Immersive Simulation of Soccer Dynamics: A Comparative Study with Traditional Training

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Virtual reality has become the focus of many points of modern human-computer interaction research. One of the important domains that VR is rapidly gaining traction in as a training methodology is sports. In recent years the line between sports and technology has significantly blurred and now many sports have implemented technologies like machine learning, digital statistics tracking, and virtual reality training. Our study aimed to explore this deeper and determine if training in a virtual environment was an effective method for improving athletic performance. The study focuses specifically on goalkeepers in soccer, and whether training to block shots in VR translates to more blocked shots in the real world. We used 6 participants that underwent three major testing phases. Shot-blocking performance was measured using a shot-blocking percentage (SBP), calculated based on the number of shots blocked out of total shots attempted. The study's findings indicate a significant improvement in participants' shot-blocking ability following VR simulation training, as shown by an increased SBP value for all participants. Future research may use our research as a stepping stone to investigate more long term affects and uses of VR in sports training.

Additional Key Words and Phrases: Virtual Reality, training, improvement, novel

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1 INTRODUCTION

Sports technology is an ever-evolving realm of research. Athletes, coaches, and trainers alike are continually looking for ways to improve their skills and performance as a whole. One the novel technologies that has recently become a facet of many sports training research studies is virtual reality (VR).[4] Virtual reality training has the potential to overcome many of the shortcomings of traditional training methods by simulating "complex" and "real-life" environments [21].

All of the common traditional training methods used today involve a player or an athlete interacting with the physical world around them. Whether this be watching videos of their current performance, training on the field they play by simulating different scenarios, and even repetitive tasks to train more psychological functions like reaction time and decision making. All of these traditional methods have some major flaw that can be addressed by implementing a more novel approach. Having athletes immersed in a virtual environment has already been shown to be a more

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effective strategy in helping young athletes make faster and better decisions, compared to only watching videos of themselves playing. [12] A study conducted by Ben Greenhough found soccer players and staff to be supportive of the use of VR training.[13] On-field training has been shown to be an effective and efficient method at improving athletes' performance; however, it is also costly for teams and athletes to rent fields or courts to practice on, they are subject to sudden weather changes and player availability may not always coincide with practice and training schedules. VR could address these issues as head-mounted displays (HMD's) are becoming ever cheaper.

Overall this study looks to investigate if a simple but immersive VR application can be used to effectively train soccer goalkeepers with little to no experience in soccer. It looks to show whether VR can be a cheap and effective way to train in sports as compared to traditional methods.

2 RELATED WORKS

2.1 Smart VR

Virtual reality (VR) has already proven itself to be an instrumental training method in many domains including "military training, sports training and... education." [32] VR is one of the best platforms for introducing effective training methodologies where facilities (fields, courts, etc.) and time are a constraint. A study done by Emil Moltu Staurset and Ekaterina Prasolova-Førland introduces how current VR training technologies can be enhanced using real-time feedback to the user. Their use case was for ski jumping in which VR sensors were attached to different extremities of the user's body and while simulating a ski jump feedback was displayed to the user about their jump statistics as well as about their form.

While this study focused on ski jumping, the same technology and ideas can be implemented into any sport. For example, many of the same methodologies can be used in soccer training, like providing feedback on blocking form, or kicking statistics. All while immersing the user into a virtual environment that simulates where they would compete. Overall smart VR technology would enhance user training by providing real time feedback into the head-mounted display (HMD). VR shows that can be safe, give you the opportunity to repeated your practice while giving feedback what need to be improve, [15]. There is another study shows that VR can analyze the complex relationship between perception and action in sport performance, and create scenarios to help athlete, [20]. A VR study performed by David L. Newman investigates how interactive VR applications can affect sports performance, by showing how users where enhanced by the VR training[28]. Another VR study showed that virtual reality-enhanced cardiovascular exercise equipment increased attendance and adherence, with implications for exercise promotion [5]. Uhm also shows that VR can create the same sense of excitement when immersive environments are created [36]. Stone also shows how VR can be a better environment for atheletes to develop their skills [34]. Bruce Abernethy shows that even before VR, training applications have help improve atheletes skills [2].

2.2 Pressure and Competitive Anxiety

Pressure and anxiety can negatively impact an athlete's performance to a significant degree. A study done by Argelaguet Sanz et al. discusses why various stressors should be implemented into VR training. It is later discussed that most current VR sports training is directly focused on "improving motor skills", however, the study investigated whether introducing competitive anxiety into VR training would translate into better performance in the real world. [6] Their findings were that adding stressors did build mental resiliency and that performance was improved when it came to actually competing. This would prove to be important in a game like soccer, where a ball could be kicked in excess of

"15 m/s" at a goalkeeper.[19] Building mental fortitude would prove to be useful for an athlete in that position to be able to effectively block shots on the goal.

To add, the study not only found that psychological factors were improved with stressors being added to VR training but also many physiological factors were trained with the added stressors. For example, it was found that both heart rate and skin conductance (sweating) were higher when stressors were added to the training versus not having it in the training. To expand upon this, a study conducted by Kaitlyn Harrison found VR intervention to help relax female soccer players.[17] It concluded this through the evaluation of baseline confidence levels in the players. Author conduct a study to see if VR environment can trigger anxiety like in sport psychology training to see if would help with training,[33]. Craig wrote an article on his study of discover about VR help athlete make better decision-making when they are in VR. [9]. Anxiety have a big affects on performance, processes, and reading your opposite,[30]. A study performed by Harvard Review of Psychiatry shows that VR can be an effective method when treating anxiety [23]. Huang also demonstrates how VR sports has decreased anxiety in athletes, but also bettered their mental health [18].

2.3 VR Training and Motor Skills

Virtual Reality training has recently become a more popular training option for many professional and amateur athletes. In a study done by Nadiya Dovgan it was found novel technologies such as vr played a "pivotal role... in enhancing athletic performance". [10] This is due to the fact that many VR applications can be explicitly tailored to certain situations or scenarios. While VR has been found to be an effective way to train, it does come with certain challenges. It was found in the study that VR training can cause cognitive overload in which users can feel sick or get dizzy. This an lead to a loss of focus during training and prove to be more harmful than helpful. This is something that needs to be kept in mind during training, possibly by limiting the amount of time in a virtual reality. A previous study conducted by Sergei Adamovich identified various benefits in sensorimotor skills after training with VR.[3] So while there is a certain amount of risk with VR training, others have found it to be beneficial. According to this article, shows the group that was training in virtual environment had "increased their header skills in a signigicant level,"[22]. Another study that goes by Todorov shows that find that focused attention on relevant movement details can improve learning outcomes,[35]. Virtual environments does help improve real-world sports performance, by using the motor skills that come from VR, [25]. Jinzhao Wang has also showed how VR has been applied to training for competitive sports [38]. A study in 2019 showed that when using VR for tennis training there participants "significantly improved participants' real-world table tennis performance compared to a no-training control group in both quantitative ($p < .001$, Cohen's $d = 1.08$) and quality of skill assessments ($p < .001$, Cohen's $d = 1.10$" [26]. A study performed in 2019 showed that basketball players who used VR to train performed better than those who just used computer screens, and those who trained on a basketball court [29].

2.4 Cognitive Focus Using VR Goal Keeping

Goalkeeping in soccer requires a considerable amount of attention and focus to be able to block a shot on a goal. In many cases a goalkeeper may have only a few hundred milliseconds to respond to a shot being taken on a goal. The amount of time it takes for someone to change from focusing on an event, to acting on that event falls into the category of cognitive focus.[24] As such a study done by Shimi et al. was done to determine if VR and other computer-simulated tasks can actually improve cognitive focus as a goalkeeper. Their findings determined that there is a clear correlation between the amount of time spent using VR or other simulated computer training models and improved focus on the field. This serves as a solid baseline for other VR sports training simulations where time-to-respond type tasks can be trained. Vignaise did there study on goalkeeper can improve there skills in vr, by moving the ball in different direction which shows improvement[37]. A study shows that put someone into control environment like VR environment help the person control there anxiety better then playing the sport in real world, [27].

Some other potential uses for this outside of direct sports training could include the use of the same virtual reality application but for use in helping individuals with Attention Deficit Hyperactivity Disorder (ADHD). [31]This is not an area that was considered in our project but, clearly shows that virtual training can be used outside of the sports domain, to achieve similar goals in cognitive focus, and mental acuity.

2.5 Spatio-Temporal Training

Spatial-temporalilty which is the concept in team sports that players are able to move freely around [a] playing area" is critical in all team sports. [14] Its the driving factor in soccer that allows players to pass the ball to the correct place at the correct time. Its the building block for the concept of "leading a pass" where the pass is kicked ahead of the person receiving the ball so that they intercept it at a point ahead of themselves. To determine if VR training improved spatio-temporal awareness a study was done in Japan by Rojas Ferrer et al. Their findings showed that a VR application built for general use does not improve spatial awareness. However by including data and statistics about a player like their speed, height, leg length. They did find that it improved spatio-temporal awareness as the VR model fit the athlete and their playing characteristics. [11] This clearly shows that for VR training to have a tangible effect on player performance it must be tailored as closely as possible to the group using it. This may include having an app based on gender, or on years played, or on height/weight characteristics. Essentially this study shows that a general purpose training application is not a feasible idea.

3 METHODOLOGIES

The following subsections provide the details on how we conducted the experiment and how it can be recreated. The testing portion of the experiment was divided into 3 phases. The first and last phase would measure each participant's effectiveness as a soccer goalie, specifically shot-blocking. This is similar to other studies done in the field.[40] In the data analysis phase, we explain how we process the data to arrive at the conclusion.

3.1 The Soccer Goalie Simulator

In this experiment, our team developed our own soccer goalie simulator in VR that would be used by the participants. Using VR in studies on sports psychology is not a new idea and has been a large area of interest in recent years.[7] This simulator was developed using the Unity Game Engine and the scripts were written in C#. The simulator was developed specifically for use with the Meta Quest 2, shown in Figure 1. The simulator will use active hand tracking which has been found to be a suitable replacement over the controllers in most cases. [1] When the ball makes contact with the hands it will be reflected as it would in reality. In the simulator, the user will be positioned in the center of the goal, the goal is made to scale. You can see the skybox in Figure 2.

3.2 Selecting Participants

In this experiment, we selected 6 participants randomly from a pool of 10 people. These 10 people each had experience in various sports in high school, but none had ever played soccer goalie in a competitive environment. None of the participants had experience using any form of VR headset including the Quest 2 that is used in testing. Each participant

Fig. 1. The MetaQuest2 , via Diviformbuilder. (https://diviformbuilder.com/product/meta-quest-2).

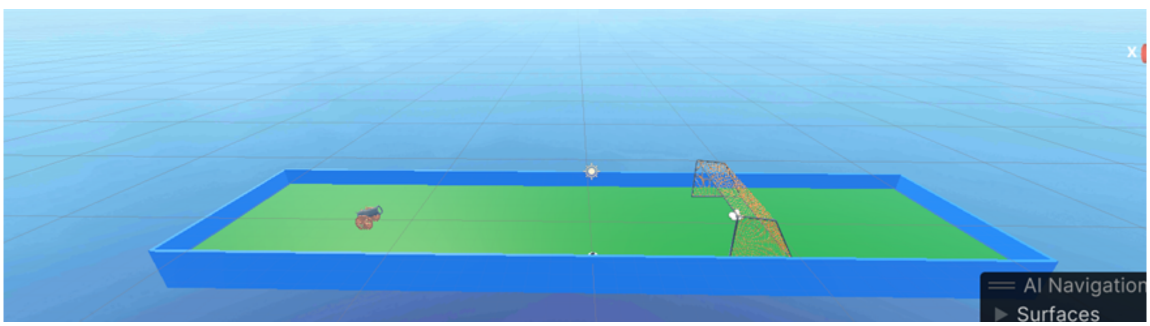

Fig. 2. The Soccer Goalie Simulator Skybox, via Screenshot.

was between the ages of 18 and 24, in good physical condition. None of the participants had any meaningful injuries that would affect their ability to act as the goalie. The participants would be an equal mix of males and females.

3.3 Testing Phase-1

For the experiment, we had 3 phases, in the first phase each participant would meet the research team at the Intermural Fields at CSU where they would be asked to act as goalie. In the first phase, each participant would be tasked with blocking 20 shots from an experienced soccer player standing 15 yards away. If the shot missed the net completely, it would not be counted towards the 20 shots. The participants would be given a mandatory 2-minute break after 10 shots where they could gather their breath. Participants were allowed to drink water during this time. Each of the 20 shots would be scored as either blocked or not blocked. The participants would be given time after a shot to reposition themselves.

3.4 Testing Phase-2

In phase 2 of the experiment, we would have each participant arrive at the Computer Science Lab the day following phase 1 for the next 3 days. Here they would be asked to use the Meta Quest 2 VR headset to play the Soccer Goalie Simulator game which we developed in Unity Game Engine. Each participant would be allowed to adjust the headset to their liking before the experiment began. Once the game began, the participant would be asked to block shots on goal using their hands, holding the controllers. There would be 5 seconds in between each shot and each shot would be from a perceived 15 yards away. The shot placement would be randomized to ensure complete goal coverage. They would be asked to use the simulation for 30 minutes each day, for 3 days in a row. The participants were allowed to take breaks as they pleased but would have a total of 30 minutes blocking shots each day.

3.5 Testing Phase-3

The day following Phase-2, each participant will be asked to return to the Intramural Fields for the final day of the experiment. Once again, each participant will be asked to block 20 shots from an experienced soccer player from 15 yards away. The data will be recorded the same as it was in Phase 1.

3.6 Data Analysis

Given the data on each participant over the 3-phase testing period, we aim to determine if our findings are significant. To start the process, we developed our null hypothesis and alternate hypothesis. The null hypothesis statistical test phase withstood the test of time and proved itself to be a valuable way to conclude studies.[16] Below are the null and alternate hypotheses for our study:

$$H_0 : \textit{The participants' shot blocking ability did not improve after simulation training.}$$

$$H_0 : \mu_d = 0$$

$$H_a : \textit{The participants' shot blocking ability did improve after simulation training.}$$

$$H_a : \mu_d \neq 0$$

Looking at our data, we will condense it down to a shot-blocking percentage for each participant and each phase. The shot-blocking percentage will be referred to as SBP. To calculate the SBP, we used the equation shown here:

$$SBP = \frac{\text{shots blocked}}{\text{total shots}} \times 100$$

The higher the SBP the more shots the participant blocked. If a participant blocked all the shots in Phase-1, they would have a SBP1 of 100. With each SBP calculated, we move on to determining whether our data is statistically significant. To do this we use a Paired T-Test. According to a paper written by Emil Coman, the T-Test is a common and accurate statistical test of differences in means.[8] First, we will make sure that the data satisfies the assumptions of the paired t-test starting with normality. We will visually test if our data is normally distributed, which will be easy given the small sample size. Because each participant does the testing alone, the subjects are independent. Finally, each participant will experience all 3 phases of testing, proving both SBP comes from the same subject. This ensures our ability to use the Paired T-Test. To conduct the T-test we will need to calculate our test statistic. This will be done by averaging the change in SBP from Phase-1 and Phase-3. This will be referenced as:

Table 1. Phase-1 Testing Shot Blockage

Participant	Blocked Shots	SBP
Participant 1	8/20	40
Participant 2	13/20	65
Participant 3	9/20	45
Participant 4	11/20	55
Participant 5	9/20	45
Participant 6	8/20	40

$$\textit{Average difference in SBP after simulation} = \bar{\pi}_d$$

With the test average difference in SBP's, we will move on to calculating the Standard Error. This is calculated as follows:

$$\textit{Standard Error} = \frac{s_d}{\sqrt{n}}$$

With the standard error calculated, we will next finally be able to calculate the test statistic as follows:

$$t = \frac{\bar{\pi}_d}{\textit{Standard Error}}$$

For this experiment, we will be setting the significance level to 0.05:

$$alpha = 0.05$$

We will next calculate the Degrees of Freedom, by subtracting 1 from our sample size. Giving us a Degree of Freedom equal to 5. Using the Degrees of Freedom and our significance value, we retrieve the t-value from a t-table:

$$\textit{t-value} = 2.571$$

Drawing conclusions, if the test statistic, t, is lower than the t-value, 2.571, you fail to reject the null hypothesis, meaning the participants blocking ability did not improve after goalie simulation. If the test statistic, t, is higher than the t-value, 2.571, you reject the null hypothesis, meaning the participants blocking ability did improve after the goalie simulation.

4 FINDINGS

In the following subsections, we will discuss the results from the testing phases and the data analysis. We will discuss what would change about testing to make the experiment better and address the problems we ran into while testing. We will also present some of the data collected from our experiment.

4.1 Phase-1 Testing Data

In Phase-1 of testing, we evaluated 10 people's ability to stop soccer shots. The entire process took about an hour, with the majority consisting of the mandatory 2-minute breaks. The day the testing was performed, the weather was nice and participants were encouraged to drink plenty of water. Table 1 shows half of the data we collected in this phase. The average SBP from all the data our team collected was 48.3.

4.2 Phase-2 Training

As discussed in the methodologies section, our team decided it was not necessary to collect data on a participant's ability to block shots in VR. This was mainly because we wanted our study to focus on a player's ability to improve at

Table 2. Phase-3 Testing Shot Blockage

Participant	Blocked Shots	SBP
Participant 1	12/20	60
Participant 2	15/20	75
Participant 3	13/20	65
Participant 4	14/20	70
Participant 5	10/20	50
Participant 6	12/20	60

blocking shots in real life and not the virtual world. Each participant took their 30-minute virtual training sessions seriously. They would block shots for the full period of time. It should be noted that 2 participants did get feelings of cyber-sickness towards the end of the thirty-minute period. Our team questioned each participant who felt this and ensured they were in a condition to continue the training sessions. These participants were monitored closely during their following training sessions.

4.3 Phase-3 Testing

In the final phase of testing, the participants returned to the intramural fields to attempt to stop 20 soccer shots. Once again, the weather was nice the day we completed the testing. In Table 2 you can see some of the data we collected from this phase. From the data we collected in this phase, we had an average SBP of 63.3. There appears to be an increase in the number of shots blocked after the virtual reality training but we will draw conclusions through statistical analysis.

4.4 Data Analysis

$$\textit{Mean Difference}: \frac{20+10+20+15+5+20}{6} = 16.67$$

$$\textit{Standard Error}: \frac{6.5839}{2.4495}$$

$$\textit{t-value} = 2.688$$

The statistical analysis of our data shows a t-value of 2.688 which is greater than the critical t-value of 2.571. This mean we reject the null hypothesis indicating that our data was significant and there is a strong correlation between training time in VR and better performance as a goalkeeper. In other words this study clearly shows that VR training for soccer goal keepers is effective in improving athletic performance.

4.5 Limitations and Caveats

After the completion of the testing, there were some things we realized that could have improved the experiment. In Phase-1 we noticed the type of shoe each participant wore, impacted their ability to get traction. This resulted in some participants slipping. It would have been beneficial to ask all participants to wear soccer cleats, keeping a participant's choice of the shoe from impacting their performance as a goalie.

In Phase-2 we did have 2 cases of cyber-sickness. Cybersickness is not a new discovery and is common with the extended use of VR.[39] This could have impacted the benefits of virtual soccer training. This is because the participants reported a slight feeling of dizziness. This feeling likely had an impact on performance. All of the participants reported only feeling the dizziness in the last few minutes of the study and were eager to complete their training.

There are also some limitations when it comes to hand tracking with the Quest 2. We deemed it accurate and fast enough for our specific experiment. In other studies, the Quest and Quest 2 had reported angular error rates over 9 degrees. [1]

One of the last major limitations we faced was the weather, as a team it was decided to try to do testing on days when the weather would be similar. However with testing taking place during mid-spring in Colorado. It was difficult to find days that would have similar weather. In fact, during the third phase of testing the winds were significantly higher than during the first phase of testing. This would cause the ball to occasionally veer off of its original kicked course making it harder to block. To address this any shots that were deemed to have been affected by the wind were nullified and re-kicked.

5 CONCLUSION

In conclusion, our study looked to determine the effectiveness of training in a virtual environment with a specific focus on soccer goalkeepers. Through rigorous testing and advanced data analysis, we found strong evidence to support our hypothesis that participants' shot-blocking performance would improve significantly after engaging in simulated training for 3 days. However, there remains many opportunities for future research to expand upon our findings and address additional questions and oversights. One avenue for future work could involve exploring the long-term retention of skills acquired through VR training while using VR long-term. As 3 days of training does not truly reflect common training schedules or regiments. Additionally, transitioning from virtual to augmented reality and running a study incorporating XR technology in a training environment to determine if that offers better training than just VR. Moreover, incorporating advanced VR technologies, such as haptic feedback, and even real-time feedback about an athlete's kicking force could enhance the realism and effectiveness of simulation training. This could possibly allow athletes to find weak points in their training while still being in a training environment. Overall, our study lays a solid foundation for continued exploration and investigation in the realm of sports training using virtual reality, with the potential to revolutionize athlete development and performance enhancement strategies in the future.

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