Development of a Virtual Reality-Based Forehand Smash Training Model for Table Tennis Athletes

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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.

Keywords: Skills, Table Tennis, Virtual Reality, Physical Education

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). 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).

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).

Table tennis, as a racket 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).

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).

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.

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.

Literature Review

A. 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.

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).

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).

B. Table Tennis

Table tennis is a racket 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.

Developing Virtual Reality (VR) to enhance table tennis skills involves several key steps to ensure an effective and engaging learning experience. Initially, the development phase focuses on designing the virtual environment, including modeling the table tennis court, player characteristics, and relevant visual elements. Integrating motion tracking technology is crucial to accurately reproduce player movements. Once the VR prototype is developed, the evaluation phase begins, with physical education students participating as test subjects. This phase includes a detailed analysis of the virtual environment's realism, motion tracking accuracy, and feedback effectiveness. The findings from these evaluations guide improvement measures.

Improvements are made based on evaluation results, including upgrading graphics for enhanced realism, adjusting training difficulty to align with student skill levels, and optimizing feedback mechanisms for better guidance. Involving students and table tennis instructors in the process is crucial for obtaining valuable insights from key stakeholders. This iterative approach ensures that the VR environment not only provides a realistic experience but also effectively helps physical education students improve their table tennis skills.

Method

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 Female = 11	Male = 16 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.

Materials and Equipment

VR Equipment. The screen that comes with the HTC Vive head (produced by HTC in April 2016 using technologies from Valve Corporation) is utilized. With head-mounted stereoscopic displays (HMDs) such as the Vive, users experience a 360-degree virtual world that moves in real time in response to their motions (Steuer, 1992). In order to interact in a virtual world, users must wear a head-mounted display (HMD) and carry two controllers, one of which simulates the spread of the ball and the other a table tennis punch.

By enabling users to wear glasses and contact lenses while using the device, HMD welcomes users who are visually impaired. Two base stations positioned at different angles are utilized with VR equipment in a room measuring 1930 x 3300 mm to provide room scale tracking.

VR Table Tennis Game. The VR game "Table Tennis" by Fun Labs involves players reacting to external inputs and competing against AI, following official table tennis rules. AI difficulty ranges from amateur to legendary, with increased service/return placements, speeds, and ball rounds. The game simulates a real environment using audio, performance, and haptic feedback, including vibrations and genuine sounds when hitting the ball. Scoreboards display points, and voice feedback is available.

Real-World Table Tennis Setup. A real-world setup includes a STIGA table tennis table, Dawei paddles, and Schildkrot 40mm balls. Service targets are ten standard-size soft drink containers.

Assessment and Measurement of Real-World Table Tennis Performance

Evaluation. A skilled table tennis trainer with over 40 years of experience and multiple international medals assesses the participants. The judge is unaware of the participants' tasks during the study. The real-world challenge is based on exercises used by trainers and is designed with significant input from the judge, using an established assessment system for quantitative and qualitative evaluation.

Quantitative Assessment. Participants receive numerical scores based on their execution of table tennis tasks. Scores are calculated from successful returns in backhand, forehand, and alternating stroke rallies. A successful return occurs when the ball lands on the player's side, touches the striker, and lands on the other side. Each participant has three chances to complete a rally, with the best two results used for scoring. Scores range from 0 to 100 for each task, with higher scores indicating more successful returns. A score of 100 signifies the completion of 100 returns.

Target precision is also assessed. Ten soft drink containers are spaced 100 millimeters apart around the table's edge, serving as targets for serving accuracy. Scores range from 0 (no targets hit) to 10 (all targets hit), with each target worth five points. The total possible score is 350, comprising serving (50), backhand (100), forehand (100), and alternating beats (100). Participants with a pre-test score above 90% are excluded from the study due to insufficient potential for improvement.

Quality of Skills Assessment. The quality of the skill assessment in the table tennis task is based on the assessor's observations, focusing on five criteria: ball height, strength, consistency, technique, and coordination. A baseline record is created for each participant during pre-tests, and the same method is used for external training assessments. The evaluator scores each category as 0 (no improvement), 1 (modest improvement), or 2 (considerable improvement). The total score, ranging from 0 to 10, reflects the overall skill quality.

Since skill quality and quantitative assessments evaluate different aspects of table tennis skills, it is expected that improvement might be seen in one evaluation but not the other. Therefore, the two evaluations are analyzed separately.

Planning

Before and after the intervention phase, real-world table tennis performance is evaluated in both the VR training and control groups. For overlays of the research design, see Figure 1.

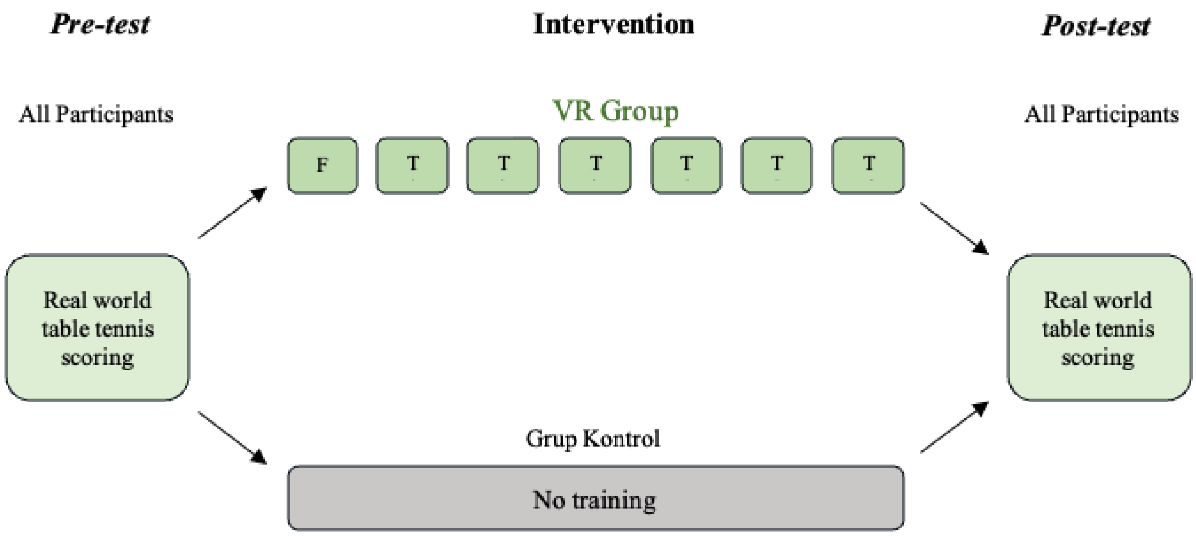

Figure 1. Wide research design lines. Participants were divided into two groups: the VR group and the control group. Every participant underwent pre- and post-assessments. After completing an orientation (F) session, participants in the VR group go through six VR training sessions (T1-T6).

The study hypothesis is examined by a mixed model's variance analysis. The analysis includes in subjects (before and after training) as well as intersubjects (VR training group vs. control group). The real-world table tennis performance evaluated by a specialist in the quantitative and quality components of abilities is the dependent variable.

Procedure

Participants first received guidance on the approval procedure and completed questionnaires on demographic information (age, gender, handedness). They then underwent a visual check to ensure normal eyesight, visual acuity, and stereo vision.

An experienced table tennis trainer evaluated participants' abilities in a real table tennis environment both before and after the intervention (VR training or no training). The expert assessed the quantitative and qualitative aspects of their performance without knowing the group assignments. Figure 1 summarizes the study design for both groups. Participants were instructed not to play table tennis outside the specified sessions during the trial. In the introduction session, participants also received cognitive evaluations and additional visual assessments, but these data are not included in this research as they are not relevant to the study's goals. (Szpak et al., 2019).

Pre-test. The participants began with five-minute rally exercises with judges, who provided brief instructions on proper table tennis regulations. No additional guidance was given on improving their skills.Following the initial instruction, participants completed alternate forehand, backhand, and rally activities from the Real World Table Tennis Assessment and Measurement section. Each task was performed in three trials, with the goal of returning as many balls to the judge as possible. Scoring points was not the objective of this task.

During the forehand duty, the player's punch should use the palm facing the punch. The assessment ends if a different technique is used to hit the ball. Players alternate hitting the ball with their backhand and forehand, and a rally ends if the player misses a return or fails to touch the judge's table. If the judge does not return the ball, a new rally begins.

After the rally, participants start a service project involving hitting a target. They have ten attempts to hit the target. Unauthorized serves that move the target do not count towards the score but still count as one of the ten tries. Participants are given three minutes to practice hitting the target before the assignment begins, with no instructions or feedback provided during or after the task.

Intervention

VR Group Training: The Eleven VR Table Tennis App and HTC Vive HMD are used for all VR training. Participants engage in tasks like service, backhand, and forehand, evaluated in pre- and post-tests. Over seven sessions, each participant spends a total of three hours and thirty minutes in VR, with the recommendation to complete two sessions per week. Only one training session is allowed per day.

Training begins with an orientation meeting where participants receive instructions on using the VR equipment and the table tennis game. During this initial session, there is no assessment of scores, and participants are given time to practice. This introduction ensures that participants understand the tasks and can comfortably use the VR equipment.

The goal of the six VR training sessions is to win a table tennis match against an AI opponent. The game is won by the first player to score 11 points, with the requirement of leading by at least two points. After a game ends, a new one begins, and the top five series are used for training. If a player wins three out of five matches in a series, the training difficulty level is increased using adaptive methods. Conversely, if a player loses three out of five matches in a series, they either drop one difficulty level or remain at the lowest level if already there. Each session lasts about thirty minutes, and any unfinished series are carried over to the next session.

Control Group: During the intervention phase, there is no training provided to the control group.

Post-test. Every participant finished a post-test consisting of table tennis tasks that were the same as those in the pre-test. Following the post-test, the participants were asked if they had played table tennis at any other point since the study began. If they had, they were excluded from the study if their total playtime had exceeded an hour.

Result

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.

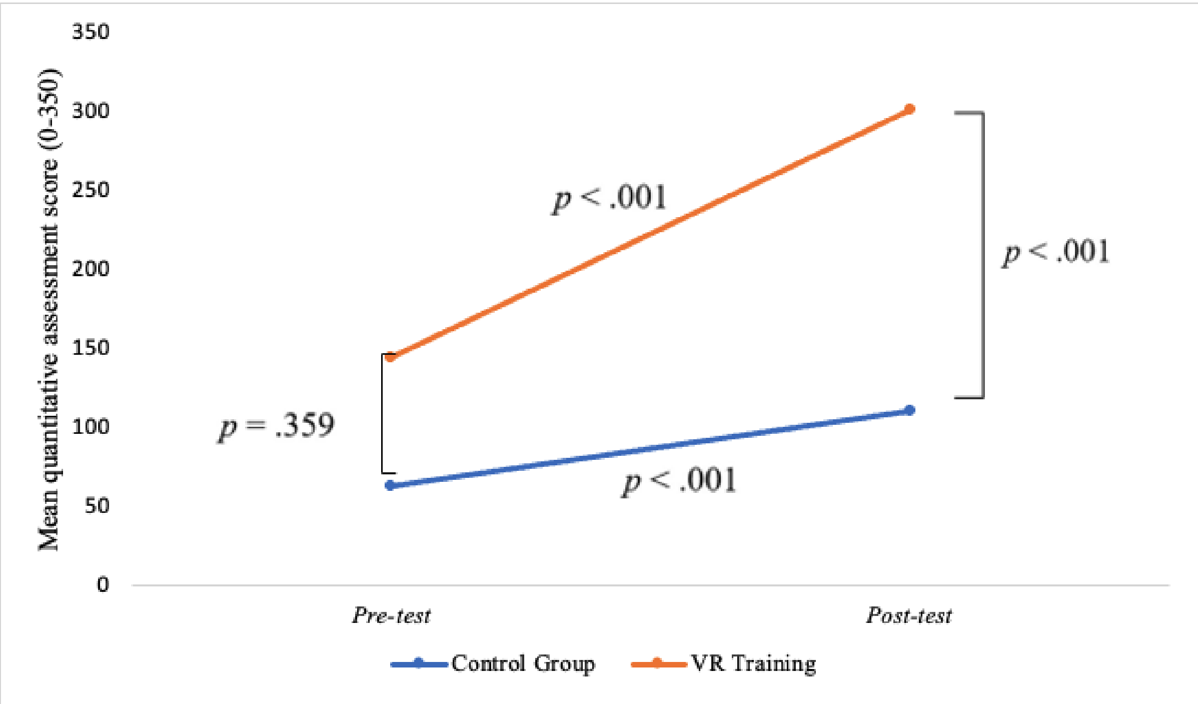

Figure 2. Quantitative assessment Mean Total Score (±standard error) for the VR training group (dark grey) and control group (light grey) at the pre-and post-test on quantitative assessments.

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.

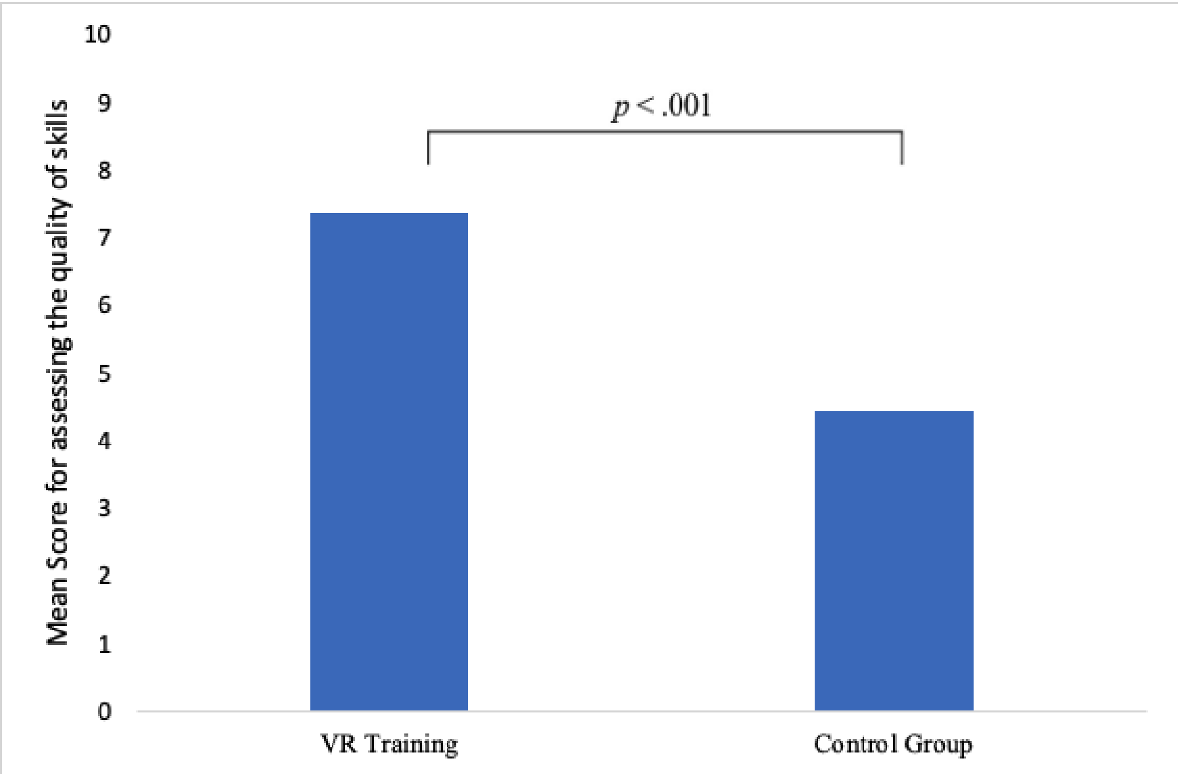

Figure 3. Quality of skill assessment. Total average (± standard error) change in the skill assessment quality scores between the pre-test and post-test for the VR training group (dark gray) and the control group (young grey).

Discussion

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.

The participants in this study were not competitive table tennis players and did not receive any advice or suggestions for improvement. Future research could benefit from providing one-on-one skill-improvement instruction from an appraiser. Some experts suggest that virtual reality (VR) may be most effective as an additional training tool for individuals who are already knowledgeable and experienced in sports (Miles et al., 2012). VR might be particularly valuable when users can apply proper forms and tactics within a realistic gaming environment. Future studies examining individuals with varying levels of experience could provide insights into who benefits the most from training in a virtual environment.

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).

Since both adaptive training (Gray, 2017) and open skill training (Wang et al., 2018) have been shown to improve performance outcomes, combining these two methods in virtual reality could significantly influence skill development. Given that table tennis is an open-ended skill sport, it is important for players to refine their abilities in VR. Exploring whether VR training leads to improved performance as competitive players against AI is valuable but outside the scope of this investigation.

Our study is among the first to examine the transfer of sports training using VR with a head-mounted display (HMD). We demonstrated transfer effects by comparing VR training groups with control groups that received no training. However, future research should consider additional factors. These include evaluating skill quality and quantitative assessments using a variety of table tennis skills to measure changes in participants' abilities. Nonetheless, some techniques like drives, flicks, and smashes are not assessed, and the study lacks objective measurements such as eye movement tracking or video-based motion analysis. (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 limitation of this study is the lack of intrinsic trustworthiness in the qualitative assessments. We used a single, highly skilled table tennis coach to ensure consistency in evaluating players' skills, which means we cannot gauge how other raters might agree with our skill evaluations.

While quantitative results show high reliability, the qualitative findings may not be as widely applicable.

Although the VR training group showed positive transfer effects, the exact cause of these benefits remains unclear. It is uncertain whether the improvements were due to the VR training itself or to general cognitive abilities like better hand-eye coordination and faster reaction times. Future research should include a control group participating in VR training with a similar tabletop sport, such as VR air hockey, to isolate the effects specific to sports activities while controlling for other variables.

Comparing VR table tennis with other VR table sports can help determine whether the gains in abilities are due to the simulation of table tennis or broader skills learned in the VR environment. Identifying the elements linked to improved real-world table tennis skills may provide insights into the benefits of developing sports-specific VR training programs.

Conclusion

The study's findings highlight the effectiveness of VR-based smash forehand training, showing significant improvements in table tennis performance among participants who received VR training compared to the untrained group. This research contributes to the emerging field of VR-based sports training, particularly in table tennis, and may inspire further investigation into VR's potential for transferring skills to real-world sports.

Future research should explore several deeper aspects. First, it is important to determine if skill improvements in VR environments correlate significantly with real-world enhancements. Additionally, researchers should evaluate whether VR training can be as effective or more effective than traditional training methods. Investigating how VR training benefits individuals across various skill levels and understanding the factors driving its positive effects are crucial.

Further studies could also examine whether the transfer of skills is specific to table tennis or if fast-paced VR training can benefit other sports disciplines as well. This exploration suggests that VR technology, rather than being merely a novelty, has the potential to significantly enhance skill development and performance in real-world settings.

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