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Pinging Between Worlds: Training Table Tennis Novice Players in Real Environment for Virtual Reality Competitions

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Figure 1: A) Three participants take turns training with the coach in a Real Environment (RE) social setting. B) A Virtual Reality (VR) table tennis player wearing a VR head-mounted display plays Eleven Table Tennis (ETT) during the evaluation session. C) A screenshot from ETT, the VR table tennis game we used in the user study, with the user's avatar turned off.

Abstract

Modern Virtual Reality (VR) technology has enabled users to experience Real Environment (RE) sports in their homes. For VR table tennis, one of the most popular VR sports, the players have rankings and tournaments and compete for RE awards. Based on this phenomenon, this paper aims to understand the benefits of RE training in improving VR table tennis skills. In a user study with 12 novice table tennis players, we measured their performance in 16 basic skills via a pre- and post-study design using a novel training protocol designed for both RE and VR players. We also asked participants for their insights into the training and to evaluate their experience. Our results show a significant improvement in all measured skills. However, participants identified issues with the technology that caused discomfort. Our findings provide valuable insights for software developers working on VR sports applications, enabling them to create better experiences for VR table tennis players. They can also help developers of VR training applications identify areas for improvement with the current technology.

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1 Introduction

Virtual Reality (VR) Head-Mounted Displays (HMDs) are becoming accessible to the general public as VR becomes mainstream technology. For example, Meta VR HMDs [1] have seen sales surpassing 20 million devices. These devices are similar to the cost of a game console and, therefore, can be affordable for a consumer to provide a realistic, immersive experience with high-quality graphics and tracking. A significant factor driving the adoption of VR HMDs is the allure of gaming. VR games that replicate real environment (RE) sports experiences, such as table tennis (e.g., Eleven Table Tennis (ETT) [1] with over 298,000 players [2]) or golf (e.g., Walkabout Mini Golf VR [2] with over 194,000 players [3]) have gained immense popularity. These VR sports games require players to use a six-degree-of-freedom (6DOF) device to interact with 3D content, yet do not require much physical space, making them ideal for VR.

The rising popularity of VR sports games has created communities within these games, where players are ranked according to their skills. For example, VR table tennis has organized tournaments with cash prices [4], which increases the participants' motivation to improve their skills. Despite the desire for players to improve, they cannot effectively train for VR sports in RE because there is no research on how to effectively improve skills in VR setting using RE methods. Most studies have focused on using VR as a tool and

[1] https://elevenvr.com/en/
[2] https://www.uploadvr.com/walkabout-mini-golf-review/

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not the purpose [5–7]. For instance, how does engaging RE physical objects or receiving immediate and personalized feedback to adjust their actions affect the user performance in VR. Moreover, it has been established that playing in RE can enhance the social aspect of the game [5]. Finally, using an RE coach has been instrumental in training RE players to acquire various skills and has greatly assisted athletes during training sessions [8] and improved their self-esteem [9]. Yet, there is no formal evaluation of the effect of these differences on players' VR skills.

This paper focuses on understanding how RE training can improve VR table tennis (VR TT) skills. Table tennis, also called ping-pong or whiff-whaff, is a two or four player game where players use a paddle to volley a ball back and forth across a fixed table. Players score points when an opponent cannot return the ball or sends it outside the table boundaries. Table tennis is a sport that requires precise hand-eye coordination and fast reaction times. RE training for VR TT offers opportunities for players to effectively train and engage, addressing scenarios of diminished realism and limited access to perceptual affordances such as lack of tactile feedback, dept perception, weight consistency of controllers [5, 10, 11]. RE training compensates for these limitations by ensuring that players develop the necessary physical skills and strengths that VR cannot adequately provide in VR, especially for novice players [5]. This is particularly crucial for novice players who might otherwise adopt incorrect techniques in VR environments [12] which could affect their performance in VR competitions where the rules are strictly followed [13]. This real-world experience enables players to navigate VR in a more natural manner [14]. Moreover, a survey of VR TT players revealed the use of RE training methods to improve their basic skills, timing, and strength, including hiring RE coaches to improve their techniques [5]. In other words, players pay to be trained for VR TT. They also identified challenges with the physics engines used in VR games, e.g., ball speed, and noted that VR applications tend to be more forgiving of their errors. However, these results have not been replicated formally.

Here, we conducted a user study to verify novice players' perceptions regarding the benefits of training in RE to improve their VR TT skills. Employing a pre-and-post-study design, we recruited 12 novice table tennis players and had a professional table tennis coach train them in RE for five days. The coach followed a novel training protocol developed to test, which skills are needed in VR TT. Our findings indicate that training RE skills for VR is feasible, with notable improvements observed in 16 fundamental skills, including serve, forehand, backhand, and footwork. Upon analyzing the player's comments about their experience, we found that RE training may positively affect the game experience due to the limitations inherent in VR HMDs, such as depth perception issues, unrealistic game physics, and paddle emulation discrepancies. These results build upon previous research on table tennis skill transfer from VR to RE [5–7], extending our understanding of the challenges encountered by VR players when transitioning from RE [5]. Finally, the training protocol developed for this study can be used for future studies involving skills transfer between VR and RE table tennis.

Our results also inform the future design of VR training applications by considering the difficulties users face when playing in VR, and those that can be trained in RE. It also informs the design of VR applications in situations where precision and speed are important [15], but the current limitations of VR HMD adversely impact user performance. For example, using RE training, novice surgeons can be trained to control image-guided surgical instruments [16] and prevent the depth perception issues of stereo displays [17, 18]. Another example, would be to use RE training to help drone pilots understand the speed sensation before using VR to pilot them [19]. In summary, the contributions of this paper are the following:

- A user study that evaluates the benefits of training novice players in RE for VR TT.
- The development and validation of a training protocol for VR TT competitions.
- Quantifying the improvement of 16 basic skills through RE training and identifying issues affecting novice VR players transitioning from RE.
- Providing recommendations for designers of VR TT systems

2 Related Work

2.1 Skill training in VR and RE

Several previous works exist on understanding skills transfer between VR and RE [20–22]. For example, surgical operations [23,24], architecture [25], education [26–28], military & police [29,30], and task performance [31–34]. Some of these studies have identified multiple issues that affect VR training for RE activities. For example, Bossard et al. [35] identified five main issues: type of transfer, facilitation of transfer process, matching features of VR with transfer, assessment of VR effectiveness, and singular context of learning which highlight the complexities involved in leveraging VR for educational and training purposes. Similarly, Pastel et al. [36] uncovered a need for real-time feedback and avatar engagement as issues that affect VR training. In summary, it is possible to train RE skills in VR, but some issues affect the benefits of VR training.

For training RE sports in VR, most past work has found that VR helps players learn complex motor skills [36] and perceptual-cognitive skills [37] including exercise drills [11] and shooting skills [38]. However, other works have shown no change in RE skills [39, 40] or even a decrease in performance [41]. Additionally, Liu et al. [11] identified the lack of tactile feedback in VR as an issue and advocated using tactile actuators, even if these devices add extra weight to the controllers. They also stated the need to match the physical and VR spaces to enjoy gameplay more.

Past work on table tennis training in RE examines motor skill [42,43], head, eye and arm coordination [44], and physiological demands [45]. Other works focus on evaluating player performance of specific skills transfer between VR HMDs and screens [42], head, eye, and arm control when performing a stroke [44] and assessing various physiological parameters to understand the metabolic demands of table tennis [45]. Similarly, previous work has studied the effect of VR training on RE table tennis skills. For example, Karatas et al. [5] identified the existence of AI and the readily availability of people to play with as advantages of playing in VR. Furthermore, Skopek et al. [10] found that the issues of the technology's lack of tactile feedback and inconsistent weights and centers of gravity of HMD controllers negatively affect players indicated by the higher muscle involvement observed in RE compared to VR. In addition, limitations in strength tracking and space also affect footwork drills [5].

Finally, we did not find previous work that trained VR users in RE. Thus, our work extends the VR training research area, identifying if it is possible to train novice VR TT players in RE and identifying the issues they face when moving from RE to VR.

2.2 VR Table Tennis

In VR TT, players use a virtual table and paddle that closely resembles an RE paddle, enhancing immersion during gameplay. Game rules remain consistent with RE table tennis, albeit with non-realistic avatars and the absence of ball retrieval tasks. Another difference is the use of AI agents, enabling players to engage in matches and practice without reliance on human opponents.

Despite the challenges noted by previous works such as latency tracking and avatar player look [5], racket's weight and its balance [11], field of view and haptic feedback [7, 10], a survey of players of VR TT conducted by Karatas et al. [5] investigated how players perceived VR as a convenient way to play. The authors found that these players spend more time playing in VR than in RE.

Yet, Karatas et al. [5] found that RE table tennis was seen as a way to make social connections. Regarding skill transfers between VR and RE, VR TT players perceived the transfer of skills between both modes of play, but this information was not empirically evaluated in a user study.

A common thread between all these works is that they focused on using VR to train RE skills. Only Karatas et al. [5] investigated RE training among VR players, relying on player experiences rather than formal studies. In addition, players have expressed interest in formal RE training to determine potential benefits among VR players. Based on this, the current research seeks to understand the advantages of RE training among VR novice players.

3 Research Questions & Motivation

VR technology is a valuable tool for simulating sports games, as evidenced by numerous studies [7, 46–48, 48–50]. However, players cannot effectively train for VR sports in RE because there is no research on how to effectively improve skills in VR setting using RE methods. While RE training for VR TT offers opportunities for players to effectively train and engage, addressing scenarios of diminished realism and limited access to perceptual affordances such as lack of tactile feedback, dept perception, weight consistency of controllers [5, 10, 11], most studies have focused on using VR as a tool and not as a training platform [5–7]. For instance, how does engaging RE physical objects or receiving immediate feedback to adjust their actions via haptic feedback affect the user performance in VR. Moreover, it has been established that playing in RE can enhance the social aspect of the game [5]. Finally, using an RE coach has been instrumental in training RE players to acquire various skills and has greatly assisted athletes during training sessions [8] and improved their self-esteem [9]. RE training compensates for these limitations by ensuring that players develop the necessary physical skills and strengths that VR cannot adequately provide in VR, especially for novice players [5]. This is particularly crucial for novice players who might otherwise adopt incorrect techniques in VR environments [12] which could affect their performance in VR competitions where the rules are strictly followed [13]. This real-world experience enables players to navigate VR in a more natural manner [14]. Yet, there is no formal evaluation of the effect of these differences on players' VR skills.

In our research, we focus on novice participants to ensure the training has the highest impact on individuals who are likely to benefit the most. Furthermore, novice players are in their awareness stage [51] and are most likely to see a training effect in our study time frame. Moreover, novices often face unique challenges such as precision of ball hits, understanding game rules, and ball control, which more experienced individuals do not, which gives more information about the task and the system. Focusing on training novices and investigating how to improve the system's usability, more users will be able to play VR TT, potentially increasing diversity and inclusion. Thus, our research questions are:

- **RQ1:** What skills can be trained in RE and improve novice player performance in VR TT?
- **RQ2:** What technological challenges do novice players encounter in VR after training in RE?

By answering these questions, we aim to understand the benefits of novice VR TT players' training in RE and identify potential challenges for VR TT players, focusing on the technological limitations of modern VR HMDs. Furthermore, we aim to identify specific skills that are transferable from RE to VR offering insights for developers of VR TT applications and training programs. We hope that future developers of VR training applications will benefit from this comprehensive study of RE training for VR competitions. Finally, our results can also be extended to other fields that train people to control machines remotely, e.g., robots or drones, as it shows how RE training can help mitigate technology limitations when practiced in RE scenarios.

4 User Study

We conducted a user study to investigate the advantages and benefits of RE training for novice VR TT players. This study was approved by the Institutional Ethics Review Board of Dalhousie University.

4.1 Methodology

4.1.1 Participants

We recruited 17 participants from the Dalhousie University community through email advertising and poster distribution. To be eligible, participants needed to have never played VR TT, played RE table tennis less than once a month, and passed the skill test. In the skill test, a researcher with over 10 years experience in table tennis (Researcher A) assesses them on three matches to 11 points. The evaluation consisted of their ability to do basic serve and return skills. After finishing all matches, the researcher counted the number of successful serves and ball returns. Then, only considering the best two out of three matches, Researcher A calculated their success percentage, e.g., how many successful serves and returns. We consider a participant novice player if their skills correspond to a 2.5 or less in the National Tennis Rating Program (NTRP) player rating scale [52], which is equivalent to 60% successful returns and serves during the evaluation. We based the 2.5 score on McPherson's work [53]. Only 15 participants passed the skill test, e.g., scored under 60%, and were eligible to participate in the study. We had an attrition rate of 20% as three participants dropped out of the study due to personal reasons, a common limitation in longitudinal research [54].

For our analysis, we focused on the data collected from twelve participants (5 female, 7 male, 0 other) from Dalhousie University. The participants' ages ranged from 18 to 34 years (M=23, STD=3.84). Regarding their experience playing organized sports, 66.7% reported having played sports, while 33.3% indicated that they have never played any sport. 42% of the participants had played table tennis in RE before, but their frequency of play was less than once a month, which aligns with our definition of novice players [55]. All participants were considered physically fit based on a self-reported physical fitness survey. See Supplementary Materials for the survey. Lastly, even if this was not a requirement of the study design, all the participants were right-handed.

4.1.2 Equipment

For accessing VR TT (Figure 1C), participants used a Meta Quest 2 VR HMD [56] and the Eleven Table Tennis game v2.314.12 [4]. We chose this game due to its widespread popularity and substantial user community, as this game has over 298,000 players [2]. See Figure 3(a) for a picture of the room used to play VR TT. We also used the AMVR Table Tennis Paddle Grip Handle for the Oculus Quest 2 controllers [3]. For the RE training, participants used Tibhar Drinkhall Allround Classic paddles [4]. Additionally, we used a Peter Karlsson's Indoor Table Tennis [5] table (2740 x 1525 x 760 mm), which is professionally approved for training purposes [57]. Finally, we used GoPro Hero 10 Black camera [58] to record the sessions, mounted on a tripod to capture a comprehensive view of the entire room. See Figure 3B for a picture of the training environment.

4.1.3 Procedure

We structured the experiment into three distinct stages over seven days. See Figure 2 for a diagram of the full user study, each stage is explained in detail below.

[3] https://www.amvrshop.com/products/amvr-table-tennis-adaptor-for-quest-2-controllers?

[4] https://tibhar.info/en/shop/drinkhall-allround-classic/

[5] https://www.kettlerusa.com/products/peter-karlsson-recreation-table-tennis-table

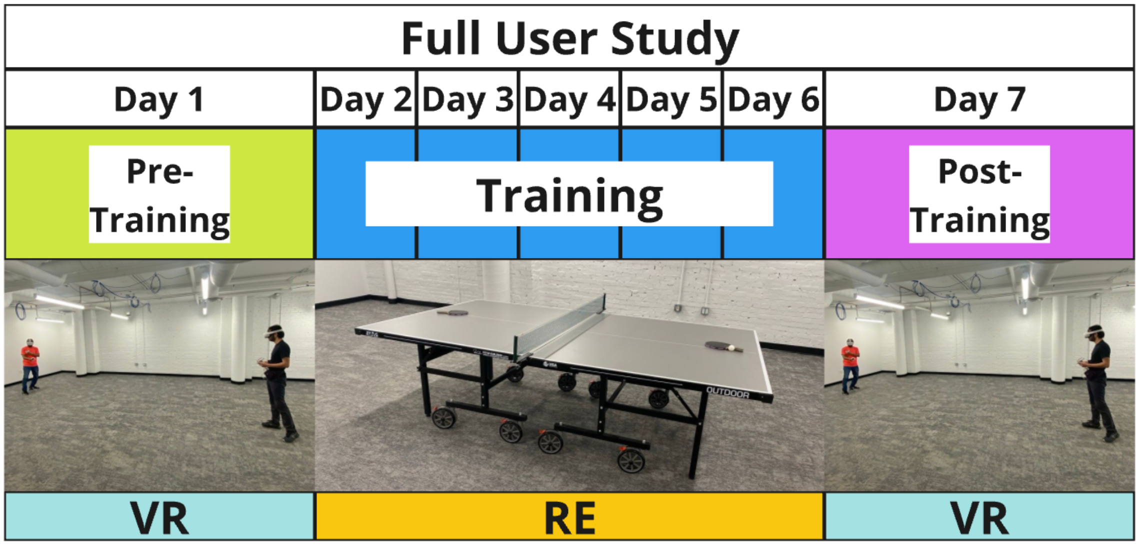

Figure 2: A) The user study procedure. We have three stages, pre-training, training, and post-training. For the pre-training stage, participants were evaluated in one day (indicated by the lime-green color). For the training stage, each group was trained for five days (indicated by the blue color) followed by post-evaluation the next day (indicated by pink). Pre- and post-training were done in VR (light-blue), and training in RE (yellow).

Pre-training stage The *pre-training stage* was a single, 20-minute session during which we evaluated each participant. Researcher A, with over 10 years of experience playing table tennis in RE and five years of playing experience in VR, ran this stage and assessed the participants' skills.

In the *pre-training stage*, each participant arrived at the noise-free lab, where there was empty space for the participants to move around (Figure 3A). Upon arrival, participants received a brief overview of the user study's purpose and procedures, including the need not to participate in any table tennis activities outside the designated training sessions, as such behaviour could potentially impact the study results. They were also informed that the study would span six consecutive days, with any missed sessions resulting in their exclusion from the study. Next, the participants reviewed and signed the consent form.

Following the briefing, participants completed a pre-experiment questionnaire covering their demographics and self-reported physical fitness level (See Supplementary Materials). After that, Researcher A conducted a six-minute assessment of the participants' RE table tennis skills to ensure that only novice participants were recruited for the study. After the skill evaluation, participants wore a Meta Quest 2 VR HMD and were assisted by the researcher in configuring the game settings, including turning off the digital self-representation of the players since previous work established that using an avatar affects the player's behavior [59]. Additionally, participants initiated the screen capture software to record their VR sessions (Figure 1C). Next, the researcher assessed 16 table tennis skills by instructing participants to place the ball in specific positions or execute particular shots. For example, participants had to put the ball close to the opponent's net for the short serve evaluation. The only skill not directly evaluated in the session was footwork, as we assessed this skill by analyzing the videos to determine the participant's ability to move effectively to the required positions for ball hits.

Training stage For the *training stage*, we hired an independent coach with over 30 years of table tennis coaching experience in RE with one year of playing experience in VR to conduct formal table tennis training with the participants. Researcher A also supervised the training sessions during the training stage to make sure the coach and participants followed the study protocol. In developing the study protocol, a collaborative effort between the researchers and the coach was undertaken. We incorporated the coach's assessment of similar training protocols [13, 60, 61] to determine the content of the training session for novice players. The coach trained the participants for five sessions; each session of the *training stage* took approximately 60 minutes. In total, we had four different groups of three participants each, as to reduce the number of students in the room simultaneously. This number of participants is similar to an RE table tennis training session. See Figure 1A for the picture of one of the groups in a training session.

The *training stage* lasted for two weeks, and there were four different groups. Although each group took the same training, the rationale behind dividing the training into four groups was to accommodate the coach's schedule, as conducting all sessions in a single day was not feasible due to the time required for each training session. Group 1 started training on Monday and concluded on Friday, while Group 2 began on Tuesday and ended on Saturday. Group 3 followed the Group 1 schedule, and Group 4 followed the Group 2 schedule the following week. Due to the time that it takes to complete the *post-training stage*, there was a shift in the starting day between groups to ensure that *Researcher A* could evaluate all participants in a group the next day after finishing the training.

On the first day of training, the coach started with a warm-up session to familiarize the players with the environment of table tennis. The players then learned the rules of the table tennis game including basic serving (short and long) and return techniques. Additionally, players were taught how to repeatedly return a short and long ball, including accurate ball placement on a specific target and the need to maintain game rally. On day two of the training, players revisited the previous day's lessons before continuing with forehand strokes, including forehand consistency and accuracy. Furthermore, players were also taught on how to execute backhand, including backhand consistency and accuracy. On the third day, players practiced what they were taught the previous day before learning spinning techniques, including spinning consistency and accuracy. On day four, players learned how to move around to successfully hit the ball to the opponent's table. Finally, on the fifth day, participants practiced all acquired skills under the guidance of the coach before engaging in matches. See supplementary materials for the full protocol.

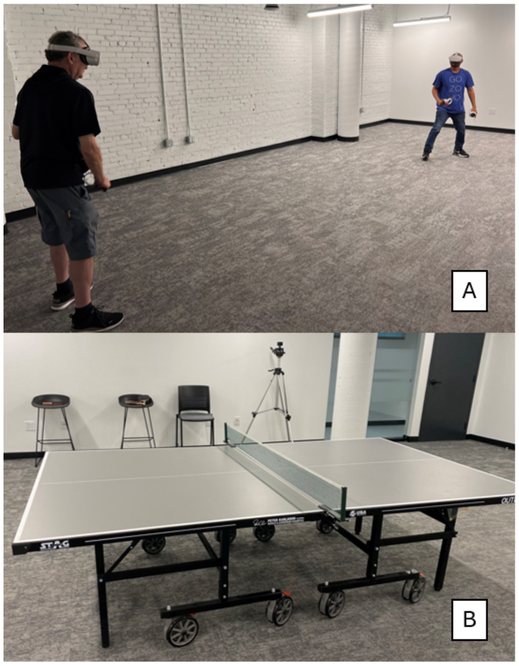

Figure 3: A) The room used for the pre- and post-training sessions. The room was empty to avoid any hazards to the participants. B) the room used for the training sessions. The room had a Peter Karlsson's Indoor Table Tennis table and enough room so players could move around the table.

Post-training stage The *post-training stage* took place on the day following the conclusion of the training stage. Researcher A also ran this stage and performed the participant's skills evaluations in random order. During this stage, both Researcher A and the participant were physically in the same room wearing the HMD, as shown in Figure 3A. The participants completed a series of exercises and skill evaluations identical to those conducted during the pre-training stage. Following completion of the VR post-training evaluation, participants were asked to fill out questionnaires and respond to an open-ended question regarding their overall experience with the study which lasted for 30 minutes. See subsection 4.3 for the list of questionnaires.

4.2 Table Tennis Skills Evaluation Metrics

To improve training performance and evaluation results, we assessed each skill based on technical proficiency and tactical performance indicators [42, 44], adopting the condensed point system (11 points instead of the traditional 21 points) [45]. We employed quantitative evaluation metrics to evaluate 16 fundamental table tennis skills. This assessment involved analyzing video recordings to quantify the number of successful serves or returns observed in 11 skill trials, corresponding to the International Table Tennis Federation (ITTF) scoring system [62]. For example, perfect execution of a short serve might be 11 points, while errors made could reduce the points below 11 points. Researcher A coded the videos quantitatively and recorded participants' scores using Microsoft Excel [63] to maintain consistency and accuracy in the assessment process between the pre- and post-training stages. This researcher is the same one who ran the user study and was familiar with the protocol followed. Participants were awarded 100 points for each successful execution of a skill, while 100 points were deducted for each unsuccessful attempt. Then, we calculated the ratio of successful serves or returns to the total number of trials conducted to derive a performance metric for each skill. The evaluated skills were: short serve, short ball consistency and accuracy, long serve, long ball consistency and accuracy, forehand, forehand consistency and accuracy, backhand, backhand consistency and accuracy, spinning, spinning consistency and accuracy, and footwork. For consistency, we evaluated the number of times participants successfully used that skill when intended; for accuracy, we evaluated the number of times participants could hit a ball using that specific skill.

4.3 User Experience

Here are the questionnaires we administered to gather subjective data regarding participants' experiences:

- **Physical Activity Enjoyment Scale (PACES-8) [64]**: to measure whether training in RE provides some level of enjoyment in VR.
- **Simulator Sickness Questionnaire (SSQ) [65]**: to identify if participants experienced any form of motion sickness during VR evaluation
- **International Physical Activity Questionnaire (IPAQ-SF) [66]**: to measure the types of intensity of physical activity and sitting time that people do as part of their daily lives.
- **Immersion Questionnaire**: to evaluate the level of immersion and experience the participants had while playing table tennis in VR. We adapted the immersion survey used by Karatas et al., [5].
- **User Experience:** Participants answered a survey with open-ended questions that were asked in written form, allowing them to express their preferences and provide insights into their experiences and motivations during the training.

5 Results

Data was pre-processed and plotted through JMP, and analyzed using a paired t-test in SPSS 28. We checked the normality of the data using Shapiro-Wilk tests. For the non-normal data, we applied log transformation. If data was still not normal, we utilized the Wilcoxon Signed-Rank Test to analyze it. We also report Cohen's d [67] and the Pearson correlation coefficient (r) values as our effect size measure. Additionally, we followed a post-hoc Benjamin Hochberg procedure [68] to reject or accept our p-values. Results are shown in Table 1, and in Figure 4. The bars in Figure 4 represent the mean of the data, and the error bars represent the standard deviation of the mean. Based on previous research that conducted training experiment [7, 41], we used G Power 3.1.9.4 [69] to determine the sample size, finding that 12 participants was enough for detecting an effect size of 0.9 with a two-tailed test, an α level of 0.05, and a power of 80%. For qualitative open responses, we used inductive coding [70] and consolidated the resulting codes to derive insights into the participants' experiences.

5.1 Table Tennis Skills

The table tennis skills analyses show a statistically significant difference between the pre-and post-evaluation of all 16 skills analyzed. The post hoc test using Benjamini-Hochberg (BH) procedure [68] reveals a statistically significant result ($p<0.001$) for all skills (See Table 1 and Figure 4a-p).

5.2 Questionnaires

We analyzed the survey results using descriptive statistics. Our findings indicate that all measures were positively rated for IPACES -8 *(Mean=6.4, SD=0.67)*, immersion *(Mean=5.83, SD=0.83)* and IPAQ-SF *Mean=95.2, SD=23.61* for vigorous; Moderate *Mean=78.75, SD=69.81* and Walking *Mean=83.83, SD=86.86*. For the SSQ, on average, the total SSQ shows that participants did not report any symptoms of motion sickness during gameplay *(Mean=1.42, SD=0.67)*. We also did a meta-analysis of the SSQ and the result

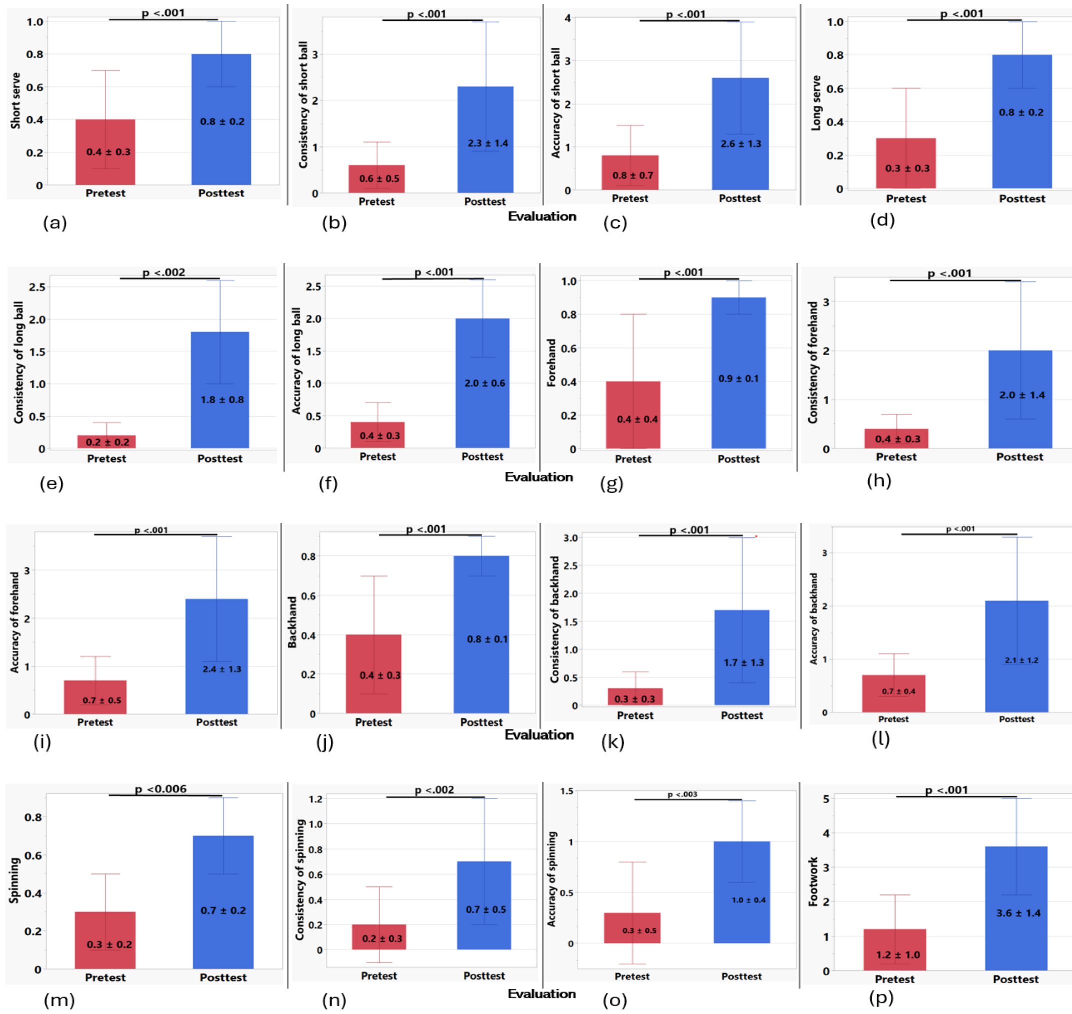

Figure 4: Comparing pre and post-evaluation of (a) Short-serve (b) Short-ball consistency (c) Accuracy of short-ball (d) Long-serve (e) Consistency of long-ball (f) Accuracy of long-ball (g) Forehand (h) Consistency of forehand drive (i) Accuracy of forehand drive (j) Backhand (k) Backhand consistency (l) Accuracy of backhand drive (m) Spinning (n) Consistency of spinning (o) Spinning accuracy (p) Footwork

indicated low levels of nausea, oculomotor, and disorientation on average (Nausea (M=0.45, SD=0.68), Oculomotor (M=0.53, SD=0.6), Disorientation (M=0.43, SD=0.63)).

5.3 User Experience

After the experiment, we asked them about the limitations of playing in VR. Six participants mentioned issues with ball control. For example, P2 stated *"...sometimes, with low pressure, it takes more power compared to real environment."*, P4 commented *"the graphic glitches sometimes; lack of feedback when hitting the ball (especially in spinning)"*; and P5 *"Occasionally there will be lag spikes which makes it difficult to return the ball. Additionally, the ball is weightless, and you can move it through the table."* Two participants mentioned walking through the table during gameplay as an issue with VR. Finally, other VR limitations include depth perception issues and the physical discomfort of wearing VR HMDs.

Participants also commented on the limitations of playing RE table tennis for VR TT. Four participants mentioned space for the table, and setting it up was an issue. For example, P3 said *"A separate large room and physical table is required."* P4 also mentioned the physical demand of playing and the table height as limitations, *"Going to go pick up the ping pong balls. Height is also a limitation, in VR I was able to change the height of the table."* And P1 mentioned the difficulty in finding opponents in RE *"...it needs a room for a table and when you go to the gym, you also need to share with another person for a table and also need a similar level friend to play with you, the VR can just find an AI to practice."*

We also asked participants whether training in RE affects their VR performance. Eleven participants improved their skills, their reaction time (one participant) or their stamina (one participant). For example, P4 commented *"...it [RE table tennis] helped greatly. Playing in RE helped me understand my movement and footwork."*, P5 mentioned *"Playing table tennis in real environment helped me react better to what's going on in the game (in VR and real environment),"* and P10 said *"It [RE table tennis] makes me have better stamina and helps me in ball control"*.

Finally, participants talked about their perceived skill improvement during the RE training. They mentioned that they perceived an improvement in overall skills, including footwork, serving, spinning, forehand, backhand, accuracy, and consistency. For example, P7 commented that *"I become more consistent when pulling the ball."* However, P11 mentioned the difficulty in executing spinning in VR, commenting *"spinning the ball in virtual reality is hard."*

Table 1: **Descriptive Statistics and Results of the Inferential Test of the Pre-Post Experiment on Participants' Skills Evaluation (Bolded Indicates Significance).**

Skills N=12	Pretest Mean (SD)	Posttest Mean (SD)	Statistical Test	P Value	Effect Size
Short serve	0.4 (0.3)	0.8 (0.2)	t(11)=-4.93	**<0.001**	d=-1.42
Consistency of short ball	0.6 (0.5)	2.3 (1.4)	t(11)=-4.34	**<0.001**	d=-1.25
Accuracy of short ball	0.8 (0.7)	2.6 (1.3)	t(11)=-4.91	**<0.001**	d=-1.42
Long serve	0.3 (0.3)	0.8 (0.2)	t(11)=-6.0	**<0.001**	d=-1.74
Consistency of long ball	0.2 (0.2)	1.8 (0.8)	Z=-3.10	**<0.006**	r=0.43
Accuracy of long ball	0.4 (0.3)	2.0 (0.6)	t(11)=-9.54	**<0.001**	d=-2.75
Forehand	0.4 (0.4)	0.9 (0.1)	t(11)=-5.0	**<0.001**	d=-1.44
Consistency of forehand	0.4 (0.3)	2.0 (1.4)	t(11)=-4.01	**<0.001**	d=-1.16
Accuracy of forehand	0.7 (0.5)	2.4 (1.3)	t(11)=-5.17	**<0.001**	d=-1.49
Backhand	0.5 (0.3)	0.8 (0.1)	t(11)=-4.59	**<0.001**	d=-1.33
Consistency of backhand	0.3 (0.3)	1.7 (1.3)	t(11)=-4.11	**<0.001**	d=-1.19
Accuracy of backhand	0.7 (0.4)	2.1 (1.2)	t(11)=-4.41	**<0.001**	d=-1.27
Spinning	0.3 (0.2)	0.7 (0.2)	Z=-2.88	**<0.006**	r=0.61
Consistency of spinning	0.2 (0.3)	0.7 (0.5)	Z=-3.06	**<0.002**	r=0.10
Accuracy of spinning	0.3 (0.5)	1.0 (0.4)	Z=-2.94	**<0.003**	r=0.10
Footwork	1.2 (1.0)	3.6 (1.4)	t(11)=-5.88	**<0.001**	d=-1.70

6 Discussion

The main goal of this research was to understand the benefits of RE training for novice VR TT players using a pre- and post-study experimental protocol. We evaluated the performance in 16 basic skills for 12 participants that had not played VR TT, had played RE table tennis less than once a month, and had passed a skill test. We collected the participants' feedback regarding their training experience, with a particular focus on the benefits of RE training for VR TT players and the limitations encountered in the VR environment.

6.1 Basic Table Tennis Skills Improvement

Past work has shown that VR is an effective tool for improving skills for complex tasks [71]. Here, we evaluated novice players' skills in returning shots, executing basic serves and footwork in VR after training in RE. From the results, we aimed to answer our first RQ1, *what skills can be trained in RE and improve novice player performance in VR TT?* Our analysis revealed that despite the technological issues in VR [5], the players demonstrated significant improvement across all 16 evaluated skills.

In compliment, participant feedback supported these findings, expressing positive insights and comments regarding their perceived skills enhancement through RE training. Since participants' VR skills improved due to RE training; therefore, our study highlights the transferability of technique skills, including backhand and short ball techniques, from RE to VR TT. Moreover, the success of the custom-made training protocol shows that other researchers can use it to test other player levels and train them in RE for VR. This comprehensive approach to skill development also supports the theory that RE training can effectively complement VR gameplay, as it lacks the issues VR training environments face, like no real-time feedback or avatar engagement [36] and lack of tactile feedback [11]. The feedback from the participants supported these results, highlighting the benefits of RE training in enhancing movement capabilities and ball control in the VR environment. This is particularly important considering the challenges associated with training gameplay skills in VR, as identified by Karatas et al., [5]. For example, spinning in VR presents difficulties due to emulating the spinning and real-world physics, yet our participants demonstrated improvements in this skill following RE training.

These results extend previous work on the perception of the VR TT community that RE table tennis improved their VR TT performance [5] and demonstrate that **it is feasible to train novice VR TT players with a set of 16 basic table tennis skills in RE** Importantly, our findings contribute to the existing body of research, which has focused predominantly on the transition from VR to RE [6, 7], by focusing on the transition from RE to VR.

6.2 VR technology limitations

In this study, we also collected participants' feedback after the study to address our **RQ2** *What technological challenges do novice players encounter in VR after training in RE?* All participants reported experiencing issues with VR technology and can be categorized into two areas: game physics and VR hardware limitations.

Regarding game physics, the participants highlighted their concerns related to the sensation that the ball did not act as expected in VR. They also mentioned that latency during gameplay affected their experience. Participants also expressed their frustrations with VR hardware limitations, including the absence of haptic feedback, such as the ability to walk through the virtual table, discomfort associated with wearing a VR HMD for a long period, and challenges related to depth perception, These limitations negatively affected the players' ability to fully engage with the VR environment, potentially limiting their immersive experience, leading to discomfort and disorientation.

Previous research already highlighted 3D graphics and haptic feedback as limitations in VR TT [5, 10]. However, our participants provided more detailed insights on these issues, which helped us pinpoint specific aspects that require attention. For instance, previous studies highlighted that lack of feedback negatively affects user performance [5, 10, 11], and our participant stated that weightlessness of the ball and the lack of tactile feedback upon hitting it are the main haptic feedback concern for VR TT applications. These detailed observations offer valuable guidance for researchers, practitioners, and game developers seeking improvement in the VR TT experience. While previous work aimed to improve VR paddle/racket controllers [72] and realistic ball physics [73], our study provides additional insights to further refine these aspects, especially in addressing challenges faced by novice players transitioning from RE to VR. For example, our participants identified issues like the difference in pressure and power needed to hit the ball.

Furthermore, we investigated participants' sense of immersion in the VR environment during table tennis gameplay. Our findings indicate that despite only having visual cues of the opponent's paddle and VR HMD, players reported a high level of immersion. This suggests a potential mitigation of the performance impact associated with self-avatar usage, as observed in previous studies [74]. Moreover, regarding the practical challenges inherent in RE TT, such as the need to have space for a table in RE and the time-consuming task of retrieving balls, our findings support the advantages of VR TT identified in prior research [5].

Our results are generalized to other VR sports games like tennis, squash, and badminton, which require fast eye-hand coordination and paddle use. It also extends to sports dependent on the game engine physics, like golf and billiards, as the feeling of hitting the ball and the technique needed to create specific effects might be affected by the limitations of the technology.

7 Recommendations for Virtual Table Tennis

In this section, we offer recommendations for designers of VR training systems to enhance the learner's experience. Our results can be generalized to VR applications where precise and fast movements are needed, e.g., drone flying or controlling robots.

7.1 Focus on User-Centered Design

In our study, we focused on novice VR TT players, exploring ways to enhance their skills through RE training. Our qualitative findings showed significant improvements in VR TT applications. However, it's crucial to consider feedback from professional players who use VR extensively, as their insights could refine these applications further. Their expertise can enrich our understanding and help the continuous enhancement of VR TT experiences. A user-centered design ensures that applications meet player needs, enhancing enjoyment and satisfaction. Although the ETT has over 298,000 players, we believe that this number will increase with more accessible VR headsets in the future and will require more research on this topic.

7.2 Integrate RE Training as Supplementary to VR Training

Our study demonstrated that RE training can help novice players identify and overcome lack of tactile feedback [11] and imperfect game physics [5] by learning the correct skills as stated by our participants. Past work has demonstrated that learning the correct motor-control skills can help players overcome issues with VR [75]. The quantitative and qualitative results also show the importance of RE training for VR applications requiring fast and precise movement. Thus, we recommend incorporating an RE training plan for people using VR to improve their gameplay skills.

7.3 Follow Training Protocols Produced in RE to Improve VR Training

Our quantitative results show that the adapted protocol used in the study enabled participants to improve their performance in all skills. Thus, We suggest creating training systems that emulate RE training and incorporate our protocol to improve table tennis skills among the players, which is in line with previous works that support the need for protocol standardization in VR environments [76, 77].

7.4 Optimize Game Physics with Concentration on the Ball

Improving game physics is crucial to creating a more immersive VR TT experience [5]. Based on our qualitative results, developers should prioritize refining two aspects of VR TT: 1) ball dynamics and collision boxes and 2) spinning effects to closely mirror real-life interactions. Ball dynamics and collision refers to the preciseness of the hit on the ball. The ball's position, angle, and force all determine the proficiency of the player's volley. We recommend designing with iterative feedback to calibrate this setting correctly. For example, it may involve continuously analyzing player movements, racket angles, and shot accuracy, then adjusting virtual ball physics and opponent behavior to provide realistic challenges and optimize skill development. Spinning effects are also important and related to the physics applied to the ball. As the ball is hit by the racket at different angles, we will produce different properties of the volley; hence, designers should replicate the physics to allow for better validity.

7.5 Mitigate VR Limitations for Playability and Accessibility

Our qualitative result shows that to mitigate the limitations of VR hardware on user experience, the developers should focus on enhancing user comfort and realism of the gameplay. This may involve optimizing HMD design for extended wear, reducing discomfort associated with long gameplay sessions, and addressing challenges related to depth perception and graphics glitches. For instance, the lack of haptic feedback led players to mistakenly break table tennis rules, i.e., touching the table is a violation of the rules; however, without feedback, participants were not aware of the location of the table in coordination with their RE position. We recommend developers identify the places in RE where the limits of the technology affect gameplay. Additionally, exploring innovative solutions for providing haptic feedback, such as virtual paddle vibration or tactile sensations, can further enhance the VR TT experience.

7.6 Incorporate Virtual Coach and Training Protocol for VR Training Applications in Real-time

Previous work has illustrated that incorrect techniques could be internalized without coach guidance [12]. Our custom-made training protocol used a coach to train novice players and significantly improved VR TT skills (see Table 1) without compromising immersion or enjoyment. Based on the results of our study, we suggest the introduction of a virtual coach who provides real-time feedback and guidance to the player in VR. This virtual coach could offer encouragement, correct mistakes, and provide tips for improving gameplay adherence to rules.

8 Limitations & Future Work

The main limitation of this work is that it focus solely on novice players, with training sessions lasting only five days. Additionally, it is important to consider players at different skill levels, including intermediate and advanced, as past work found that most VR TT players do not consider themselves beginners [5]. More experienced players who have a stronger skill set may need additional training time to improve their skills in a meaningful way.

Another limitation is the use of ETT as the VR TT game, which may restrict the generalizability of our findings to other games with different game and physics engines. While ETT is among the most popular VR TT games, future research should assess other games featuring different physics engines, which can be even closer to real-life physics. Additionally, the study lacks multiple raters to assess table tennis performance. Yet, the video coding involved an expert with ten years of experience who counted points in a match. Moreover, novice players lack the speed or technique to execute complex strokes that require multiple perspectives to determine a scored point. Finally, all our participants were part of the able-bodied population, and in the future, a similar study should be made with individuals for whom VR TT may be accessible.

Future research should explore the impact of RE training on other VR sports games and how it improves user skills. This could broaden our understanding of skill transfer between RE and VR. Future work should also compare other RL and VR training regimes to identify the most effective RL training regimes. Lastly, we encourage researchers from various fields to focus on this emerging area of training VR players using RL, opening avenues for interdisciplinary collaboration and innovation.

9 Conclusion

In this paper, we conducted a longitudinal user study with pre- and post-training stages, involving novice Virtual Reality table tennis (VR TT) players to investigate the impact of Real Environment (RE) training on their performance and to understand the challenges they face when transitioning from RE to VR. Our study aimed to determine whether training in RE could improve 16 basic table tennis skills in VR and to identify any limitations encountered in the VR environment. For this, we developed and implemented a custom-made table tennis protocol. Our findings revealed significant improvements in all 16 skills after RE training, indicating the efficacy of such training for novice VR players. In addition, the participants identified various limitations and challenges in VR TT, including issues with depth perception and constraints related to game physics. Based on these results, we also provide a series of recommendations to enhance the gaming experience for VR TT players.

These results are crucial for understanding the training needs of novice VR TT players and developing effective training systems. By addressing the challenges identified in this study, developers, practitioners, and engineers can improve the VR gaming experience and optimizing skill development for VR TT players.

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