"I consider VR Table Tennis to be my secret weapon!": An Analysis of the VR Table Tennis Players' Experiences Outside the Lab

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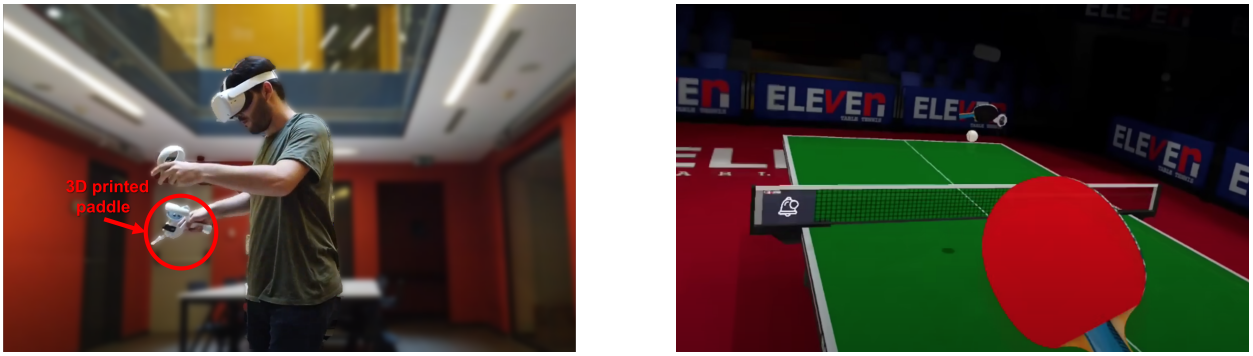

(a) (b)

Figure 1: a) A participant is playing ETT with a VR HMD. The 3D printed Table Tennis paddle is visible in the figure. b) The first-person view of the ETT VR game. Users can see their virtual racket, the table, the ball, and the opponent's headset and racket.

ABSTRACT

Thanks to stand-alone Virtual Reality (VR) advances, users can play realistic simulations of real-life sports at their homes. In these game simulations, players control their avatars by doing the same movements as in real life (RL) while playing against a person or AI opponent, making VR sports attractive for the players. In this paper, we surveyed a popular VR table tennis game community, focusing on understanding their demographics, challenges, and experiences with skill transfers between VR and RL. Our results show that, on average, VR table tennis players are primarily men, live in Europe/Asia, and are 38 years old. We also found that the current state of VR technology affects the player's experience and that players see VR as a convenient way to play matches but that RL is better for socialization. Finally, we identified skills like backhand and forehand strikes that players perceived to be transferred from VR to RL and vice versa. Our research findings have the potential to serve as a valuable resource for VR table tennis game developers seeking to integrate mid-air controllers into their future projects.

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CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**; *Empirical studies in HCI*.

KEYWORDS

Virtual Reality, Table Tennis, Training, Survey, Skill Transfer

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1 INTRODUCTION

Virtual Reality (VR) is becoming a mainstream technology as modern VR Head-Mounted Displays (HMDs) offer users a realistic experience in terms of graphics and tracking. New devices are also cheap enough that most people can buy them. One of the reasons people give when buying a VR HMD is the ability to play games, with popular titles like Beat Saber selling over 4 million copies [51]. Thanks to its popularity as a platform (over 20 million Meta VR HMDs sold [28]), we now have a community of users that spend significant time in a VR game. Yet, few previous works have attempted to understand the VR game player communities that form around these games, which makes it difficult to understand their motivation and challenges when playing their games.

Here, we focus on understanding the communities around VR games that emulate real-life (RL) sports, as these games require players to utilize a six-degree-of-freedom (6DOF) device and interact with 3D content, which is different than other gaming communities. Specifically, we focus on *table tennis, ping-pong, or whiff-whaff*, here called table tennis. In this game, two players use a paddle to hit a ball back and forth across a table. Players win a point when their opponent cannot return the ball or sends it outside the table. Table tennis is a sport that requires precise hand-eye coordination and fast reaction times, and players only move around a table. As a result of the confined playing area, table tennis is a perfect game for being played with a VR HMD. Currently, there are various VR tables tennis games in the market, including PingPong Kings VR, Racket Fury: Table Tennis VR and Eleven Table Tennis (commonly abbreviated as ETT) [1].

Similar to previous work that studied VR social platforms [16] and multiplayer games [25], specifically, we examine the community of ETT, as it is the most popular VR table tennis games with over 290,000 players [2, 45]. Eleven Table Tennis, called VR table tennis in this paper, includes real physics, playing against other people in online multiplayer, and practicing against AI players. Our main goal is to better understand the VR table tennis community and, based on their needs, provide guidelines for developers of VR games that emulate RL sports. Moreover, as previous work has found VR table tennis to be able to improve participants' RL table tennis skills [37], we investigated the "active" players' experiences outside the research environment and provided a detailed analysis of skill transfer between VR and RL table tennis and what challenges they face during the transition from RL to VR. In order to conduct our research, we surveyed 40 current ETT community members to gather their opinions about the game. In summary, our contributions are:

(1) We discovered that the majority of VR table tennis players are men from Asia and Europe who also play RL table tennis.
(2) We uncovered practical issues that players experience when playing in VR, such as difficulties using the controller and the 3D graphics affecting their experience. We also found skills like footwork and paddle feeling are difficult to experience in VR.
(3) We found that players use VR to practice RL table tennis and experience skill transfer for basic skills like forehand and backhand attacks.
(4) Based on the insights of our participants, we propose guidelines for designers of future VR table tennis games.

[1] https://www.appnori.com/, https://www.pixeledgegames.com/, https://elevenvr.com/en/

2 PREVIOUS WORK

2.1 VR Sport Games

Numerous studies have explored the emulation of various sports in VR. For instance, football [19, 47], basketball [56], golf [21], skiing [15, 22], boxing/martial arts [10, 13, 44, 49], cycling [36, 48], swimming [24, 31], baseball [38, 64], hockey [7], cricket [17, 23], and athletics [12, 50]. These studies collectively showcase the efficacy of VR in enhancing sports training and user experiences across a wide range of disciplines.

In real life, table tennis requires a physical racket or paddle to play the game. In order to improve the realism of the virtual environment (VE), this additional tool should be mimicked from the real world. Previous studies investigated how this transfer affects user performance and user experience for other racket sports [1, 30, 40, 54]. For example, Ashok et al. [1] explored users' perceptions regarding a VR squash sports experience. The study involved 30 users, and the results indicated that users perceived the VR tool as effective in promoting hand-eye coordination, similar to traditional training methods. Similarly, Le et al. [30] studied VR in tennis, focusing on capturing real-life movements in VR, including swing techniques for various shot types such as volley, serve, backhand, and forehand. The study's findings indicated a strong sense of presence among participants in VE, with their actions closely resembling RL tennis. Other studies on VR paddle/racket-based sports also focused on lab studies around using VR for training [30, 37, 54]. Overall, these studies highlight the effectiveness of VR in enhancing user experiences and training for racket/paddle-based sports (see Table 2). Nonetheless, little is known regarding how the gaming communities are affected by these interventions, which this paper aims to address.

2.2 VR Table Tennis

Several previous works have studied VR table tennis. Some early work like Yan et al.'s system [60] and "CamBall" [58] uses augmented reality (AR) to combine real paddles and ball tracking to improve user involvement and game enjoyment. Another example is the Li et al. [32] system for two players using hand motions.

Researchers also investigated several methods to improve the VR table tennis experience[9, 30, 33, 40, 55]. These works focused on improving players' gameplay immersion [40] or their engagement, spatial awareness, and the ecological validity of the system [30]. Moreover, Lin et al. [33] add multiplayer games that stress player cooperation and communication. The researchers also focused on improving the technical aspect of VR table tennis by better tracking

Table 1: Relevant works based on paddle/racket sports

Reference	Sport	Environment	Measures	Community of users	Guidelines for Designers
[30]	Tennis	VR to RL	O,S	None	None
[20]	Badminton	VR	O	None	None
[1]	Squash	VR and RL	S	None	None
[40]	Table tennis	VR to RL	O,S	None	None
[37]	Table tennis	VR to RL	O	None	None
Ours	Table tennis	VR to RL and RL to VR	S	Yes	Yes

O=Objective, S=Subjective

of hand-held objects [9] or by enhancing the VR paddle experience with unbalanced, directional force feedback [55].

Other studies have investigated the potential benefits of VR in the skill acquisition and transfer to RL table tennis [34, 37, 59]. For example, Liu et al.' s [34] created a VR system where users can adjust the objectives and the exercise intensity level by defining the cost terms related to the game's mechanics and then applying machine learning to enhance the exercise drill. Another example is Michalski et al. [37] work, which investigated the skill transfer between VR and RL table tennis using players of various levels and found that VR can improve a player's reaction time and accuracy. Wu et al. [59] conducted a study on a ball spinning in VR. They demonstrated the feasibility of using VR to teach users how to return spin serves and acquire the necessary skills effectively.

A common thread between all these works is that they use controlled user studies to test their prototypes or the skill acquisition of players. In contrast, this paper aims to explore players' perceptions and perspectives regarding their skill transfers, providing insights into the limitations of existing commercial VR table tennis systems. We also did not find any previous studies that have examined the demographics of VR table tennis players in detail, which can be utilized to improve user experience.

3 MOTIVATION & HYPOTHESES

VR technology is a valuable tool for games that simulate sports [1, 19, 30, 30, 40, 47, 54]. When looking at table tennis, VR provides a safe and controlled environment for players to practice specific strokes and drills in a multi-ball fashion, improving eye-hand coordination, reaction time, and overall performance [63]. However, most previous works did short-term studies to understand skill transfer from VR to RL within a lab setting or environment, which only partially represents the experience of players of commercial games. Other previous work has only evaluated VR table tennis systems built for specific tasks, such as testing haptic devices, without the full array of features that commercial games have.

Here, we aim to extend these previous works in two distinct directions. First, we identified the demographics of the VR table tennis players and their experiences with the technology to identify their needs. Second, we collected the players' opinions about the skills they can transfer and how they use VR and RL as training grounds for the other medium to inform the design and implementation of new VR table tennis games. Based on this, we investigated the following research questions:

- **RQ1** What are the demographic characteristics of VR table tennis players?
- **RQ2** What challenges do players face when playing VR table tennis?
- **RQ3** What is the players' experience with skill transfer between VR and RL table tennis?

By answering our research questions, we aim to understand the users who play VR table tennis and their gaming experience to provide insights into the population's demographic characteristics, user experience, and skills learned. Furthermore, our aim is to identify potential challenges for VR table tennis players, including skill acquisition in RL and technological limitations. Finally, by identifying the specific skills that players have indicated that are to be transferred between VR and RL, we propose determining the missing features of current VR table tennis commercial systems. We hope that future developers of VR table tennis applications and training programs will benefit from this comprehensive study of the VR table tennis community.

4 SURVEY

We ran a survey with VR table tennis players interested in sharing their knowledge about the game. The survey was designed based on interviews with novice VR table tennis players. The survey comprised 34 items divided into five parts. See the Appendix for the full survey. Participants had to read and accept an informed consent form that introduced respondents to the purpose of the study and survey, the research team, and the completion time (around 30 minutes). It also clarified that participation was voluntary and that participants were not compensated for doing the survey. Finally, we followed a continuous consent model, meaning participants could stop at any time without risk, and had their data excluded from analysis.

4.1 Recruitment and Data Collection

The survey, implemented in Microsoft Forms [2], was distributed online in October 2022. We promoted it via ETT Facebook, Reddit Pages, Discord Channel; the authors' social media channels (Twitter); and word of mouth. We also asked call recipients to share it with their networks. We focus on ETT players, as the game has an active community interested in discussing it and how it improves

[2] https://forms.microsoft.com/

their skills. The Institutional Ethics Review Board of Dalhousie University approved the study design.

4.2 Data Analysis

After performing data cleaning, which involved removing invalid data such as responses from participants under 18 years of age and incomplete responses, a total of 40 valid responses were retained for further analysis. The survey questions were divided into demographics, immersion & experience, and comparison questions. Demographic questions included age, gender, country, time playing VR and RL table tennis, frequency of playing VR and RL table tennis, and level of skills in VR and RL. We used a Wilcoxon signed-rank test to compare these answers between the two groups. Immersion & experience questions refer to the participant's immersion while playing VR and RL table tennis and their experience of specific game elements. We conducted the Shapiro-Wilk test to check if data is normally distributed. As the assumption of normality was not satisfied and also considering the dependence of our sample groups, we then applied Wilcoxon signed-rank to test our hypothesis.

The survey also presented six open-ended questions, aimed at getting a deeper glimpse at respondents' experiences in VR and RL table tennis. We conducted a qualitative analysis to identify the differences between VR and RL table tennis. Two researchers coded the open-ended questions. We agreed on an approach inspired by Braun and Clarke [3, 4], using researcher reflexivity as a pillar. Because of this epistemological and ontological positionality, we purposely avoid measuring inter-coder agreement –which poses the existence of a researcher 'bias' and tries to minimize it– as well as performing consensus coding –anchored in the belief that there is an objective way of coding, and that it is desirable. Instead, we recognize the situated nature of coding and its partiality and subjectivity [14].

The coders used a template with columns for codes and comments. Individually and inductively, they coded their transcripts, creating codes while keeping a list of codes and descriptions to keep track of their process. Then, they shared the coded data and discussed the construction of themes. We then refined the themes in conversations among coders. One author with experience playing table tennis (20 years of experience playing at the university level) went over the codes to ensure that they were grounded in the rules and technicalities of table tennis. Finally, the coders presented the proposed themes to the rest of the team for further discussion.

4.3 Demographic Results

Table 2 shows the participant's demographic information. Next, we present our findings.

4.3.1 Average VR table tennis player. The survey shows that the average VR table tennis player is 38 years old and male. Additionally, it will probably live in Europe and, to a lesser extent, in Asia. Moreover, the average player will most likely have previous experience playing table tennis.

4.3.2 Time playing. Regarding time playing, i.e., how long have they played table tennis, the survey found that most VR table tennis players have played for 1-2 years in VR. Yet, for RL table tennis, they have over two years of experience. When comparing both groups using a Wilcoxon signed-rank test, we found a difference between the time spent playing table tennis between RL and VR, where the RL players had played for a longer time than the VR players ($V = 0.0, p < 0.007$).

4.3.3 Frequency of play. For the frequency of play, i.e., how often they play table tennis, the survey found that most players played more than twice a week or twice a week in VR. For RL-table tennis, most players played twice a week or once every six months. When comparing both groups using a Wilcoxon signed-rank test, we found a difference between the frequency of playing table tennis between RL and VR, where our participants played more frequently in VR than RL ($V = 49.0, p < 0.006$).

4.3.4 Skill level. For their perceived skills level, i.e., how much they know about table tennis, the survey found that most VR table tennis players consider themselves to have advanced skills. For RL table tennis, players consider themselves to have intermediate skills. When comparing both groups using a Wilcoxon signed-rank test, we found a difference between the skill level of RL and VR table tennis players, where VR had a higher skill level than RL ($V = 0.0, p < 0.005$).

4.4 Immersion & Experience Results

The Pearson's correlation coefficient, r, was reported as the effect size measure, and the result is summarised in Table 3. We further summarized the number of participants who selected a specific Likert scale rating for immersion and experience in relation to the VR and RL environments in Figure 4. For brevity, we only discussed the significant results in the following subsections.

4.4.1 Difficulty in staying focused. For the question "I found it difficult to stay focused", which concerns the difficulty participants experienced in concentrating on the game while playing. The results show a significant difference in the difficulty in staying focused between VR and RL players (Figure 3c). According to these results, participants had more difficulty staying focused in RL (M=2.42) compared to VR (M=1.68).

4.4.2 Forgot about the surrounding. For the question, "My attention was so focused on the game that I forgot about the surroundings", the result shows a statistically significant difference between VR and RL table tennis (Figure 3b). In other words, players forget about their surroundings while playing in the VR (M=4.35) more compared to the RL (M=3.40).

4.4.3 Forgot about the world. For the question, "I was so concentrated on the game that I forgot the world around me", the result shows a statistically significant difference between VR and RL table tennis (Figure 3a). VR players (M=4.22) forgot more about the word than RL players (M=3.63).

4.4.4 Immersion. For the question, "I was immersed in the game during playing", there is a statistically significant difference between VR and RL table tennis (Figure 3d). Our results show that VR players (M = 6.28) were more immersed in playing the game compared to RL players (M=5.60).

4.4.5 Body strength tracking. Body strength tracking involves using different body strengths based on the game situation.. The result

Table 2: Participant's Demographic Information

Respondents (n=40)			**Time playing in VR**	**Time playing in RL**
Age	21-60 years	0-3 months	6%	2%
Female	2%	3-6 months	12%	12%
Male	98%	6-12 months	24%	5%
Mean Age (Male)	38.05	1-2 Years	52%	6%
		2+ Years	6%	75%
Continent			**How often they played in VR**	**How often they played in RL**
North America	11%	More than twice a week	60%	14%
Asia	26%	Twice a week	24%	36%
Europe	59%	Once a week	10%	12%
Australia	4%	A couple of times a month	2%	5%
		Once a month	2%	12%
		Every 6 months	2%	16%
		Once a Year	0%	5%
			Skills level in VR	**Skills level in RL**
		Novice	14%	26%
		Intermediate	38%	62%
		Advanced	46%	12%
		Expert	2%	0%

shows a statistically significant difference between VR and RL table tennis (Figure 4f). Our participants needed more strength in RL (M=5.63) compared to VR (M=4.80).

4.4.6 Hand/Wrist strength tracking. Hand/Wrist strength tracking is about the need to use different hand/wrist strengths while playing table tennis. Our results show a statistically significant difference between VR and RL table tennis (Figure 4c). Our participants require more hand/wrist strength when playing in RL (M=5.70) compared to VR (M=5.0).

4.4.7 Arm strength tracking. Arm strength tracking is about the need to use different arm strengths while playing table tennis. Our results show a statistically significant difference between VR and RL table tennis (Figure 4d). Our participants require more arm strength when playing in RL (M=5.68) compared to VR (M=5.08).

4.4.8 Spin tracking. Spin tracking is about how well participants were able to do the desired spins while playing table tennis. Our results show a statistically significant difference between VR and RL table tennis (Figure 4a). Our participants perceived their spin tracking to be better in RL (M=5.80) compared to VR (M=5.03).

4.4.9 Speed tracking. Speed tracking is about how well participants were able to use their full speed while playing table tennis. Our results show a statistically significant difference between VR and RL table tennis (Figure 4b). Our participants perceived their speed to be better in RL (M=5.80) compared to VR (M=5.10).

4.4.10 Rubber/Paddle/Sponge Imitation. This question was about the perceived properties of playing device, e.g. rubber or paddle or sponge. Our results show a statistically significant difference between VR and RL table tennis (Figure 4e). Our participants perceived the properties of the playing device better in RL (M=5.75) compared to VR (M=4.63).

4.5 Analysis of Open-Ended Questions: Skills Transfers between VR and RL Table Tennis

Our analysis of the open-ended questions allowed us to better understand the perceived skills transferred between VR and RL. In our survey, we asked about what skills improved the most and which the least. Our data shows that players see playing in VR and RL as training for the other modality. However, they mentioned that different skills and techniques are more suited to training in VR or RL. Each mode has unique features, such as the facility to play matches in VR and the social aspect of RL. Finally, we found that the technological limitations of VR affected the participant's experiences. For example, they mention the inability of current VR technology to recreate the RL experience and bugs in the game (ETT). In the following subsections, we describe our results in more detail, focusing on the perceived skill transfer from VR to RL, RL to VR, and the perceived differences between RL and VR. From now on, we use the notation $pn, n = 1, 2, 3..40$ to mention participant n.

4.6 From VR to RL

Participants generally feel that playing in VR helps them improve their performance in RL table tennis. Furthermore, most participants especially saw VR table tennis as a convenient training platform that could provide them with matches fast (Figure 2 (a)). For example, p14 said, *"no need for a partner or ball machine or table or to pick up loose balls; virtual ball machine is flexible; players of all skill level are available all the time."* This increase in matches improved their confidence in their skills and physical fitness, as mentioned by p30 and p48, respectively.

When discussing specific skills improved by playing VR table tennis, our participants mentioned different skills and techniques. For general gameplay, participants said that their general knowledge of the game improved, emphasizing their defense and spiking.

Figure 2: Word cloud of themes from the open questions (a)Participants' perception of skill transfer from VR to RL, where green represents positive comments (38) and blue represents neutral (2) (b) Participants' perception of skill transfer from RL to VR, where green represents positive comments (37) and blue represents neutral (3) (c) Participant's reasons for preferring VR or RL, where green represents VR and blue represents RL, (d) Limitations of Playing VR Table Tennis, where each theme is shown in different color

Participants also mentioned the following basic techniques: backhand and forehand attacks, general attacks, and spinning. The way to grip the paddle also improved, especially when using an adapter to play. And improvement in the following intermediate techniques: looping, left-right play, and service. Finally, they only saw an improvement in one advanced technique: wrist control. Moreover, participants mentioned that their movement skills improved, like footwork and body position. Besides enhancing their skills, players also improved the quality of their strokes, e.g., the level and variety of spins, speed, and timing. Finally, participants also felt their handle of the ball improved, e.g., eye-hand coordination, tracking, feeling, understanding the trajectory, and reaction time. For example, p15 mentioned *"understanding effects of the spin and how it affects ball trajectory."* as something VR has improved in their RL skills.

Yet, there are also some negative aspects of using VR to play table tennis. Most participants mentioned a need to adjust their game style when changing to RL table tennis, including adjusting to the physics of RL, e.g., they had to adjust to the ball movement and the expectations of their strokes. For example, p33 said, *"it can take time to adjust to different physics."* This adjustment was also about the paddle and their feeling, even when using an adapter to play. As said by p29, *"it can take several minutes to adjust from VR to RL play due to differences in the paddle and ball weight."* Our participants also mentioned that some specific skills had no improvement or they improved less after playing in VR. For example, the following general gameplay activities were affected: shooting, blocking, attacking, and pushing. Spinning was the only basic technique, and fast movements were the only advanced technique mentioned. However, participants mentioned intermediate techniques such as forehand and backhand loop, smashing, looping, and service. The participants also mentioned their footwork as the most affected when playing VR table tennis. Finally, p23 said that *"after a certain point, there is no more progress in their training, which is similar to another participant who also mentioned no improvement at all."*

4.7 From RL to VR

Our participants felt that playing in RL helped them improve their performance in VR table tennis. Most participants consider RL a place to get coaching and practice skills that they can later transfer to VR (Figure 2 (b)). For example, p13 said, *"RL coaching improved my technique, which works in VR."* Participants also mentioned general gameplay elements of RL table tennis that positively impacted VR, including their technique, basic skills, and timing. For basic skills, the participants noted the swing and the paddle speed. The movement skills that can be improved in RL include body positioning around the table and footwork. For example, p23 said, *"I think posture, swing, and position improvements in RL have transferred and helped my ETT."* Some participants also felt their reaction time and position of the ball improved. For example, p47 said, *"[RL] improves reaction time and footwork."* Finally, two participants mentioned that they did not experience any improvement during their transition from RL to VR.

The participants also mentioned some aspects of RL table tennis that affected their VR table tennis gameplay. These were a difference in timing, especially as VR table tennis felt slower and had a different feeling. For example, p10 said, *"makes the game seem slower/ feel like I have a lot of time."* The way the ball behaved is also different, as participants found that they could put less effect in RL than to VR. For example, p38 said *"It is very similar to RL, but I am able to put more effect to the ball in VR."* Another problem with the ball was its physics; in RL, it felt heavier than in VR. For example, p9 said, *"Timing is quite different, ball is heavier."* Participants mentioned that the forehand differed between VR and RL regarding specific skills.

4.8 VR versus RL

We asked our participants to specify if they preferred to play VR or RL table tennis and why. Our results showed that 26 participants preferred RL and 14 VR. Yet, not all participants answered this question, and four mentioned they liked both, like p18, which said, *"Actually, I prefer to say both. Both are so good."* Participants that preferred VR mentioned the convenience of starting a game and not having to pick balls, the availability of matches, and the possibility of playing matches easily (Figure 2 (c)). For example, p37 said, *"No travel time to table tennis facility, less ball handling."* Participants also mentioned the possibility of having more control of the environment and the option to train with an AI, like p29, which said *"playing with AI + VR robot for drills/practice."* Other reasons include novelty and the game's competitive scene (Eleven Table Tennis). Finally, when focusing on the trained skills, people mentioned that they had a more intense workout in VR and that

Table 3: Descriptive Statistics and Inferential Test (Wilcoxon signed-rank) of the playing pattern in VR and RL (Results with p<0.05 are shown with bold in the table

Variables N=40	Mean (VR/RL)	SD (VR/RL)	Median (VR/RL)	Effect Size(r)	W.signed-rank Test p-values
Lost track of time	4.38/4.45	1.66/1.74	5.0/4.5	0.38	0.78
Difficulty in staying focused	1.68/2.42	0.92/1.47	1.0/2.0	0.07	**<0.01**
Forgot about the surrounding	4.35/3.40	1.60/1.71	5.0/3.0	0.32	**<0.00**
Forgot about the world	4.22/3.63	1.70/1.66	4.0/4.0	0.39	**<0.05**
Immersion	6.28/5.60	0.88/1.53	6.5/6.0	-0.09	**<0.04**
Ball movement (VR)	5.48	0.85	5.5		
Body strength tracking	4.80/5.63	1.34/1.55	5.0/6.0	-0.07	**<0.01**
Hand/Wrist strength tracking	5.0/5.70	1.22/1.54	5.0/6.0	-0.07	**<0.03**
Arm strength tracking	5.08/5.68	1.14/1.51	5.0/6.0	-0.16	**<0.04**
Spin tracking	5.03/5.80	1.35/1.57	5.0/6.0	-0.12	**<0.02**
Speed tracking	5.10/5.80	0.98/1.45	5.0/6.0	-0.17	**<0.03**
Rubber/Paddle/Sponge Imitation	4.63/5.75	1.13/1.46	5.0/6.0	-0.32	**<0.00**
Game sounds (VR)	5.05	1.57	5.0		
Controller vibration feedback (VR)	4.88	1.36	5.0		

using some techniques was easier. For example, p21 said, *"For some reason, I am better in VR, have longer rallies, and more success."*

On the other hand, participants that preferred RL table tennis focus more on the community aspect of table tennis, as they see it as a way to socialize and have more fun (Figure 2 (c)). For example, p17 said, *"It's the real thing, meeting friends, the atmosphere in the club, etc."* P23 also mentioned something similar, *"Better movement and rapport with other players. Banter and switch to doubles."* The technology aspect was also important, as participants preferred using something other than the VR HMD and mistrusted the technology. For example, player p14 said, *"I can trust RL more; when mistakes happen in VR, there is sometimes a lingering doubt the issue was with the statement rather than with me."* These issues with the technology also affected the feel of the ball to make it natural, and it generally had a more realistic experience. For example, p42 said, *"Eleven is a great game, but it is only 95% realistic. You can feel the ball in RL, and touch shots/short game is more predictable."* Finally, they said they had better skill acquisition in RL and that playing felt less tiring.

We also asked participants to mention the current limitations of playing VR table tennis. We found that VR table tennis had some limitations on participants' skills, as basic techniques such as spin and touch shoots were challenging (Figure 2 (d)). The participants also mentioned different movement skills that could not be used, including arm movement, footwork, and fine movements. As p14 said, *"Trust, latency, super-fine motor movements, space constraints, paddle sweet spot simulation, human emotion display, net flexibility."* When talking about ball skills, participants mentioned the difficulty of emulating ball weight and that using physics exploits to improve your game was possible. For example, p47 said, *"In Eleven Table Tennis, you can kind of cheat the physics by flicking your wrist, and by doing this, you are able to make the tracking think you are moving the paddle faster than you are."* Another limitation of VR was the paddle, as some players did not use an adapter, and the haptic feedback was limited, e.g., the feeling of the rubber hitting the ball. For example, p25 said, *"Feeling of the ball, unable to serve as cannot grip the rubber and use hand and grip pressure."* Other skills related to gameplay include difficulty emulating their power, speed, and control in VR compared to RL. Moreover, participants mentioned depth perception (p1) and the limited space in their living room (p10) as reasons for this. For example, p13 said, *"Space around table, walking through table."* Finally, p40 mentioned the avatar as another limitation.

Playing VR table tennis also has technical limitations that affect gameplay. These include problems with latency and controller tracking, translated into game speed. For example, p7 said *"Network delay/latency,"* and p12 said *"tracking the performance of the headset."* Another problem mentioned is using the HMD to play, as it has limited FOV, gets foggy/ sweaty, and is heavy. For example, p31 said, *"Controller tracking not perfect as yet, mask too heavy, limited field of view."* The participants also mentioned some problems with the game we studied (Eleven Table Tennis), including problems with the physics, e.g., net simulation and a slow update of the game to fix bugs. On the user side, participants mentioned that technical limitations in haptics and audio affected the feedback they received when playing. For example, p35 said, *"Spin is overstated, speed is a bit too high compared to reality, the physics is slightly too forgiving."*

4.9 Discussion

This paper aims to investigate the VR table tennis players' demographic, challenges they face, and perceived skill transfer between VR and RL table tennis by conducting a survey. Here, we discuss our findings and answer our research questions.

4.9.1 VR table tennis demographics. Our **RQ1** is *what are the demographic characteristics of VR table tennis players?* To answer it, we collected the participants' demographic information, including their age, gender, country, play frequency, play duration, and skills level in VR and RL (see Table 2). Our first insight was the mean

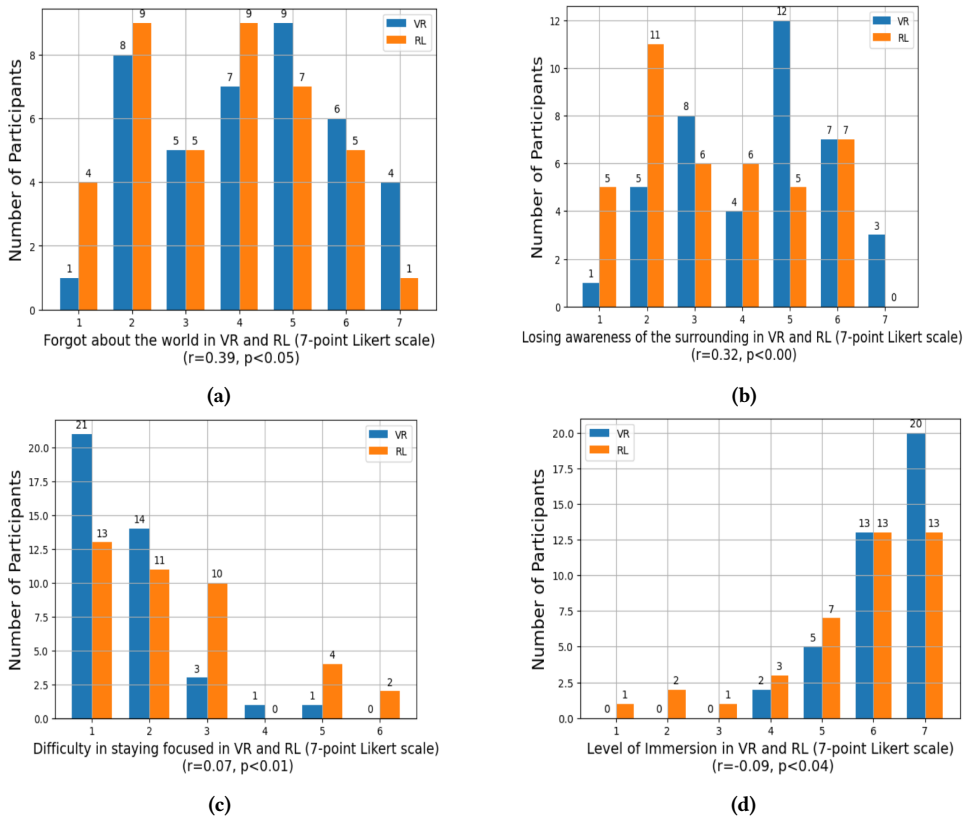

Figure 3: (a) Comparing the level of forgetfulness of the world by VR and RL players, (b) Comparing losing awareness of the surrounding by VR and RL players, (c) Comparing difficulty in staying focused between VR and RL players, (d) Comparing the level of immersion between VR and RL players

age of the survey participants (age= 38.05), which talks to an older player base in VR than in RL, where most people play in school or university. We also found that most VR players are in Europe (59%) and Asia (26%). While these findings may suggest a correlation with the sport's popularity in these continents, it is important to consider other factors that may influence the results. Interestingly, we did not get any responses from people from the African and South American continents, indicating a potential disparity in participation from this region, most probably due to the need to have expensive technology to play [53]. Finally, when looking at the gender of our participants, only 2% were female. We speculate that this is due to the lack of self-identification of women playing virtual reality games, as discussed by Peck et al.[43]. For example, the official Eleven Table Tennis women raking for Germany only has 32 players that self-identify as women [3]. Another reason could be that we were unable to reach the channels used by women and were unable to find them online or on social media.

When talking about time spent playing each modality, 75% of the participants have played RL table tennis for over two years. On the other hand, 52% of the participants have only been playing in VR for 1-2 years. This time frame matches the release of ETT in the Oculus Store (2020), which talks about the popularity of the Quest HMD. Interestingly, despite having less time playing in VR, more participants classified their skills higher in VR than in RL, which aligns with findings from other studies where complex motor skills were found to be easily learned in VR [37, 40]. For example, 46% of the participants said their skills in VR were advanced compared to 12% in RL, and only 14% said they were novices in VR compared to RL (26%). One reason for this difference could be the frequency of play, as our participants played more often in VR than in RL. For example, 60% of our participants played more than twice a week in VR, compared to only 14% in RL. Conversely, 5% of the participants said they played once a year in RL, compared to 0% in VR. These results are supported by the open-ended questions, where one of the main advantages of VR over RL was the possibility to play at any time of the day. These results support Michalski et al. [37]'s proposed advantages of VR training over RL training, e.g., the possibility for people to train without needing access to the necessary sporting environment. Another possible reason for the difference in skills between VR and RL might be the possibility of matches and the ability to train with AI, which was also mentioned in open-ended questions. We hope that these results can guide future virtual table tennis game developers when they want to create accurate user personas while aiming to improve the user experience.

[3]https://eleven-germany.de/ett-ranking-women/

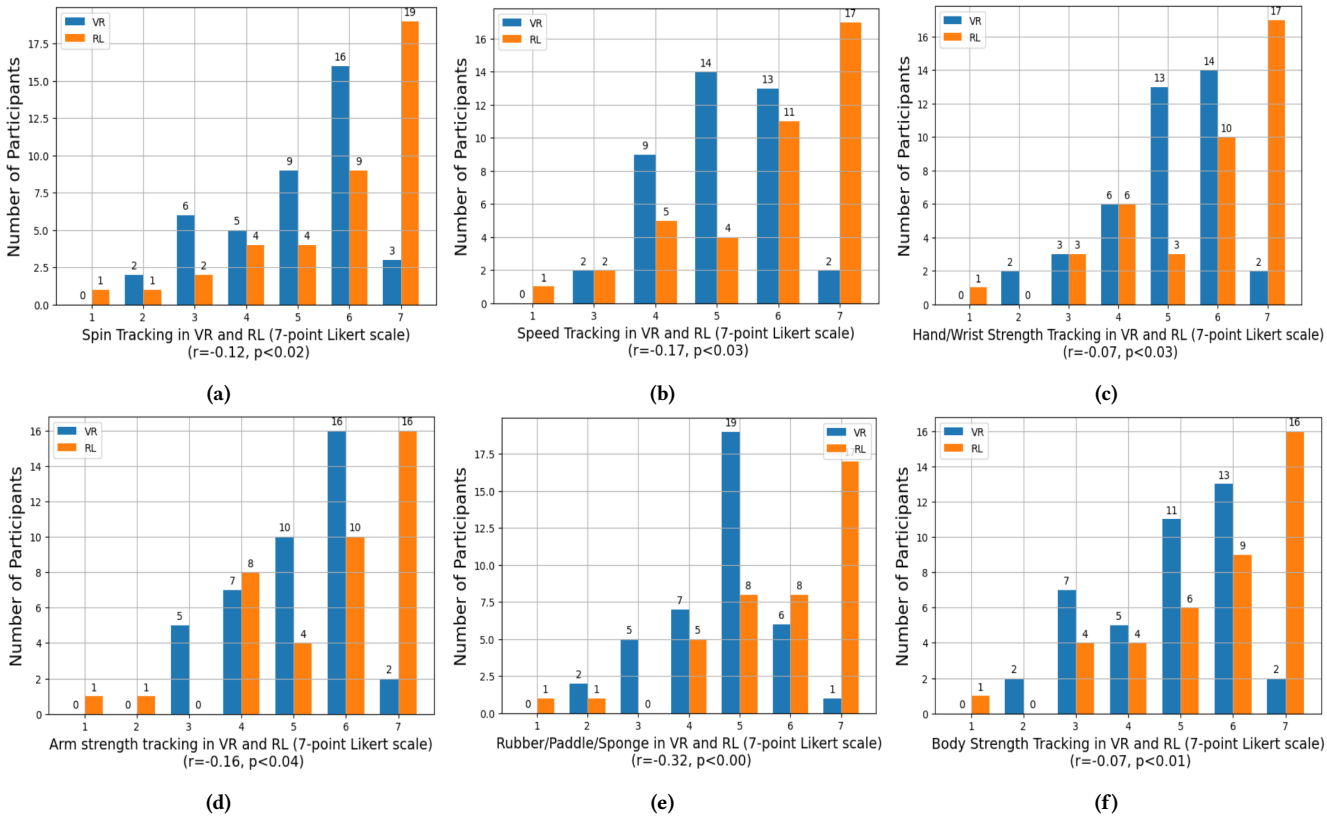

Figure 4: (a) Comparing spin tracking between VR and RL players, (b) Comparing speed tracking between VR and RL players, (c) Comparing hand/wrist strength between VR and RL players, (d) Comparing arm tracking between VR and RL players, (e) Comparing rubber/paddle/sponge imitation between VR and RL players, (f) Comparing body strength between VR and RL players.

4.9.2 Challenges when playing VR table tennis. Our **RQ2** is *What challenges do players face when playing VR table tennis?* This question was answered by analyzing the open-ended question about the limitations of ETT and the comparison between VR and RL. Our results show that the participants perceived the technology used to play VR table tennis as the main challenge when switching from RL to VR. For example, participants mentioned issues with latency, tracking, the HMD, and various bugs that could be exploited to manipulate game results. These results extend previous work that primarily focused on the transition from VR to RL [37, 40]. The participants also said several features need to be improved, such as the graphics, sounds, and avatar player look. It is especially important to consider the avatar player look, as previous work has shown that the use of self-avatar affects user performance [42]. Another significant challenge is using a VR controller to play, e.g., the lack of a paddle. Furthermore, the absence of a way to emulate the paddle's rubber, as it affects participants' expectations of the haptic feedback they get in RL when hitting a ball was also a challenge. Yet, the utilization of a racket adapter with a VR controller enhanced the realism of the experience and reduced the level of challenge for the players. Nevertheless, using an adapter does not substitute a paddle, e.g., weight distribution is different. Moreover, when asked about the perceived properties of the playing device, our results show that our participants perceived them to be better in RL than in VR, which further confirms that using an adapter is not enough to emulate playing with a racket. Importantly, our study contradicts previous research, which indicated that the visibility of the paddle in VR can enhance performance [52], and shows the need to study this issue further.

4.9.3 Perception of Skill Transfer. Our **RQ3** is *what is the players' experience with skill transfer between VR and RL table tennis?* Our thematic analysis helped us understand which skills our participants perceived they had been able to transfer from VR to RL and from RL to VR. Our first insight is that players felt there was a difference between the number and type of skills transferred from one game environment to another. When considering the number of skills, participants perceived a larger transfer from VR to RL, as they mentioned 28 skills learned in VR that improved their RL game which is similar to other findings in the literature [37, 40]. However, our work extended previous research to discover that participants only perceived 12 skills transferred from RL to VR. When discussing types of skills, most perceived skills transfer from RL to VR is about the general gameplay, like timing and where and how to send the ball to a specific position. Yet, perceived skills transferred from VR

to RL include basic, intermediate, and advanced techniques such as backhand attack, looping, and service. Participants also perceived several skills transferred back and forth between VR and RL. These include footwork, body positioning, and reaction time. One possible explanation of the differences in skills transfer is that the skills learned in VR are about technique, which can be understood by practicing. However, the skills learned in RL are more about general gameplay, which the environment affects. Finally, the existing challenges of VR table tennis might be why skills transfer in both directions, as they affect the game's realism and players' expectations in RL.

We also identified five table tennis skills players perceived to be better in RL than in VR. These skills are body strength tracking, hand/wrist strength tracking, arm strength tracking, spin tracking, and speed tracking. All these skills are essential for gameplay. For example, when a ball is approaching rapidly, the player must match that speed to return the ball. As demonstrated in [11], target speed is a significant determinant of user performance in moving target selection. Yet, the perceived speed tracking in VR is worse than in RL, which further shows that the current VR table tennis technology still needs to emulate the RL table tennis experience completely. They also help better understand the participant's answers about the perceived skills transfers between VR and RL and the need to adjust when changing environments constantly. Finally, we also found that players felt more immersive when playing VR table tennis than RL table tennis in terms of staying focused on the game and forgetting about their surroundings and the world. These results also provide insight into better understanding the players' perception of VR table tennis as a training machine, as they could focus more on the game. It also further confirms that RL table tennis is seen as a place to be social and talk with friends, which multiple participants commented as an advantage of RL over VR.

These findings also provide valuable insights into the behavior of VR gamers. VR table tennis games have established their own distinct ecosystem, where players do not necessarily aim to transfer their VR skills to RL. We observed that among the participants, five individuals focused solely on developing their skills in VR with no intention of transferring them to RL. While the majority of the existing literature concentrates on enhancing participant skills in VR training systems and transferring them to RL e.g., [5, 35, 37, 40, 41], our results underscore the importance of conducting further studies to better comprehend players who are exclusively interested in skill development within VR or in transferring skills from RL to VR.

4.10 Recommendations for Designers of Sport-Based VR Games

Inevitably, there are still gaps between playing table tennis in RL and in VR, and here we provide some recommendations for designers of VR table tennis games, specifically for those who want to create training systems to improve player skills.

Based on our results, we recommend that designers recognize the existing challenges in VR table tennis that impact skill transfer, realism, and player expectations in RL. For instance, haptic feedback provided by devices in VR may not fully replicate the tactile feedback experienced in RL, affecting the player's ability to perceive essential properties of the ball, such as speed, spin, and impact, which are crucial for skillful gameplay. Designers should strive to enhance the emulation of the RL table tennis experience in VR, specifically in areas like body strength tracking, hand/wrist strength tracking, arm strength tracking, spin tracking, and speed tracking. Improving the speed tracking system in VR to match the responsiveness and precision of RL table tennis is also important. Designers could consult professional (or former) RL table tennis players for advice on improving the game, e.g., how to make it more realistic.

Designers of VR table tennis games should consider the unique characteristics of beginner players. Most of these players use VR as a place to start playing without having to access a physical table tennis venue or a personal coach. For these players, the physics in current games mimics the RL physics very well, so the players grasp a good general feeling of the ball and the strokes. These players also need a way to practice alone, either using a virtual ball machine or an AI agent, especially to practice different strokes and drills. A virtual coach can be added to the game to give real-time feedback to the players, such as correcting players' strokes and footwork, giving complimentary words, and easing players' mental stress. Table tennis is a really skillful sport that demands the focus of players. A virtual coach will make the game extremely more beginner-friendly.

Moreover, designers should add an option to have players follow a training plan where they learn and practice the basic table tennis skills in order – forehand attack, backhand attack, forehand push with backspin, backhand push with backspin, forehand loop, backhand loop, topspin serve, backspin serve, top spin receiving, and backspin receiving [6, 27, 61]. An incentive mechanism in the game design can be used to keep players encouraged while improving their skills.

When designing a VR table tennis game for advanced players, current commercial VR table tennis games do not meet their needs. For example, these players need a way to practice and use skills such as footwork, body strength utilization, wrist control, stroke combos, and the time to hit the ball need to be improved [8, 26, 29, 46]. Unfortunately, these skills are harder to practice in VR. For example, due to hardware limitations, body strength tracking cannot be practiced effectively in VR, and thus it is harder to improve it in VR [57]. For another example, due to space limitations, it is often difficult for players to move large ranges in one room, which is essential for some footwork drills. For these advanced players, we recommend designers focus on the social aspect of the game and the possibility of playing against multiple people to bring them to the game despite the technological limitations. For example, to include well-organized table tennis tournaments in VR [18]. Tournaments have a more formal setting and intense atmosphere, which often greatly helps RL players to improve both their skills and mental strength. It is highly recommended that designers add tournaments for players of all levels and focus on the way to match players based on their skills correctly.

4.11 Limitations and Future Work

The main limitation of this work is that our results are based on an online survey. Although we took all the precautions during the

data collection and analysis, like removing unfinished surveys and surveys with invalid data, e.g., less than 18 years old, our results are based on self-reported measures of VR table tennis players. Especially for the information about skills transfers, future work should do a controlled study that compares skill transfer between VR and RL to verify them.

Also, we only collected data from ETT players, as it has a large player community on social media and more downloads than other table tennis games. Yet, ETT uses a specific game engine, which also runs a particular physics engine in the background. Although most of the players find the game's physics realistic, future applications might use other game engines, which can be even closer to real-life physics, e.g., [62]. When the players play the VR table tennis game, they also get familiar with the environment used in the physics engine and acquire skills based on that environment. Thus, future work should conduct similar surveys with players of other VR table tennis games to gain a better understanding of the differences between VR and RL table tennis.

VR can provide valuable feedback on players' performance, allowing them to identify areas for improvement and adjust their training accordingly. In the future, we plan to conduct a longitudinal user study to evaluate RL and VR skill transfer for table tennis training. We want to assess the difference in skill transfer for casual and advanced users in a more extended VR and RL training period. We also want to determine whether VR is a powerful tool to enhance the training experience for table tennis players of all levels.

Computer games are also significant contributors to table tennis gameplay[39]. In our future endeavors, we intend to perform a comparative analysis examining the impact of VR, RL, and video games on the acquisition of table tennis skills. Our objective is to assess the extent to which playing video games enhances skill development in comparison to other training methods.

5 CONCLUSION

In this paper, we conducted a survey with players of ETT, a VR table tennis application. We aimed to identify the player's demographics, experiences, and perceived skills transferred between the VR and RL and vice versa. We also focused on understanding players' challenges when playing table tennis in VR. Our results show that players perceive a skill transfer between VR and RL and vice versa. However, the type and amount of skills transferred change depending on the medium. We also found that players favor VR for playing matches and training and RL for the game's social aspect. Finally, our survey identified differences between playing table tennis in VR and RL attributed to the current state of VR technology, which frequently impacts the user experience.

These results play an important role in better understanding the expectations of VR table tennis and the challenges they encounter when switching to RL table tennis. They can also be used to improve user experience by creating better tools, such as personas, journey maps, and scenario maps for VR table tennis, as well as developing novel table tennis training systems for VR that match players' expectations.

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