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RESEARCH ARTICLE

# Effectiveness of Virtual Reality-Based Forehand Smash Training Model for Table Tennis Athletes Performance

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**ABSTRACT**

The aim of this research is to analyze the effectiveness of the forehand smash training model in table tennis using virtual reality (VR) technology, especially for athletes aged 13–17 years. This model consists of four components aimed at increasing motivation: concentration, hand movement technique, waist rotation, and standing position. Performance in VR-based forehand smash training was assessed using mixed model analysis of variance. This analysis involved between-subject factors (VR training group and control group) and within-subject factors (pre- and post-training). This study involved 60 participants, who were divided into a VR training group (n = 30) and a control group without training (n = 30). During VR training sessions, participants engage in competitive table tennis matches against artificial intelligence-based players. An expert table tennis coach evaluates the participant's performance in real table tennis before and after the training phase. Expert coaches assess participants' forehand smashes in terms of quantitative aspects (number of rallies without errors) and quality aspects of skills (technique and consistency). The results of the research prove that the application of the VR-based forehand smash training model significantly improved the performance of table tennis athletes compared to the control group without VR-based forehand smash training, both in terms of quantitative assessment ($p < 0.001$, Cohen's d = 1.08) and assessment of skill quality ($p < 0.001$, Cohen's d = 1.10). It was concluded that the implementation of a VR-based smash forehand training model significantly improved the performance of table tennis athletes.

## INTRODUCTION

Virtual Reality (VR) technology becomes a vital tool to help in a variety of daily activities and has enormous potential for future development (Putranto et al., 2022; Zhou, 2020). In order to bring about further benefits, including FDA-approved pain medications, several commercial sectors, like the EaseVRx health industry, have already embraced VR (Putranto et al., 2022). VR was originally applied in sports science, where it was utilized to simulate situations and enhance athlete performance (Neumann et al., 2018). Even if a lot of sports organizations invest in virtual reality, there isn't enough scientific data to support its efficacy (Neumann et al., 2018).

Virtual reality (VR) use in sports is thought to be a method to lower injury risk and increase accessibility and mobility while training (Cotterill, 2018). It's unclear, though, if VR can foster skill development outside of its particular practice and how successful it is in comparison to other teaching techniques. (Arndt et al., 2018). Particularly in the development of improved design learning for athletes during the design of traditional exercises, it is critical to evaluate whether the time, money, and effort invested in VR is equal to the outcomes received (Arndt et al., 2018).

At first, limitations like bad weather, a lack of training facilities, and specific seasonal barriers hindered sports teaching and training. VR is therefore viewed as a way to get around these limitations and increase training effectiveness using extra digital tools (Stone et al., 2018).

Table tennis, as a rocket sport, is heavily influenced by technology that supports performance. (He & Fekete, 2021; Fuchs et al., 2018). High-level players require technical skills such as forehand, backhand, smash, and push. (Wu et al., 2021). Forehand drive training became the main focus of the trainer for beginners, but the challenge arose due to the lack of variation in the training model and the difficulty of the athlete in mastering basic techniques (Pane et al., 2021).

Effective training methods for forehand beats can include multiball training, skill tests, and the use of VR technology. (Budi & Arwand, 2020; Sari & Antoni, 2020; Zhu et al., 2023). Although VR has been applied in sports including table tennis, its effectiveness requires further evaluation, including measurement through test and situation simulation (Pagé et al., 2019; Witte et al. 2022).

In addition to improving technical skills, the use of VR in sports can help in decision-making, tactical training, and even minimize the risk of injury. (Tsai et al., 2022; Nambi et al., 2020). With the growing popularity of VR, it is seen that this technology can be an effective and versatile training tool in sports such as table tennis. (Michalski et al., 2019).

VR utilized in sports allows tailored training for technical-tactical and motor skills, without limitation by time and place, versus opponents or specified situations (Akbas et al., 2019). Virtual reality also lessens interference in intricate research with intricate subjects or techniques. According to Pereira et al. (2018), virtual reality simulation offers precise control and synchronization of every component in the experiment and may be repeated and compared across many trials.

The creation of the forehand kick training model in the context of table tennis highlights the environment's capacity to serve as an efficient resource for development, offering the variety and obstacles required to advance novice athletes' abilities (Pane et al., 2020).

Numerous earlier studies have indicated that the forehand kick is crucial to table tennis (Johor & Rahmadiky, 2020; Safari et al., 2018). An athlete's hand can be coordinated to hit the ball appropriately with the use of proper training techniques. Tests, such as those administered to table tennis players to gauge their forehand skill, can be used to assess forehand ability (Sari & Antoni, 2020). Besides, in order to the accuracy of the forehand stroke, one should try to implement the form of exercise using two tables (Herliana, 2019).

Exercises with a lot of balls (multiball) can also be used to improve forehand kicking skills (Budi & Arwand, 2020) and backhand kicking in table tennis (Falahi & Andrijanto, 2019). Teaching the forehand kicking technique more effectively (Nurdianti et al., 2018; Sukamto, 2017). In fact, the method of training with a lot of balls is more significant in frequency in the table tennis exercise than the shadow training method (Setyawan et al., 2018)(Zhu et al., 2023).

Forehand kick training models can also take advantage of a variety of media, such as movies (Dehkordi, 2017). The kinematics of the lower extremities during the forehand loop topspin varied significantly amongst different levels of table tennis athletes, according to the study (Zhu et al., 2023) which can aid in the development of technical training for trainers and performance enhancement for athletes. Four primary components have been established around the idea of forehand kick training: ball shadow, ball roll, multiball MP, and multiball DP (Pane et al., 2020).

In recent years, table tennis technology has been evolving, including a change in the ball diameter from 38 mm to 40+ mm (Zhu et al., 2023). Professional table tennis athletes face difficulties in scoring live in one round of matches (Yu, 2022; Zhang et al., 2018). In order to test the variations in forehand loop skills amongst beginners, the study (Wu et al., 2021) constructed an intelligent table tennis e-training system based on a neural network model that detects data from sensors built into the arm tire device.

Certain real-world sports activities can be adapted into virtual settings to get over physical space restrictions as virtual reality technology grows in popularity. It has been demonstrated that some users' real-life performance improves when they exercise in virtual reality. Virtual gaming and practice allows users to stay amused while simultaneously improving their physical and general health. (Hülsmann et al., 2018; Liu et al., 2020).

Virtual reality (VR) technology has been used in many sports, including table tennis, basketball, and football. There are several ways to use virtual reality (VR) technology in sports education and training, including head-mounted display (HMD) systems, head tracking systems, and motion-based video games (MBVG) (Kittel et al., 2020)(Soares et al., 2021). Based on evaluations of virtual environment scores (VEA), sense of presence (IPQ), and correlation of the presence in the VR environment, some studies quantify the efficacy of soccer simulations in VR environments (Ferrer et al., 2020).

The use of virtual reality as a training medium has a substantial impact on user development, as demonstrated by numerous studies. In this situation, the training tool's purpose extends beyond merely honing abilities in a virtual setting via Head-Mounted Displays (HMDs). VR training is beneficial for decision-making, tactical training, and users with certain medical concerns. The study came to the conclusion that it was impossible to generalize the training video delivery approach utilizing the main monitor because it could divert attention. Conversely, in the study's setting, seeing a video through virtual reality enhanced comprehension and decision-making skills (Pagé et al., 2019).

For tactical training, the use of VR as a personal basketball trainer is a very in-depth VR interaction system that can improve the effectiveness of tactical trainings (Tsai et al., 2022). Training in a natural setting using VR technology also has the benefit of lowering the chance of damage. Virtual reality (VR) training may be appropriate for athletes with particular medical histories. VR training systems also assist injured athletes in lessening their discomfort, maintaining better health, and maintaining peak performance (Nambi et al., 2020). VR training has proven to be very significant in the sporting world to improve motor behavior and train specific situations in standard conditions (Witte et al., 2022). Some studies analyze the effects of VR training in some sports, such as table tennis (Michalski et al., 2019).

Proficient table tennis players should focus closely on honing this kicking technique in order to maintain its quality and stability and bolster its application in actual matches. (Zhu et al., 2023). Table tennis is a sport that requires open skills. Sports with open skills are sports in which players have to respond in an environment that is constantly changing, unpredictable, and influenced by external factors (Wang et al., 2018), usually involving the presence of opponents.

In particular, table tennis demands quick decision-making, flexibility in visual attention, and quick interceptive action in reaction to opponents engaging. (Michalski et al., 2019). There is some research that supports the idea that basic closed skills can be transferred from VR to the real world (Gray, 2017), It is unknown if more sophisticated open skills which are essential in games like table tennis can be developed with VR.

This approach is also in line with the spirit of Makassar State University in providing an education that is adaptive and relevant to the development of the times. This article will explain the steps and process of VR development aimed at improving the table tennis skills of students of Jasmani Education at Makassar State University, digging the potential of the application of this technology in the context of sports education.

## MATERIALS AND METHODS

### Materials

### Virtual Reality

Virtual Reality (VR) technology is one of the promising technologies with great potential for future development (Putranto et al., 2022). Virtual reality (VR) technology is one of the fields with the most promising potential for future development (Zhou, 2020). Computer experts in several industries are integrating VR technology to boost their bottom line. One such field is the health sector, where EaseVRx is used. The FDA authorized the prescription-only analgesic for adult use (Putranto et al., 2022).

Since the advent of virtual reality (VR), people have been able to behave and interact in more realistic settings with relative ease and affordability because to the technology's rapid expansion and emergence (Düking et al., 2018). VR is the first technology to be used in sports research. VR involves the creation of computer-simulated environments with the aim of immersing individuals in a way that makes them feel mentally or physically present in different locations (Neumann et al., 2018).

Virtual reality (VR) technology is marketed to athletes as a way to lower their risk of injury during training. VR systems' enhanced mobility and accessibility in sports have sparked interest in using them to improve athlete performance (Cotterill, 2018). However, there is currently little scientific data to guide and support the VR system's application, despite the fact that many sports organizations have invested in it (Neumann et al., 2018).

It is not clear whether the VR system develops skills and expertise outside the specific practice context in which it is applied, and how the effectiveness of VR is compared to other learning and training methods. While there may be some benefits for the athlete, the assessment needs to be made, whether the VR system is worth the time, money and effort involved in its implementation. It is important to understand whether such time, cash, and effort can be invested better in developing enhanced design learning for athletes during traditional training designs (Arndt et al., 2018).

The majority of sports instruction and training takes place in wide areas with lots of obstacles. Unpredictable weather, intense or specialized training facilities that are only appropriate for select individuals, and additional challenges unique to a given season. (Arndt et al., 2018). These obstacles influenced the concept of virtual reality training and sports education. Using virtual technology in training sessions can help overcome numerous challenges associated with routine training and increase the effectiveness of training with extra digital tools (Stone et al., 2018).

### Table Tennis

Table tennis is a rocket sport (He & Fekete, 2021) whose technology is considered an important factor in performance (Fuchs et al., 2018; Yang et al., 2021). Table tennis requires a variety of technical skills, including push, smash, forehand, and backhand (Wu et al., 2021). A proficient table tennis player can hit the ball quickly and is prepared to beat the subsequent ball (Qian et al., 2018). One of the most crucial table tennis techniques is kicking because if players don't get the hang of it, they risk losing the game (Pane et al., 2021).

The development of a virtual table tennis environment is a key step in creating an effective and realistic learning experience. In this environment, planning should pay attention to the details of the table tennis court, the characteristics of the player, and other elements that support learning. Attractive and accurate graphic design choices will enhance immersion, creating nuances similar to real fields. In addition, authentic sound integration and ball sound effects can enrich the user experience, help in movement detection and provide realistic feedback. Development continuity also includes training difficulty level adjustments, challenge scenarios, and variation of game conditions to improve player flexibility and adaptability. By detailing each of these aspects, developing a virtual table tennis environment can create a platform that supports the development of physical education students' skills at state universities in an innovative and fun way.

Virtual Reality (VR) development to enhance table tennis skills involves a series of steps to create an effective and exciting learning experience. First of all, in the development phase, the design of the virtual environment is carefully observed, including the modeling of the table tennis court, the character of the player, and the relevant visual elements. The integration of motion tracking technology is also an important part, ensuring that player motion responses can be reproduced accurately.

After the prototyping of the VR, the evaluation phase was conducted involving students of physical education as test participants. The evaluation included in-depth analysis of the realism of the virtual environment, the accuracy of motion tracking, and feedback responses. Furthermore, these evaluations form the basis for improvement measures.

Improvements are made by taking into account every aspect assessed during the evaluation. This can include graphical upgrades to enhance realism, adjustment of the difficulty level of the training to match the student's skill level, as well as optimization of feedback to provide more effective guidance. During this process, the participation of students and table tennis instructors is highly appreciated for obtaining a direct perspective from key stakeholders. This ongoing evaluation and improvement process enables quick adjustment to user needs and feedback. VR development not only creates a realistic virtual environment, but also ensures that the solution is truly effective in helping students of physical education improve their table tennis skills.

The application of Virtual Reality in entertainment can be seen from the variety of VR-based games that have been developed. VR technology supports an increasingly real gaming experience so that users can play as if they were in the environment of the game. Virtual reality technology can also be applied to the field of sports. Various sports can be played using VR as if users were playing in a real sports field. One of the sports that can be played with VR is table tennis, as in the picture.

## Methods

A total of 60 table tennis athletes aged between 13 and 17 took part in the investigation and were taken into account in the analysis (Mage = 21.81, SD = 3.58). Thirty participants each were assigned to a VR training group and a control group. Table 1 shows the primary attributes of the individuals in the VR training group and control group.

**Table 1. Main characteristics of participants in VR training groups and control groups**

| Variable | VR Training | Control |
|---|---|---|
| N | 30 | 30 |
| Mean age (±SD) | 22.07 (4.27) | 21.54 (2.75) |
| Gender | Male = 18<br>Female = 11 | Male = 16<br>Female = 12 |
| Hand preference (Nicholls et al., 2013)* | Right (n = 29) | Right (n = 28) |
| Average days from pre-test to post-test (± SD)** | 25.17 (6.86) | 23.25 (3.58) |

There were no participant injuries, limitations, or other issues that would have precluded them from participating in this study. The Snellen Eye Chart, RAF Rule, and Fonda Anderson Reading Chart were among the tests used to examine the participants in order to determine whether they had normal or corrected visual acuity to normal vision. By using the Butterfly Stereo Accuracy Test, participants in the VR training group have normal or corrected stereo acuity to normal (Vision Assessment Corporation, 2007). There was not a single player that played table tennis competitively.

## RESULTS

### Quantitative Assessment

Time (pre- and post-test) is used as a factor in the subject and group (VR training and control) is used as an inter-subject factor in an ANOVA mix. This test passes the condition of homogeneity of variance because Levene's Test is insignificant. As a result, it is expected that the same variance exists. Time and group had significant primary effects (F(1, 55) = 86.47, p <.001, partial Eta2 =.611) and p =.003. Additionally, there is a significant interaction effect (F(1, 55) = 23.66, p <.001) between group and time. See Figure 2 for partial Eta2 =.301.

A series of post-hoc corrected Bonferroni post hoc corrected by Bon Ferroni was conducted in order to further explore significant interactions. For certain comparisons involving four variables, bon ferroni adjustments (a =.0125) were used. The test-t sample pairings showed that both the control groups' and VR training's real-world table tennis performance improved dramatically both before and after the test. The post-test score for the VR training group was M = 189.93 (SD = 80.68) compared to M = 92.46 (SD = 42.25) on the pre-test (t(28) = -7.8, p <.001). Cohen's d came out at 1.70. T(27) = -5.6, p <.001) The control group's score increased from M = 80.62 (SD = 53.93) on the pre-test to M = 111.14 (SD = 63.47) on the post-test.

The VR training group (M = 92.46, SD = 42.25) and the control group (M = 80.62, SD = 53.93) did not differ significantly on the pre-test of the quantitative assessment, according to an independent sample t-test (t(55) =.92, p =.359).

An independent sample t-test revealed that during the post-test, individuals in the VR training group (M = 189.93, SD = 80.68) scored considerably higher than participants in the control group (M = 111.14, SD = 63.47) on the quantitative evaluation, t (55) = 4.08, p <.001. Cohen's d came to 1.08.

Test-retest reliability. Test-retest reliability was assessed by correlating the pre-test and post-test scores of the control group. Based on (Hopkins, 2015), the intraclass correlation coefficient (ICC 3.1) is 0.89. Thus, ICC shows good test-retest reliability.

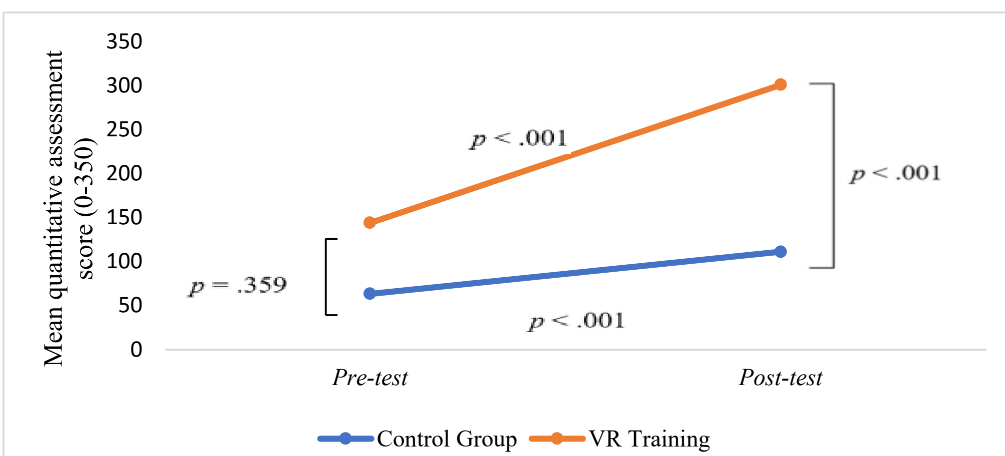


**Figure 2. quantitative assessment Mean Total Score (±standard error) for the VR training group (dark grey) and control group (light grey) at the pre- and post-test on quantitative assessments.**

**Quality of Skills Assessment**

On the quality of skills assessment, an independent sample t-test showed that participants in the VR training group had change scores on the quality of skills assessment (M = 7.37, SD = 2.24) that were substantially higher than those of participants in the control group (M = 4.46, SD = 2.97), t (55) = 4.18, p <.001. Cohen's d = 1.10.

A one-sample t-test reveals that the VR training group's scores (M = 7.37, SD = 2.24, (t (28) = 17.71, p <.001), as well as the control group's (M = 4.46, SD = 2.97, (t (27) = 7.94, p <.001), are significantly different from zero, indicating no change from pre-test to post-test.

Figure 3 displays the average change in participants' scores from the pre-test to the post-test depending on groups and the overall variations in skill assessment quality between groups.

The quality of skills evaluation and the changes in participant scores in the quantitative assessment had a substantial positive link, according to Pearson correlation analysis (r(55) =.74, p <.001). Of the variance, 54.6% was explained by the connection.

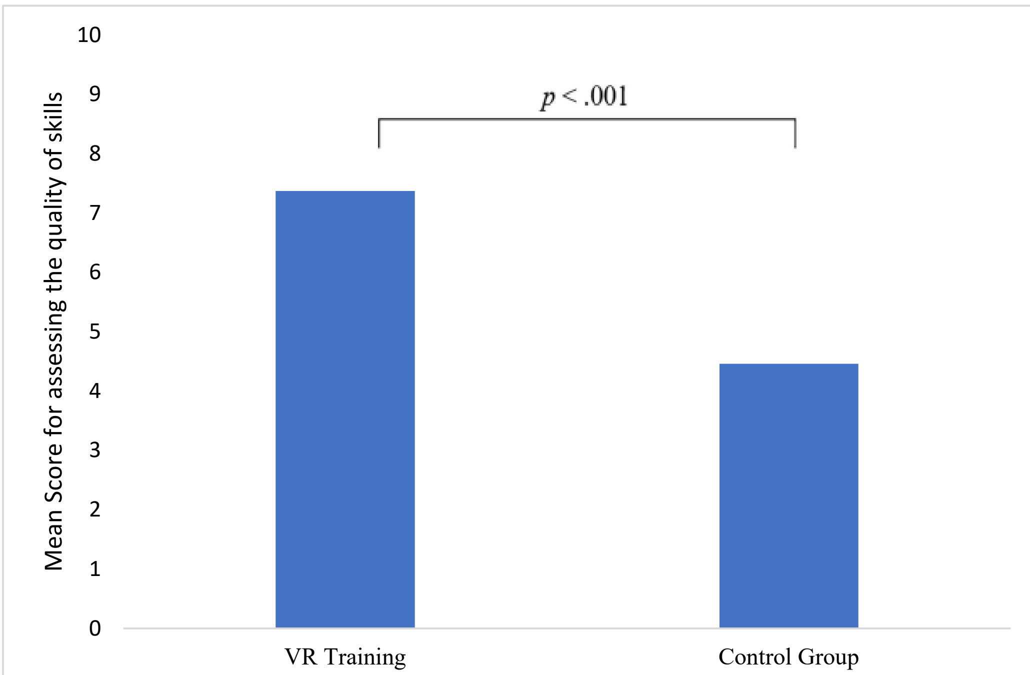


**Figure 3. Quality of skill assessment. Total average (± standard error) change in the skill assessment quality scores between the pre-test and post-test for the VR training group (dark gray) and the control group (young grey).**

## DISCUSSION

The transfer effects of virtual reality table tennis training on actual table tennis performance are investigated in this study. According to the hypothesis, real-world table tennis play greatly improved over a control group that did not get any training in both quantitative elements and overall skill quality. These results add to the small but expanding body of research on the application of virtual reality (VR) to the learning and improvement of sports skills.

As one of the first studies looking into the transfer of VR training to sports, it is first important to show that the advantages outweigh the drawbacks as compared to no training at all. According to recent research, there is benefit to adopting virtual reality (VR) as an additional training tool, particularly in circumstances when instruction is logistically challenging to administer or impractical in real life. Future studies could take VR for skill levels and other training contexts into account, broadening the breadth of existing findings.

One noteworthy finding was that from the pre-test to the post-test, participants in both groups showed improvement. Quantitative tests showed gains for 93.1% (27/29) of the VR training group's participants, but there were also improvements for 85.7% (24/28) of the control group's participants who did not receive the training. Based on self-report, the control group did not get any training in table tennis. The control group may have improved greatly because they were given the evaluation more than once, got to know the instructions better, and had more time to consider how to do the job. Given that it is unknown why individuals improved in spite of not receiving formal instruction, this emphasizes the value of having a control group.

It is well established that a student's traits affect how well they learn (Baldwin & Ford, 1988). The expertise level of participants in the sport under evaluation is one of the key factors that should be taken into account when it comes to sports training. However, none of the sample's members have any prior experience playing table tennis. Therefore, the question of whether VR training will be beneficial for competitive and advanced players is unanswered by this study. It is possible that an experienced player will detect a subtle distinction in stroke times, reflections, rounds, and ball connections between virtual reality games and traditional games, even though novices may find the game physics to be realistic. If this is the issue, competitive players may even have negative or poor efficiency transfer from training to the actual world (Baldwin & Ford, 1988; Rose et al., 2000). Additionally, it would be highly beneficial to research the traits of other people that are known to influence transfer, like motivation, personality, and cognitive ability (Sackett et al., 1998).

The participants in this study were not players of table tennis who competed, nor did they get any advice or suggestions on how to get better. It can be advantageous for participants to get one-on-one skill-improvement instruction from the appraiser in the future. When it comes to using virtual reality (VR) in the real world, some experts believe it could be most beneficial when utilized as an additional training tool for people who are already knowledgeable and experienced in sports (Miles et al., 2012). When users can apply the proper forms and tactics in a realistic gaming environment, this is maybe when VR will be most useful as a training tool. Future studies looking at persons with varying degrees of experience can shed light on who gains the most from training in a virtual environment.

The study's training tools might be highly beneficial due to the efficient fusion of open-ended and adaptive skills training in virtual reality. Since both adaptive training (Gray, 2017) and open skill training (Wang et al., 2018) have been demonstrated to improve performance outcomes, we propose that the combination of these two training methods significantly influences how participants' skills develop in virtual reality. We felt it was crucial for players to be able to hone their talents in virtual reality because table tennis is really an open-ended skill sport. It would be helpful to find out if participants in VR training improve as competitive gamers against AI, as the training involves playing against AI. But this is outside the purview of this investigation.

One of the first studies to look into the transfer of sports training from VR with HMD is ours. When comparing VR training groups to control groups that did not get any training, we can show transfer; nevertheless, there are a few things to take into account for more research. These variables include skill quality and quantitative assessment, which use a range of table tennis skills to gauge changes in participants' abilities. However, they do not assess all table tennis beats, such as drive, flick, and smash, and they are not grounded in objective measurements like eye movement measurements or video-based motion tracks (Streuber et al., 2012)(Piras et al., 2016).

Due to the absence of real-world training groups, this study was unable to evaluate the efficacy of VR sports training to traditional training methods. While these issues can be addressed to provide more thorough evaluations in subsequent studies, the metrics included in this analysis enable the conclusion that VR training can be utilized to help novices improve their fundamental table tennis abilities.

This exam was created recently to evaluate transfer. Validity and dependability need to be considered in this investigation. To guarantee the legitimacy of the material, the creators of the table tennis exam conferred with specialists from Table Tennis Indonesia. The fact that these assessments evaluate what they are supposed to measure real-world table tennis skills gives them additional face validity. This test's quantitative measurements show strong test-retest reliability, as seen by its 0.89 intraclass correlation coefficient.

A disadvantage of this study approach resides in our inability to remark on the intrinsic trustworthiness of the qualitative assessments. We decided to employ a single, very skilled table tennis coach in order to maintain uniformity in the evaluation of players' talents. As a result, it is impossible for us as researchers to determine how much other raters would concur with our evaluation of skill quality. As a result, even although quantitative evaluation results show a high degree of dependability, qualitative findings may not be as broadly applicable as they may be.

Even though the VR training group showed a favorable transfer impact in this study, it is still unclear what caused the benefit. It was unclear from comparing the VR training group's results to those of the no-training control group whether the noted improvements were due to the training itself or to the emergence of more general cognitive abilities like improved eye-hand coordination and quicker reaction times. It might be beneficial for future research to include a control group that participates in VR training inside a comparable tabletop sports environment. One may, for instance, compare the effectiveness of VR table tennis training to that of a control group practicing VR air hockey or another table sport. This aims to maintain consistency in variables except movements related to sports activities.

In order to determine whether the gain in abilities is due to the simulation of table tennis or, more broadly, the skills learned in the VR environment—such as eye coordination—comparisons between VR table tennis and other VR table sports are helpful. Determining the elements linked to enhanced abilities in table tennis in the actual world might provide light on the benefits of creating sports-specific VR training programs.

## CONCLUSION

The study's findings demonstrated the efficacy of VR-based smash forehand training, demonstrating a noteworthy enhancement in table tennis participants' performance across the board following VR training in contrast to the untrained group. The study adds to the small but growing body of research on the application of virtual reality (VR)-based sports training in table tennis. This study is among the first to investigate the potential for open talents to be transferred into actual sporting situations, which may encourage more research.

A suggestion for future research to involve some extensive and deeper aspects. First, it is necessary to investigate whether skills improvements that occur in VR environments have a significant correlation with real-world improvements. Furthermore, it is necessary to determine to what extent VR training can be equivalent or even more effective than conventional training in the real world. Further research is needed to understand whether VR training benefits individuals of different skill levels. It's also important to investigate the factors that drive the positive effects behind the VR training.

Subsequent studies might examine if the transfer of abilities is exclusive to table tennis or if fast-paced virtual reality training can benefit other sports disciplines as well. Further investigation into this unexplored field suggests that virtual reality (VR) is not just a toy; rather, it has the potential to greatly enhance the development of abilities and performance in a real-world setting.

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