]

3.2.6 Audio Feedback

When the ball hits the target, the cola can, the paddle, or spawns to the basket, making a different sound each time. In other words, users get specific sound feedback whenever the ball hits something so they can sense it better.

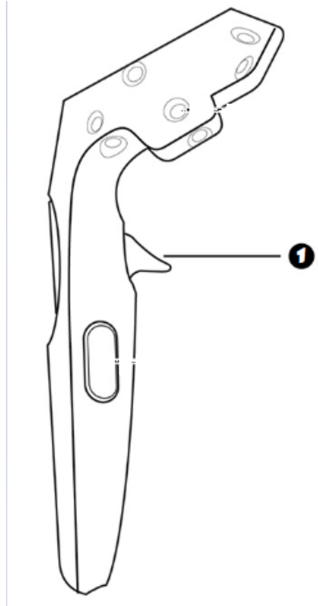


[Figure 3.2.6.1- Audio Source]

3.2.7 Mini Game to understand VR devices

(a) Controller:

The controller's basic information was passed to the participants. It should be noted that in the figure below, button number one is used to pick and throw the ball. In the VE, one of the controllers was also visible to the participants as a table tennis paddle.



[Figure 3.2.7.1- HTC Vive Controller]

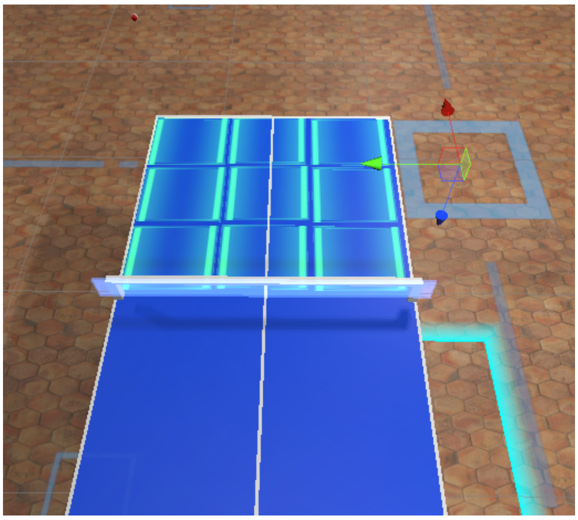
(b) Basic Design of the Mini Game:

[Figure 3.2.7.2- Cola Cans Top View]

In order to get familiarized with the concepts of VE and VR, we have created a mini-game. The game was similar to that of the beer pong game concept. Cola cans were used instead of cups. The participants were told to pick the ball from the basket with the help of a controller and throw it toward the cola cans. The main idea was to get users acquainted with the VR world and the controller's clicks.

3.2.8 Targets

The opponent's side of the target is divided into nine equal square parts. They start from 1 in the upper left corner to 9 in the lower right corner. The participant will receive new random targets each time they attempt, whether they successfully hit the target or not.

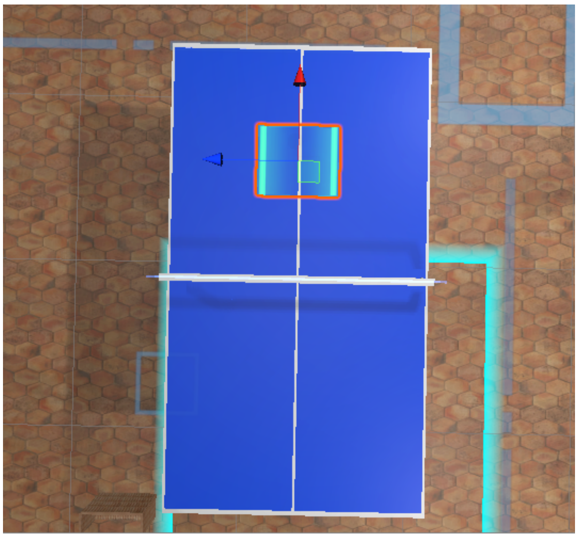


[Figure 3.2.8.1- All Targets]

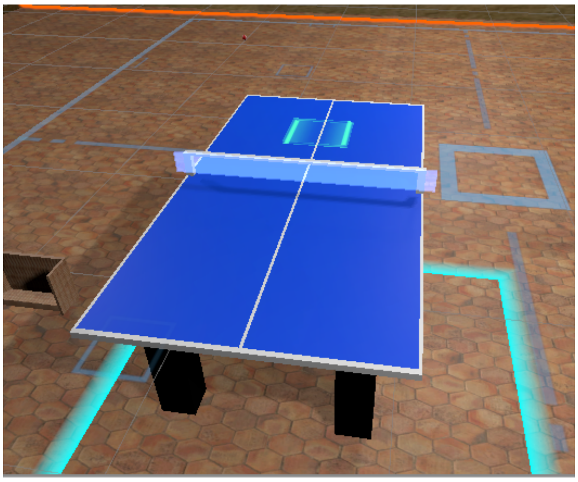
3.2.9 Experiment Logic

The logic behind the experiment was not to give the participants targets in a particular order. Each time, the participant was given a random target. This concept ensures proper and equal training. As once habitual to the pattern, it would have become more accessible for them hence not giving us actual results.

We began by analyzing their week target section using their real-time data. A few users were having trouble hitting the target close to the net, while a few were finding the target from the top corner. So we have started training accordingly.



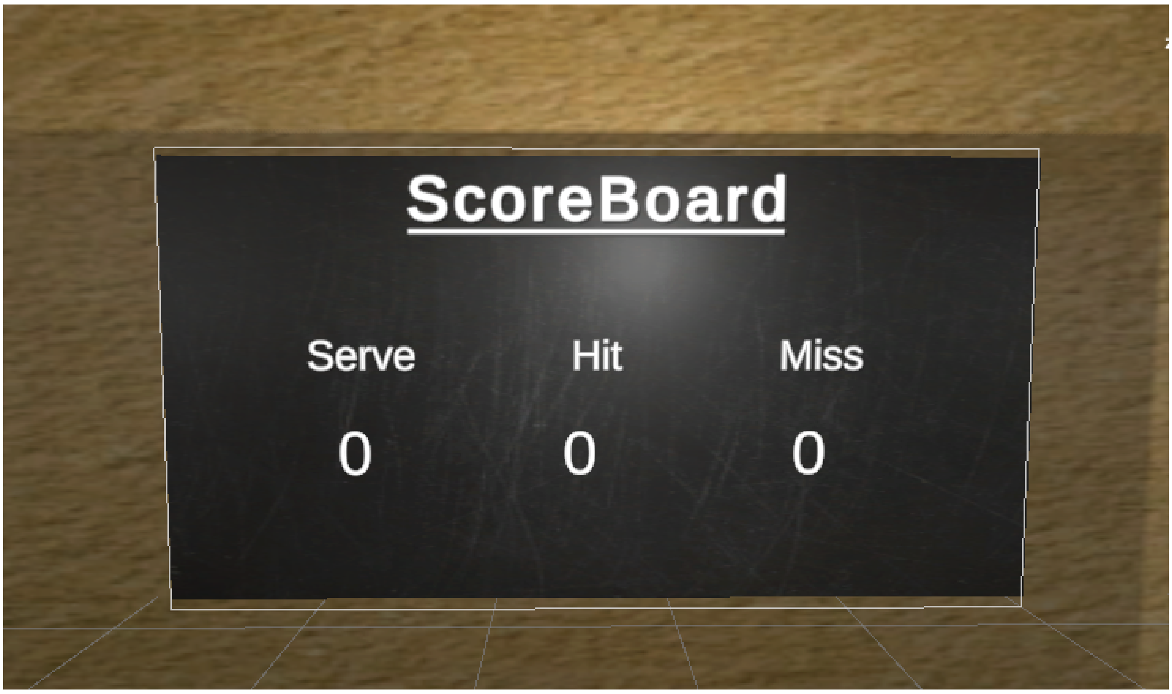
[Figure 3.2.9.1- Random target top view]



[Figure 3.2.9.2- Random target players' view]

3.2.10 Score Board

The scoreboard gave the overall score of all the targets rather than giving the score of an individual to the participants; internally, we have recorded the data target-wise. The scoreboard presented three sections: number of serves, number of misses, and number of hits. One point was given to the participant for each hit or miss.



[Figure 3.2.10.1- Score Board]

3.3 Issue occurred during VR application design:

Throughout this complete VR application design, we encountered a few issues with Unity3D.

3.3.1 3D game Object:

Throughout this investigation, we encountered a few issues with the game's design. First, when creating a game, designers need to include game objects. It could be hard to create own game assets apart from basic objects because it takes a separate course in 3D designing to produce these designs, which may have taken additional few weeks. So we had to settle for a ready-made model from the unity asset store. The Nathan Dewell created Low-Poly Table Tennis Set asset[06] was downloaded for free from the Unity Asset Store. The advantage of using low polygon 3d models is that they load more quickly.

3.3.2 Collision detection:

Secondly, the Unity software has a significant problem with collision detection. The software does not precisely react after detecting collisions between dynamically fast-moving objects; instead, one object passes through the other. Although, the collision can be detected by one static object and one moving object. As a result, the paddle occasionally failed to detect the ball accurately. Currently, this problem is one that the Unity software already has. As a solution, the TT ball was destroyed as soon as it collided with the paddle, and a new ball immediately spawned in the exact location and added a force in the reverse direction. This entire activity can not be visible with human eyes, so the user does not feel lagging while hitting the ball.

Chapter 4 Implementation

4.1 Software and Hardware used

Hardware and software are the backbones of any application, and the same goes for this study. For the experiment, the following hardware and software were used:

Hardware used:

- HTC Vive HMD
- HTC Vive Controller
- Base stations
- High-end Graphics card
- 16 GB of RAM

Software and Assets:

- Unity 3D version 2019.3.0f6
- Visual Studio 2019
- SteamVR Unity Plugin - v2.5
- Windows 10

Unity [Version 2019.3.0f6]:

Unity3D is a cross-platform game engine for creating 2D and 3D game applications. Anyone who wants to effortlessly create 3D games and applications for mobile, desktop, the web, and consoles should be interested in Unity since it is both powerful enough for the professional and simple enough for the beginner.

Unity has been used to build this experiment. It provides an environment to develop a 3D environment or application quickly and can be used to build for different platforms simultaneously. This application has been tested in Windows.

SteamVR Unity Plugin - v2.5 (SDK 1.8.19):

A wide variety of headsets and controllers are compatible with SteamVR. It is convenient to represent a tracked gadget in virtual reality accurately. SteamVR can handle this for the user rather than shipping each unique model and texture for each controller with each application.

This asset is used to enable features with the different HMDs it supports. In this case, HTC VIVE has been used.

4.2 Participants

The experiment was conducted with five different participants. The study was conducted with participants that volunteered to take part in the study. Of the five volunteers, three were male, and two were female. All the participants were within the age range of 24 to 28 (mean 26.2). All the participants were new to the game during the time of participation, and each one of them was familiar with the basic serving rules before starting the experiment. One participant was left-handed, and the rest of them were right-handed. All five participants were fluent in English. None of the participants had any disabilities. The questionnaire given to the participants also included a question about their experience with VR devices, as this might positively influence training. Overall, the experiment generally took about 55 to 70 mins to finish, including the training, breaks, and the actual user experiment.

No participant had a physical or mental impairment that may have prevented them from participating in the study. None of the contestants were accomplished players of table tennis. Before participating, each subject gave informed consent and was compensated €10 for each study.

Variable	VR training
Participants	5
Mean age	26.2
Gender	Males = 3 Females = 2
Hand preference	Right =4, Left =1

[Table 4.2: Sample participants]

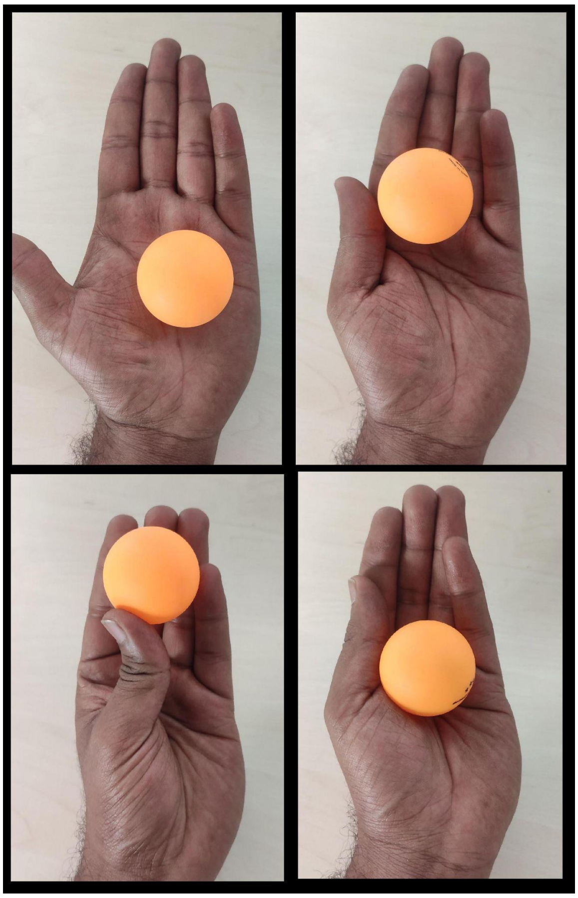
4.3 Implementation: Detailed Description

4.3.1 User Training

User training has been performed entirely differently in the virtual and real-time worlds. In this section, we will discuss it separately.

4.3.1.1 In real Time

Since all the participants had never or rarely played Table Tennis before, they were given "Serve Training" before their actual training. When practicing their serves, they were instructed to place the ball behind the end of the table while still holding it in their hand. The opponent should be able to see the ball. They were told to toss it at least 6" up and strike it on the way down. They were instructed that the ball must strike their side of the table first, followed by the other side, for it to be called a perfect shot, even though only the number of hits was used to examine the results. Figure(4.3.1.1) shows the correct way of holding the ball in real-time. In VR user is grabbing the ball through the controller.



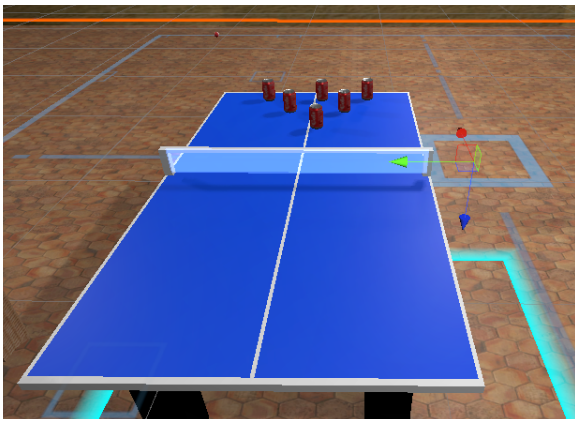
[Figure 4.3.1.1-Correct and Incorrect Ways to Hold the Ball Before Serving.]

4.3.1.2 In VR

[Figure 4.3.1.2.1 Visual representation of the practice game- Top View]

Before beginning the training, participants were asked to practice throwing the ball at the cola cans in a VR game similar to beer pong. This activity was done to ensure that the user has no problems with VR controllers and clicks. Because many users were unfamiliar with VR devices, the goal of this was to familiarize them with the concept and controllers of VR. Figures (4.3.1.2.1 and 4.3.1.2.2) show us how the game looked.

After their proper training on serving and a demo game of beer pong with coke cans on VR, the participants were finally ready to start their Table Tennis training on VR. They were also instructed to play a "Real-time' game of Table Tennis beforehand, and their data were recorded for analysis.



[Figure 4.3.1.2.2 Visual representation of the practice game- Player View]

4.4 User Experiment

Finally, their training started. Each participant has five sessions of VR training and two real-time game sessions (one before and one after VR). They have to hit the target which was given to them. The other side of the table is divided into nine equal parts, and each participant got 40 attempts for every target, which was randomly given to the user, giving a total of 360 targets per session. The final score was based on two categories: hitting and missing the target. For each hit or miss, 1 point was given. In [Figure 4.2.10.1- Score Board], you can see the scoreboard for the game.

In real-time, the participants had a session of 60-70 minutes each that included training and break. While in VR, each participant had a session of around 50-60 minutes each. However, there was an inevitable side-effect observed during the experiment. One of the users faced a problem related to the field of view (FOV). Per his comment, 'While focusing on a serve (bat and ball), he could not sense the complete table.' The visible FOV of the HTC Vive is 110 degrees[21], and the FOV of both human eyes is 180 degrees. Another user faced a similar problem, and when he was focusing on the corner of the scene, he was getting a little VR sickness [Dizziness].

Chapter 5 Experiment

5.1 Aim of the Experiment

The experiment aims to study the Effectiveness and efficiency of Table Tennis serve training in Virtual Reality and skill transfer to the real world. *Table tennis* is a game that demands players to move about and react to outside stimuli. However, our focus was solely on improving the participants' serve techniques. Users are involved in a competitive table tennis match with an opponent using the sport's formal regulations. The number of serve locations, serve speed, and opponent ball spin correlates with increased difficulty. Although, in our research, there was no opponent. Random targets were supplied to the participants. The participants had never played table tennis before or had only occasionally.

We did not incorporate "spin" in our training. Since the players in VR could not feel the actual paddle and ball, aural feedback was provided for each action. To make the experience more authentic, each action, such as hitting the ball with the paddle, hitting the targets with the ball, seeing the scoreboard and basket, and spawning, has its distinct sound.

5.2 Procedure to execute the study:

This experiment was conducted in four stages:

- the first real-world table tennis session
- a VR mini-game (similar to beer pong)
- VR training
- the final real-world table tennis session

Five distinct users were used in this investigation. We were instructed to attempt 40 serves for each target throughout each session. Here is the outcome for all users and sessions combined. Each participant has seven sessions in total—2 in real-time and 5 in virtual reality.

In light of the fact that none of the participants had ever or only occasionally played table tennis, "Serve Instruction" was taught to them before their actual training. For the serving practice, they were told to keep the ball in their hands and place it behind the end of the table. The ball should be visible to the opposition. They were instructed to toss it at least 6" in the air and strike it as it descended. Although the results were solely evaluated based on the number of times they struck their target, they were taught that the ball must strike their side of the table first, followed by the opposite side, for it to be declared a perfect shot. This session was crucial for comparing the before and after impacts of VR training on participants and determining the degree to which abilities are transferable to the real world.

Participants were asked to practice throwing the ball at the cola cans in a VR game resembling beer pong before the instruction started. This training ensured the user had no issues with VR controllers and clicks. This purpose was to acquaint consumers with the concept and controls of VR devices because many were unfamiliar with VR technology.

The players were finally prepared to begin their Table Tennis training in VR after receiving correct instruction on serving and playing a demonstration game of beer pong using coke cans in virtual reality. Finally, they began their training. Each participant received two real-time game sessions and five VR training sessions (one before and one after VR). They were instructed to hit the designated objective. Each participant had 40 attempts for each target randomly assigned to them on the other side of the table, giving them 360 targets per session. The other side of the table was divided into nine equal portions [Figure 3.2.8.1]. Two categories—hitting and missing the target—were used to determine the final score. For each hit or miss, 1 point was given.

All participants received a final VR session in real life towards the conclusion. We noticed a significant difference. The number of hits also showed a notable improvement. If we examine all of the participants' hits and misses, the error rate dropped from 49% (from the first time) to 29%. (last time). Similar to this, the mistake rate also dropped from 48% to 30% with VR training.

5.3 Problems that occurred during the study:

5.3.1 Selection of participants:

Even while this experiment was a success, it had drawbacks, just like any other study. First of all, we chose our volunteers in a somewhat haphazard manner. We made a minimal effort. Even though we knew everyone's inexperience, we did not ask many questions of the other participants. An essential flaw in the experiments is the small number of participants. Only five people were included in the initial user study. Larger sample sizes are required to statistically examine the data. Moreover, draw more definitive conclusions regarding the value of the research.

5.3.2 VR sickness:

Secondly, one of the users experienced VR dizziness; as he focused on the scene's corner, he felt a little dizzy (dizziness). "Nausea, headaches, and dizziness" are some signs of VR sickness, comparable to motion sickness. Because the severity of the symptoms varies widely from person to person, not everyone will experience it in the same way. Because the VR's orientation and point of view change, some people get VR sickness. As a result, we had to deal with yet another problem.

5.3.3 Intervals:

The intervals between the sessions were the third issue we ran into. The entire course of instruction was anticipated to end in a week (2 days of the real-life session and five days of VR training). However, the participants were not available nonstop for seven days. There were pauses of two or more sessions in between. Since continual training is required for trials like these, it is unknown if gaps or breaks in the training sessions will benefit or harm the outcome.

5.4 The Sample Participants

Before the VR training began, we tested the entire study with one participant. It was intended to check how effective this study could be. We explained the proper table tennis regulations throughout this practice session. The pilot study was conducted -

- To verify that the user study can finish within the desired time frame, which is 60 minutes.
- To determine if a candidate can comprehend the study's goal and the instructions.
- Before doing the final user studies, obtain comments and suggestions regarding the user study and make additional modifications.
- To get feedback and comments related to the study and to make additional changes in the application before starting the final user studies.

Based on the feedback and results from the pilot user study, changes were made to the application to make them clearer and easier to understand for future participants. In order to be safe, a break in the VR session has been added for 5 mins to avoid VR sickness as some participants might be entirely new to the VR environment.

5.5 Results of the pilot user study

We have carefully observed the pilot study participant's performance to determine the aggregate hits and misses. In their first real-time game, without any VR training, the player's overall hits and misses ratio was 71.11% and 28.89 %, respectively. The player's performance changed after the VR instruction and training. The participant's score increased by 75.00% hits, and 25.00% misses in their final real-time practice. This study shows that the error rate decreased after the VR training.

5.6 Apparatus Used

Real-world table tennis setup: A regulation-sized table tennis table, PRO-SPIN tennis rackets, and 40mm PRO-SPIN table tennis balls were all included in the table tennis setup.

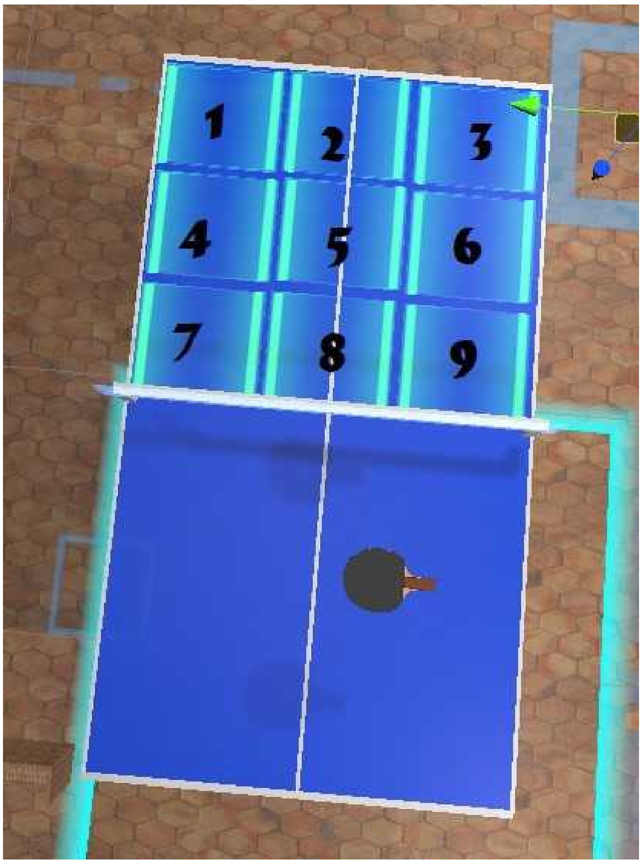
VR apparatus: A head-mounted display called the HTC Vive was employed (HTC, April 2016; technology provided by Valve Corporation). A 360-degree virtual world that moves in real-time in line with the participant's motions is displayed on immersive stereoscopic head-mounted displays (HMDs) like the HTC Vive, giving the user a sensation of presence. Users had to wear the HMD and grip two controllers to participate in the virtual world; one of the controllers served as a tool to mimic ball dispersion and the other as a table tennis bat. By letting users who need to wear glasses or contact lenses while using the device, the HMD accommodates users with visual impairments. Four base stations were built in each corner of the 4000mm × 4000mm room, where the VR equipment was utilized to enable room-scale tracking.

5.7 Experimental Design:

Many users were unfamiliar with VR technology for practice in the real world, so we urged them to practice by playing a VR version of a game like beer pong, where they had to throw the ball at the cola cans to get more comfortable. This process was done to ensure the user could handle VR controllers and clicks without any problems. Order to play table tennis in the virtual world helped the participants become accustomed to it. A baseline for each participant was established after careful observation of the pretest and thorough notes on each ability level. Each target had a maximum of 40 rounds that the participants were free to play during each session. All of them were carefully monitored and recorded. In order to determine the points in this instance, we may divide the serve into Hit and Miss. Depending on whether it reads 1 for a miss if the target is missed. Moreover, 1 for a hit if the target is hit while serving. Higher scores demonstrated better skill development.

Based on how well each participant performed on the table tennis tasks, a numerical score was generated for them. Scores were determined based on how many serve shots successfully hit the target. A shot was considered good when the participants were able to hit the target as instructed. The opposing team's side of the table was divided into nine equal square sections [figure No.], and each participant received 40 attempts on one target in each session. The score was given based on 'hits' and 'misses.' One point was given for each hit or miss, and it was 0 for any other situation. Serving accuracy was evaluated using target accuracy.

The number of targets a player may hit when serving was used to calculate their score, which ranged from 0 (no target hit) to 1 (targets hit).



[Figure 4.6.1- All targets]

Chapter 6 Result

We hardly ever have access to all of the users. To estimate the unknown population numbers, we must instead rely on sampling. We must conduct statistical analysis on the available data size to determine how our sample will affect the enormous population.

Even our best estimate from a particular sample will be roughly accurate when we do not have complete access to the entire population. Therefore, it will be less accurate the smaller the sample size. We need a way to know how accurate our estimates are. To do so, we need to calculate the confidence intervals[05].

6.1 Statistical analysis:

Statistics analysis is a scientific method of analyzing numerical data to help us make the best possible interpretations and applications. This method indicates that statistics aid in transforming data into information, i.e., data that have been analyzed, comprehended, and are beneficial to the recipient. The researcher needs to understand the ideas underlying the fundamental statistical analysis procedures employed in scientific research. Statistics analysis will assist in conducting a well-designed study that will yield valid and reliable data.

	Before VR training	**After VR training**
Total Hit by User1	119	194
Total Hit by User2	130	276
Total Hit by User3	161	215
Total Hit by User4	122	222
Total Hit by User5	159	231
Mean	138.2	227.6
standard deviation	18.17030545	27.10424321

[Table 6.1.1: total number of hits by each user: paired data]

6.2 T-Test:

To compare the means of two groups, a t-test statistical test is used. It is frequently employed in hypothesis testing to see if a procedure or treatment truly affects two groups or whether the population of interest differs from one another.

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{(s^2(\frac{1}{n_1} + \frac{1}{n_2}))}}$$

In this equation, t stands for the t-value, x1 and x2 for the means of the two groups under comparison, s2 for the combined standard error of the two groups, and n1 and n2 for the total number of observations in each group.

A bigger t-value indicates a more significant difference between the groups since it demonstrates the difference between group. If the mean difference is greater than the pooled standard error.

A statistical hypothesis test, the one-tail t-test, examines if an unknown population mean differs from a given value. Use a one-tailed t-test to determine whether one population mean it is higher or lower than the other.

The two-sample t-test is commonly referred to as the independent sample. The T-test determines if the population mean of the two groups is unknown and equal. A two-tailed t-test should be used if you only care about whether the two populations vary from one another.

Why we have chosen the one-tail t-test: If the study has a hypothesis regarding the direction of an effect since it has a higher power to detect an effect, then a one-tailed test should be used. However, we must think about the consequences of missing an effect going the opposite way before responding.

Type of t-test: Before selecting the t-test, one must consider whether the groups being compared are drawn from one population or two.

- Use a paired t-test if the groups are drawn from the same population.
    - We are using this method because we have paired data.
- Use a two-sample t-test if the groups are from two separate populations (independent t-test).
- Use a one-sample t-test if only one group is compared to a standard value.

The p-value, also known as the probability value, indicates the likelihood that one's data happened under the null hypothesis. The p-value in statistics is the probability of receiving values at least as extreme as the obtained outcome of a statistical hypothesis test, given that the null hypothesis is valid. The p-value is used instead of rejection points to determine a minor significance level at which the null hypothesis would be rejected. In order to determine whether to reject the null hypothesis, P-values are utilized in hypothesis testing. You are plausibly to discard the null hypothesis the smaller the p-value.

One Tail T-test:

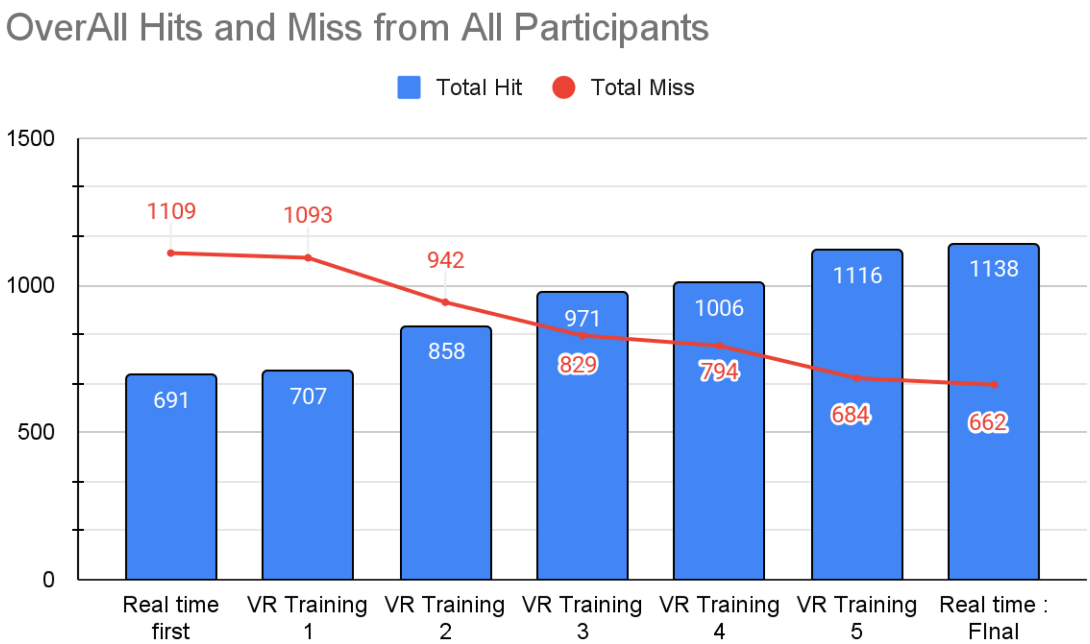
Did the after VR training users perform significantly better than before training?

p = 0.002480161

The most typical threshold is $p < 0.05$, which means that you should only expect to see a test statistic as severe as the one obtained by your test 5% of the time. However, the threshold depends on your field of research; certain fields demand 0.01, even 0.001.

6.3 Analysis

This study has been conducted on five different users. In each session, used asked to attempt 40 serves for each target. Here is the overall result for all users and all sessions. Each participant includes seven sessions [2 in real time + 5 in VR]. Y-axis represents the number of attempts in the chart.



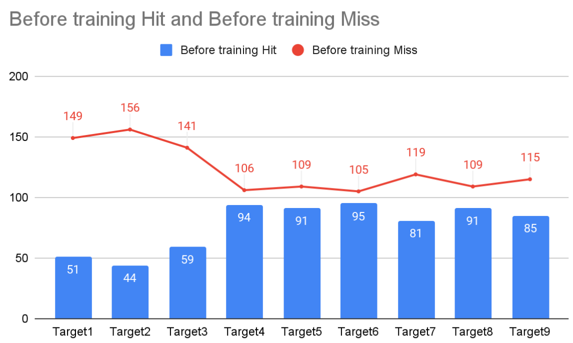
We have carefully assessed each participant's performance to determine the aggregate hits and misses. The data above allows us to contrast real-time player performance without VR training with real-time performance after VR training. In their first real-time game, without any VR training, the player's overall hits and misses recorded 38.39 % and 61.61 %, respectively.

The player's performance changed dramatically after five VR training sessions. We began noticing changes between the first and second VR training, and it steadily persisted until the fifth VR training. The participant's score increased by 63.22% hits and 36.78% misses in their final real-time, which is a 64.67% increment in the hit section.

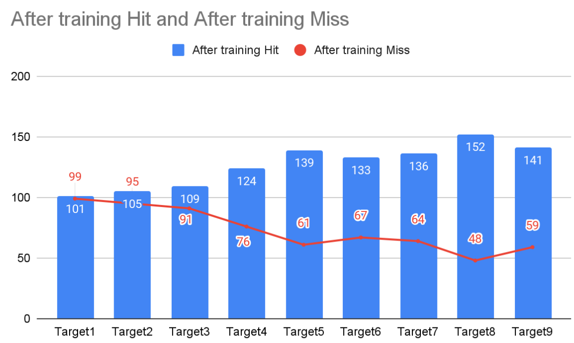
The statistics reveal that there is not much difference between initial real-time training and first VR training or between last real-time training and VR training. As a result, we may say that virtual reality and real-time training are very similar.

Targets 1, 2, and 3 provide comparable results because they are farther away from the player and closer to the edge. As a result, in attempting to avoid hitting the ball beyond the table, participants missed the targets, increasing the error rate. Similarly, targets 4–9 show similar results since they were closer to the player and more accessible to hit than targets 1–3. Hence the error rate was reduced towards the final real-time training.

Real-time[Before training]



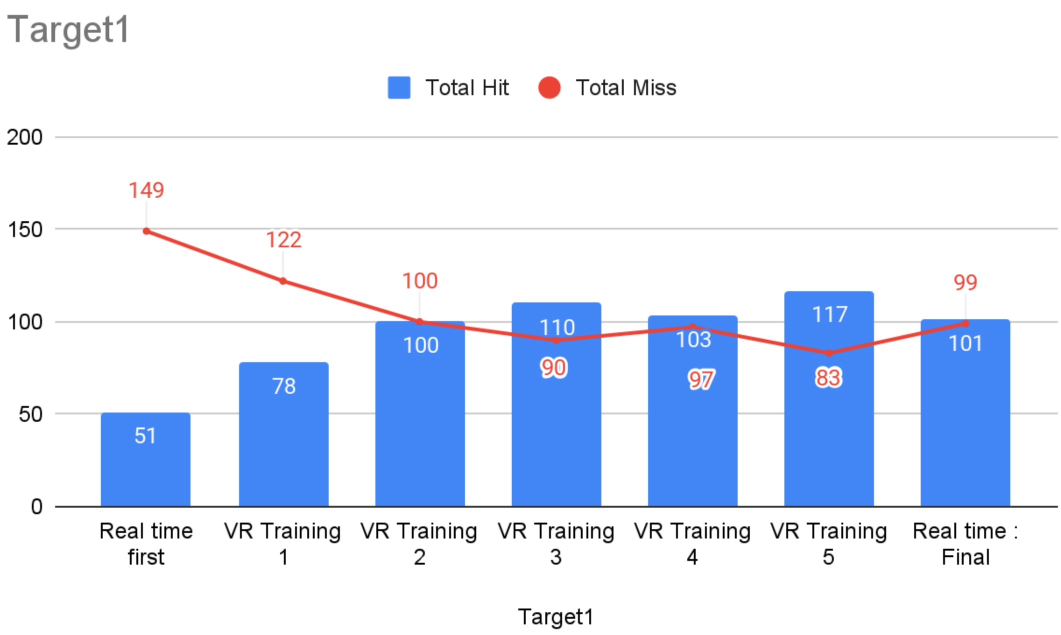
Real-time[After training]



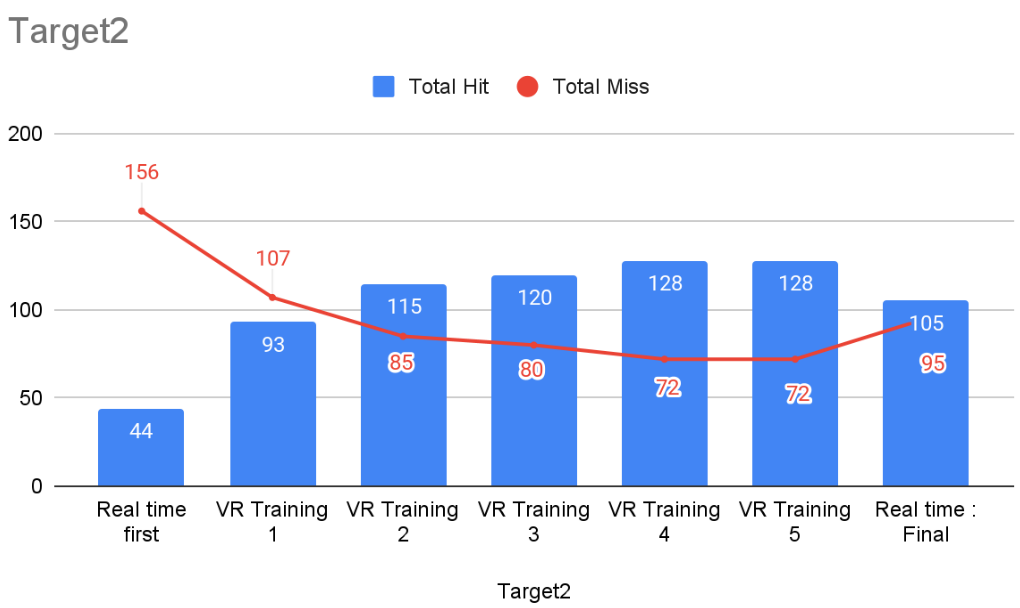
Overall performance in VR shows positive growth, and the number of hits also increases for each target. The stark difference between hits and misses was discovered when we carefully compared the real-time graph before and after VR training. Errors were recorded between targets 1 to 9. Also, we can see that targets 1, 2, and 3 show the highest variation in the number of hits after the VR training. Whereas targets 4, 5, and 6 show the lowest variation. This is because targets 4, 5, and 6 already had high hit scores before the training due to their favorable position at the center of the table, which was more accessible for the participants to hit. Moreover, each target analysis of players is mentioned below.

One Tail T-test: *Did the final VR training users perform significantly better than first VR training?*

$$\mathbf{p = 0.000566427}$$



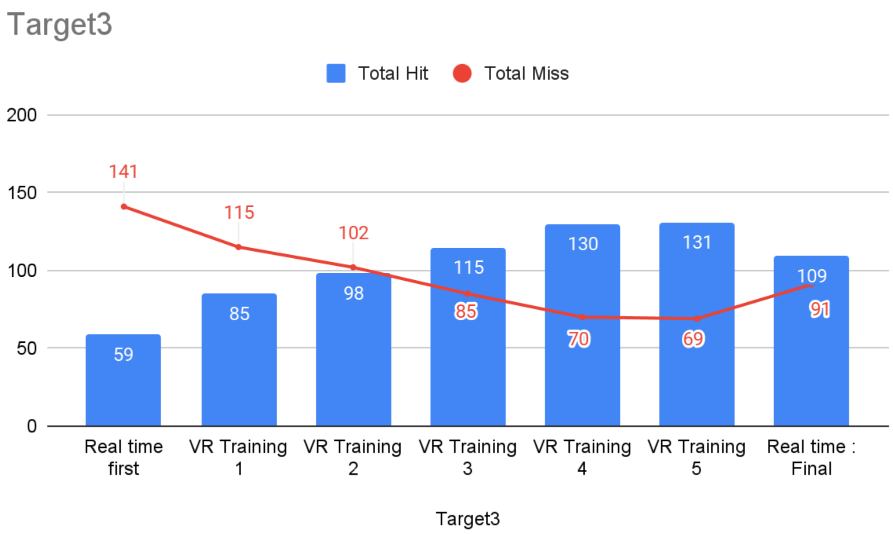
Target 1 : Without VR training, the player's hits and misses differ significantly in real-time, roughly 25.50 % and 74.50 %, respectively. Following VR training, this has grown. We can see a 52.94% increase in hits in the second VR training compared to the first. After the second VR training, there were tiny variations in hits and misses until the fifth VR training, even though errors drastically changed in the final actual time result.



Target 2 : Without VR training, the player's real-time hits and misses differ significantly, by around 22% and 78%, respectively, for target no 2, which was placed at the center top of the table and far from the participants. After VR training, the number of hits has increased. Comparing the results of the second VR training to the results of the first VR training, we can observe an increase in hits by 23.65%.

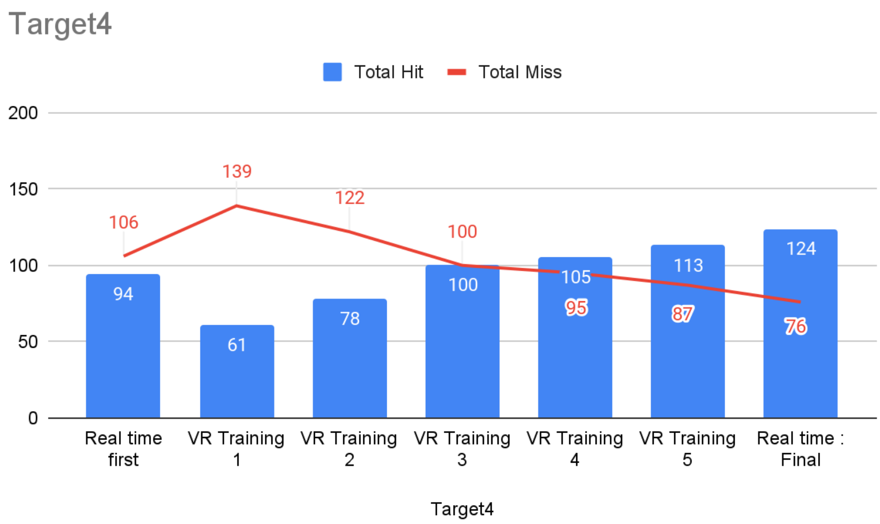
From the second VR training onward, there were only very slight variances in hits and misses.

As can be seen, the error rate has deeply dropped from the first real-time training to the first VR training. However, the error rate increased from the last VR training to the final real-time training. It shows the stark difference in skill transfer between the real-time and VR difference of target two. Similar results can be observed for targets 1 and 3.

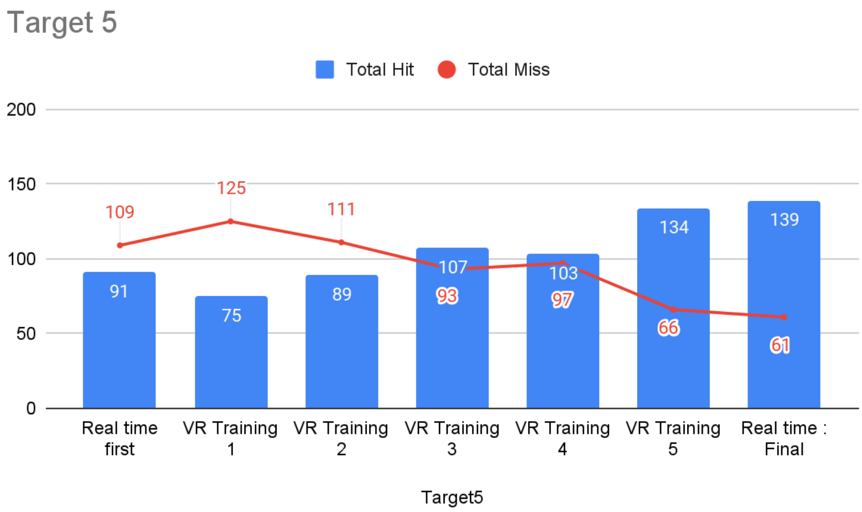


Target 3 : Overall the miss rates have dropped, but we can see a massive change in data between real-time to VR and VR to real-time transformation. As shown, the error rate dropped from the initial real-time training to the last VR training. However, the error rate climbed slightly in the final real-time session, which seems to be similar behavior for all targets which were far from the participants. We can observe that targets 1, 2, and 3 show similar results since they were farther and towards the edge.

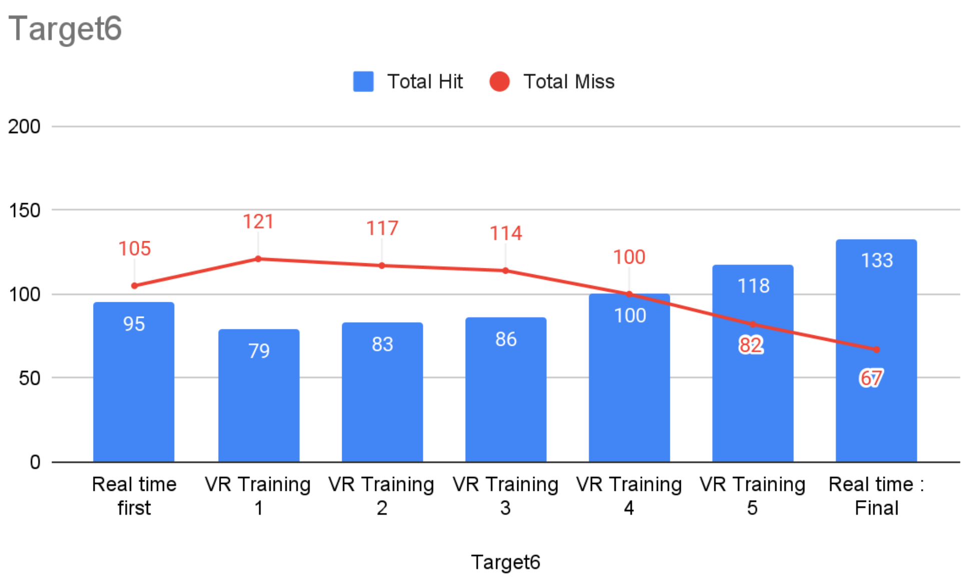
After the complete VR training, the number of hits increased. From the second VR training onward, there were only very slight variances in hits and misses. Even though errors significantly decreased in the actual time immediately after the VR training.



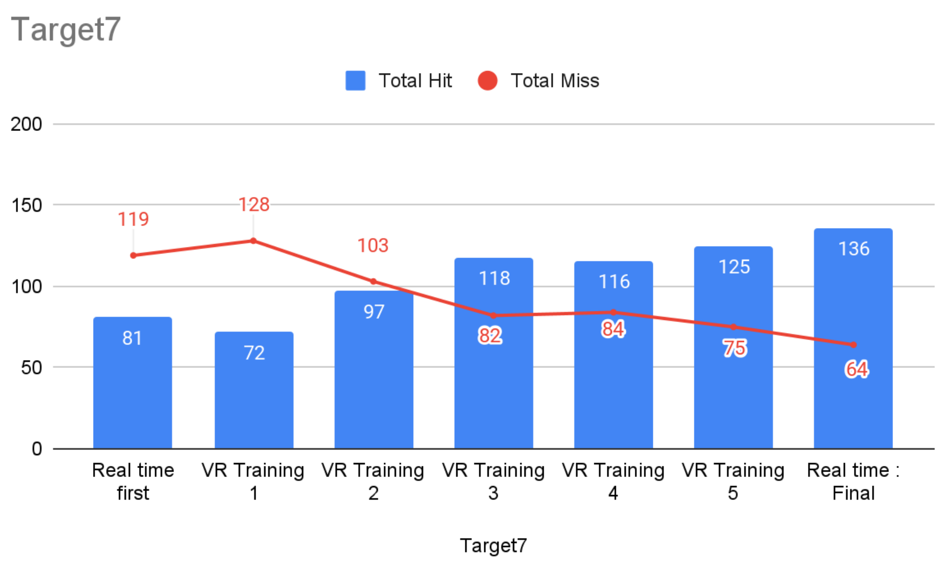
Target 4 : The error rate of miss in the first VR training is 16.5% more than in the first real-life session. With the user data, we can conclude that the error rate increased from the first real-time training to the first VR training for target number four. Then, it started decreasing till the final real-time session.



Target 5 : The error rate of a miss for target 5 is 8% higher in the first VR training than in the first real-life session. Errors were significantly decreased in the final real-world session after the VR training by about 24% for misses and increased by 76% for hits. We can observe that the variation of results during VR training was non-uniform. Also, we can see that targets 4, 5, and 6 had high hit scores before VR training.

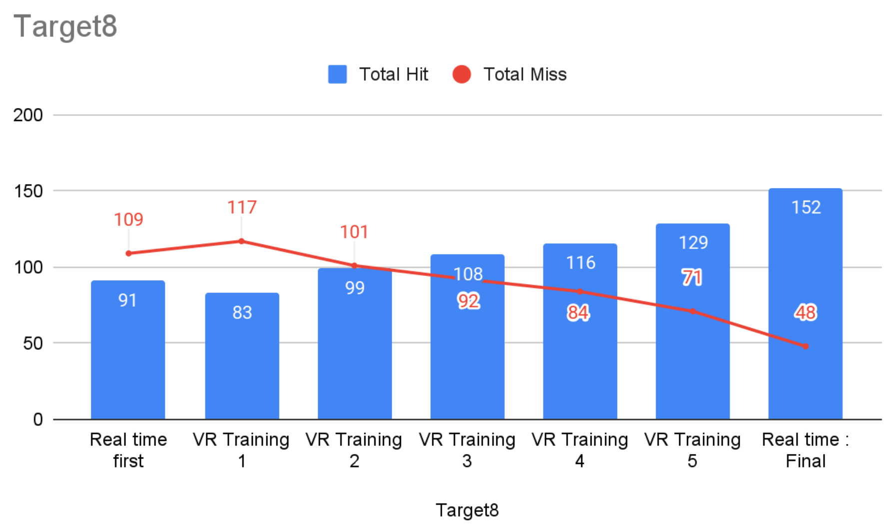


Target 6 : Compared to the first real-world session, the mistake rate in the first VR training is 8% higher. The error rate was significantly reduced in the final real-world session and which increased 81% accuracy to the target. A sharp increase in error rate can be seen from the first actual time session to the first VR training for target 6. Also, the error rate started decreasing from the second VR training.

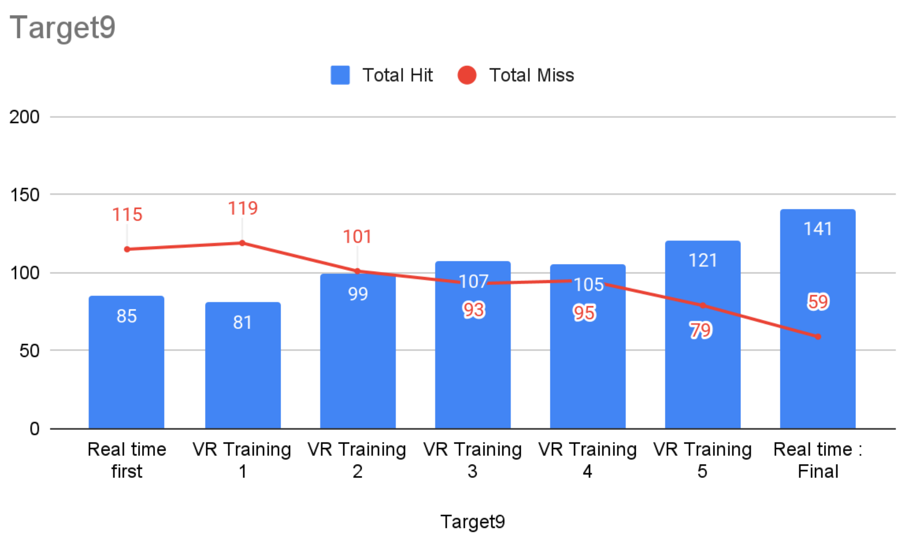


Target 7: Without VR training, the player's real-time hits and misses differ significantly by around 40.50 % and 59.50%, respectively. In this case, the initial VR training's mistake rate is 5% higher than it would be in the actual world without VR training. When comparing the results of the second VR training to those of the first VR training, we may see a little increase in hits of around 12%. After the second, particularly in the third and fourth VR sessions, only minor differences in hits and misses were seen.

After the VR training, errors significantly decreased by 46.21%.



Target 8: Without VR training, the player's real-time hits and misses differ significantly by around 45.50% and 54.50%, respectively. Errors were significantly decreased in the real world by about 30%.



Target 9: The error rate of misses in the first VR training is 4% greater than in the first real-world session. Errors in the final real world were significantly reduced by 48% and increased by 65% for hits after the final training session with VR. Similar to targets 4 to 8, we can observe a spike in error rate from the first real-time session to the final real-time session for target nine and a decrease in error rate from second VR training to final VR training. We can observe that targets 4 to 9 shows similar traits since they were comparatively nearer to the player than target 1 to 3.

6.4 Results

A significant improvement was observed and the number of hits. Suppose we analyze the overall hits and misses of the participants: In real-time, the error rate reduced from 49% (from the first time) to 29% (last time). Similarly, the error rate was reduced during VR training from 48% to 30%. And the p-value reported from a t-test is less than 0.05, so that result is said to be statistically significant, which indicates that the data did not occur by chance.

We have found no significant difference between real-time to VR data and final VR training data to after-training real data, so the skill transfer is almost 100%, with no loss in transition.

Chapter 7 Discussion

This study was written to aid others in comprehending the roles played by VR in athletic training. There has been numerous research done on VR sports training in various fields. Our study focused on newcomers who had never or infrequently played tennis before. In order to help the participants enhance their target-hitting abilities, we only concentrated on serve practice. As a result, our study was an excellent resource for people interested in learning more about the operation of VR and the training and outcomes for new players. Our research revealed that after VR training, serving measures significantly improved.

Overall, the study was successful and would be a great help for people who want to get training or would like to play Table tennis in VR. This training will also affect their real-time performance. We have only conducted the study for serve, but I believe this would also work for the rally. Also, after the T-test, we received a positive result so that this study would work for a larger population.

7.1 Limitations

1. This research study is not an exception to the rule that every study has its limits. A notable disadvantage of the experiments is the small number of participants. There were only five participants in the initial user study. Higher sample sizes are needed to do statistical analysis of the data and draw more conclusive findings regarding the value of the research.

2. One of our participants also struggled with the Field of View (FOV). He stated that he could not sense the entire table when concentrating on a serve (bat and ball). The FOV of the HTC Vive is 110 degrees viewable[21], compared to 180+ degrees for each of the human eyes. Over the whole visual field of the headset display, HTC Vive can track user gaze positions. The entire trackable field of view for both eyes is 110 degrees.

The human eye has a vast range of vision, excellent depth perception, and clarity. Technically speaking, the human eye can see a 180-degree field of vision without moving the eyeballs. Furthermore, when the eyeballs are fully rotated, they can perceive a field of view of up to 270 degrees[20]. Therefore, the small range of VR FOV was another problem for the study.

3. Another user encountered a similar issue; when he concentrated on the scene's corner, he began to experience mild VR sickness (dizziness). The symptoms of VR sickness, which are similar when compared to motion sickness, include "nausea, headaches, and dizziness." Not everyone will have the same experience with it as you because the severity of the symptoms vary significantly from person to person. Following is the statement Dr. Hillary Hawkins made: "*You do not get sick when you are walking; you get sick when the body is in a still position, but something else is generating. The balance centers in your inner ear perceive something different than reality*." [19] People experience VR sickness as a result of the VR's changing orientation and point of view. Therefore, there was yet another issue we had to cope with.

4. There is no rally or spin training, and the participants are all beginners, which proved to be our other drawbacks. Our study did not have an opponent, and we were unable to train with a rally; instead, we just practiced serving. Since none of the users had ever played table tennis before or had only occasionally, our options were limited. We were unable to add spin training to our experiment or raise the level of difficulty. Due to the fact that all of our participants were beginners, we were unable to determine how VR training would affect intermediate or advanced players. Therefore, we are unsure of how it will affect them.

5. In the Unity3d game, if two dynamic objects collide, then objects pass through at high speed. This is a significant limitation of the Unity3d game engine. The solution is already proposed in section 3.3.2.

7.2 Future Directions

Future research may undertake comparable experiments given the limited sample sizes of the two experiments to see if they produce the same outcomes as those reported in this study. In order to undertake statistical analysis of the data and come to more firm conclusions about the usefulness of the research, higher sample sizes are required. In order to obtain more precise data and analysis, studies might be expanded to include a more significant number of participants. Additionally, advanced and intermediate players can be included in the experiment to examine the impact of VR training on people adequately. By doing so, future research can use other procedures, tests, and criteria to evaluate the results. No one has control over technical issues like poor FOV and VR sickness. Therefore, the development of technologies is the only way to address those.

Although there have been VR training studies for badminton and tennis in the past, a new study for serve training in badminton and tennis with a larger group and additional methodologies may be conducted in the future. This study will enable people to hone their abilities without needing a large playing area, much room, or special sporting equipment. This study will enable individuals to perfect their skills without requiring a big playing field, ample space, or specialized athletic equipment. In addition to those two sports, many more can benefit from VR training. The ability to run an endless number of reps in the most realistic environment imaginable in a virtual reality sports environment allows athletes to speed up their training program, even while on the go, so they are prepared to perform at their very best when it counts.

The use of virtual reality has helped athletes perform better. It is not required to visit a golf course to perfect one's swing mechanics or to visit a basketball court to perform as many shooting drills as necessary. The oldest strategy for enhancing individual technique is repetition.

Athletes can practice in "real" settings using virtual reality by connecting to a device, and the data it gathers is so precise that you can compare your performance and refine your technique. You are cutting a few milliseconds from the clock, improving your game vision, anticipating your opponent's moves, and honing your technique. Virtually "being" in your place of training without having to leave home, watching a sporting event on the other side of this world without having to board a plane, and watching a game from the bench of your favorite team are just a few of the advantages that virtual reality can provide. Virtual reality has already made all of this possible.

The sports sector has long been involved with "big data" and continuously adopts new technological developments. Technical advancements can no longer be understood without thorough data analysis. Most athletes would rather not hear the adage, "You are only as good as your last result." Nevertheless, despite how difficult it may seem, it is the case. Virtual reality is proving to be one of the other methods for advancement.

Virtual reality exposure can cause sensory system disruption and symptoms, including nausea, vertigo, sweating, pallor, loss of balance, Etc., which are collectively referred to as "virtual reality sickness." These symptoms may show up within the first few minutes of consumption in sensitive people. The effect of virtual reality illness is still the most well-known. There is currently a dearth of information on potential neurological ramifications or long-term developmental implications. Therefore they require more research. A number of organizations have conducted an expert evaluation of the impacts of digital tools on the health of children and adolescents in addition to VR and as a supplement to their work on the health consequences of new technologies.

Advances in immersive technology go far beyond consumer and commercial use cases and can turn complex industrial content into vivid, lifelike experiences. Virtual reality (VR) training has been utilized for many years with great success in various facets of workforce training to train astronauts, pilots, and military personnel as part of this wave of immersive technology. A more comprehensive range of process industries may now afford to create these virtual environments thanks to computer and graphical processing power improvements.

Businesses, including oil and gas, refineries, and power generation, have recently resorted to VR models to help with on-the-job training for various crucial operations and tasks. These industries must maintain and institutionalize employee knowledge and successfully sustain operational excellence. Investigating why and how VR implementations will continue to take shape in these businesses is crucial because developments in this field will only continue to grow in the future. Some of the critical goals of simulation-based training are reducing the time to competency and effectively transferring high levels of ability, plant knowledge, and situational awareness to each team member. Utilizing VR technology, immersive training systems (ITS) place personnel at the center of learning and practicing critical plant operation and maintenance skills. Trainees also have a higher chance of remembering information by putting the manuals and information sheets aside. Thus, VR-based industrial training is more affordable and tends to produce errors that are less likely to occur in the real world.

Chapter 8 Conclusion

This study has examined the **effectiveness and efficiency of Table Tennis serve training in Virtual Reality and skill transfer to the real world**. The research question that this study aimed to answer was:

"Did the after VR training users perform significantly better for table tennis serve?"

In order to get the answer to this question, an initial experiment was carried out, and I discovered that the number of hits significantly increased. The mistake rate dropped from 49% to 29% in real-time. According to our research, the skill transfer is nearly 100%, with no loss in transition since there is no discernible difference between real-time and VR data before and after training.

Numerous significant difficulties were identified through this literature review process. In the current study, we discovered that real-world table tennis performance increased following VR training for the serve technique. In this study, we outline the creation and assessment of a VR training program for a specific table tennis skill. Virtual reality helps athletes train in real situations by connecting to a device. Since the data is so accurate, you may compare your outcomes and refine your methodology. Investigating if VR training is equivalent to or superior to real-world training, whether it is helpful for user of all skill levels, and what is causing the impacts of VR training should be the next step. The question of whether training in a fast-paced sport also results in practical benefits in other sports should be asked.

The transfer may not just apply to table tennis. It indicates that VR is more than just a tool for amusement and has the potential to support the improvement of real-world performance and competence in a field that is yet completely unexplored. The experiment's goal is to investigate the effectiveness and efficiency of learning table tennis serves in virtual reality and the transfer of such skills to the real world. The game of table tennis requires players to move about and respond to external cues. Our primary goal was to help the participants' serve techniques.

This study was also prepared to help people understand the functions of VR in sports training. Numerous studies on VR sports training have been conducted in various disciplines. Our research focused on newcomers who had either never played tennis previously. We exclusively focused on serve practice to assist the players in improving their target-hitting skills. Consequently, our study served as a fantastic resource for those curious about how VR works and the training and results for new gamers. Our research showed that service metrics significantly increased following VR training.

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Appendix

DEMOGRAPHIC INFORMATION (English)

Name:	
Age:	
Gender:	
Student ID:	
Hand preference	Right left
Occupational status	Undergraduate Student Master Student Ph.D. Student Research Assistant/Fellow Staff /Faculty Other
Are you taking any medication?	Yes No | If yes, please specify
Did you consume more than 2 units of alcohol within the last 6 hours? *(2 units of alcohol = 1 pint of beer or 2 glasses of wine)*	Yes No
Any injury, or disability that can affect this study?	Yes No
Do you aware of the basic rules of the table tennis serve process?	Yes No
Please state your level of English language skill on a scale of (1...7) (novice) 1 2 3 4 5 6 7 (expert)	
Have you ever experienced 'virtual reality before? (novice) 1 2 3 4 5 6 7 (expert)	
Please state your level of Table tennis(ping pong) skill on a scale of (1...7) (novice) 1 2 3 4 5 6 7 (expert)	

Please state your level of Table tennis(ping pong) skill in VR on a scale of (1...7)
(no exp) 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ (expert)

Consent Form English Version

PARTICIPANT INFORMED CONSENT

Participants are needed to finish this. Please read the questionnaire that follow very carefully.

Have you read the study's information sheet? YES/NO

Have you got a chance to inquire about this study? YES/NO

Have all of your questions been satisfactorily answered? YES/NO

Have you received enough knowledge about this study? YES/NO

Do you realize that you have the option to leave this study at any time?

- At any time YES/NO
- without providing an explanation YES/NO

Do you consent to participating in this research?

I certify that:
-I'm over the age of 18.
-I have no visual impairment.
-I don't take any psychotropic drugs.
-I haven't had any alcohol (or other drugs) in the previous eight hours.
-I acknowledge that I won't play table tennis outside of the study session.

In case you have any questions or comment concerning this experiment please contact
Prof. Jörg Müller, Universität Bayreuth, Serious Games, Universitätsstraße 30, 95447 Bayreuth (Germany)

Signed………………………………...………… **Date**……………………………...

Name in block letters……………………………..…………………………………...

We never report the data we gather in a way that makes it possible to identify specific people. Any verbal remarks you provide will be reported in aggregate, and if they are included in subsequent studies, they will be presented anonymously. You have the right to ask us at any moment to remove your information from our databases.

User Name:________ **Date: ________** **Start Time:________** **End Time:**

Real world		

VR World					

Target	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Total**
Attempt 1										
Attempt 2										
Attempt 3										
Attempt 4										
Attempt 5										
Attempt 6										
Attempt 7										
Attempt 8										
Attempt 9										
Attempt 10										
Attempt 11										
Attempt 12										
Attempt 13										
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Attempt 31										
Attempt 32										
Attempt 33										
Attempt 34										
Attempt 35										
Attempt 36										
Attempt 37										
Attempt 38										
Attempt 39										
Attempt 40										
Total										

Questionnaire after Real Time session:

How would you rate overall experience on a scale of (1...7) (Bad) 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ (Good)	
Any particular target was difficult to hit?? No ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○	
Any comment/suggestion?	

Questionnaire after VR session:

Are you feeling any VR Sickness?	discomfort, headache, stomach awareness, nausea, vomiting, sweating, fatigue, drowsiness, disorientation, Other

How would you rate overall experience on a scale of (1...7) (Bad) 1 2 3 4 5 6 7 (Good)	
Any particular target was difficult to hit?? No 1 2 3 4 5 6 7 8 9	
Any comment/suggestion?	

Questionnaire after Entire session:

How would you rate overall experience on a scale of (1...7) (Bad) 1 2 3 4 5 6 7 (Good)	
Any particular target was difficult to hit?? No 1 2 3 4 5 6 7 8 9	
Do you think your overall serve performance is improved?	Yes No
Would you like to get trained in VR for games like Table Tennis?	

Any comment/suggestion?	

Declaration

I declare that this thesis has been written independently by myself and no other sources were used other than those cited, and that this thesis has not yet been submitted towards an academic degree.

Date : 30-08-2022 --------------------------

Sign