仮想現実のユーザー エクスペリエンス: 大規模なレビュー データ分析からの洞察

User Experience of Virtual Reality Games: Insights from a Large-scale Review Data Analysis

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Declaration

I hereby declare that this thesis is my own work and effort and that it has not been submitted anywhere for any award. Wherever contributions of others are involved, every effort is made to indicate this clearly, with due reference to the literature, and acknowledgement of collaborative research and discussions.

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an academic achievement but also the beginning of a new chapter in our lives together. I am incredibly grateful for her enduring love and support, and I look forward to the future we will share as we embark on this next exciting phase of our life journey.

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Abstract

As Virtual Reality (VR) technology continues to advance and reshape the gaming landscape, understanding user experience (UX) becomes critical for developers, researchers, and the gaming community as a whole. This dissertation presents an empirical investigation into UX in VR games, focusing on four key aspects: the tendency of VR games, cross-linguistic analysis of player preferences, the impact of VR gaming experiences on varied user populations, and the cybersickness in VR games.

In this dissertation, I first analyze the tendencies of VR games price, play area, input devices, Head-mounted Displays (HMDs). Then I explore the cross-linguistic preferences of players in VR games, revealing the user concerns in different language regions. This analysis provides valuable insights for developers seeking to create culturally tailored content and optimize localization efforts. Next, I investigate the impact of VR gaming experiences on varied user populations, addressing the ways in which age, gender, and other demographic factors can shape user engagement, immersion, and overall enjoyment. By identifying the unique needs and preferences of different user groups, our findings can inform the development of more inclusive and accessible VR gaming experiences. Finally, I delve into the issue of cybersickness in VR games, examining its causes, symptoms, and implications for users and the industry. I also discuss potential strategies for mitigating the occurrence of cybersickness, with the aim of enhancing user comfort and promoting the long-term success of VR gaming.

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Chapter 1

Introduction

1.1 Background

1.1.1 The Development of VR Games

Virtual Reality (VR) games are played in an immersive three-dimension environment, usually requires VR glasses or a head-mounted wearable device. The research on VR games in the game industry can be traced back to the 1980s, most notably with Mattel's Power Glove [97] and Atari's Battlezone [91].

In the 1990s, as major innovations in real-time 3D graphics had been achieved on computers, and as affordable consumer technology improved further, more vendors tried their hand at VR gaming. For example, Sega announced the Sega VR headset for arcade games and its home console, the Sega Genesis [98] in 1991. However, the home version was never released due to concerns about motion sickness and other health issues. In 1995, Nintendo launched the Virtual Boy [100], a portable tabletop gaming console with a monochromatic 3D display. The system was a commercial failure, largely due to its limited library of games and uncomfortable design. In addition, during the 1990s, various PC-based VR systems were developed, such as the Forte VFX1 [92], which allowed users to play a limited number of VR-compatible games.

During the early 2000s, Head-mounted Displays (HMDs) were primarily used in research, military applications, and specialized professional fields due to their high cost and limited availability. However, advancements in display technology, such as the development of lightweight LCD (Liquid Crystal Display) panels and OLED (Organic Light-emitting Diode) displays, contributed to more portable and user-friendly HMDs. In 2007, Sensics, a VR technology company, released the "xSight" HMD [99], featuring a 123-degree field of view and a resolution of 1280x1024 pixels per eye.

Early 2000s VR systems often relied on expensive and cumbersome motion tracking technology, such as electromagnetic or ultrasonic trackers. However, advancements in inertial and optical tracking technologies enabled more accurate, affordable, and accessible motion tracking solutions. In 2003, the release of NaturalPoint's OptiTrack system [64] made optical motion capture more accessible to researchers and developers.

In 2006, Nintendo launched the Wii Console [101], which featured motion-sensitive controllers (Wii Remote and Nunchuk) that allowed users to interact with games using physical gestures. Although not a VR system, the Wii pioneered the concept of motion-based gaming and influenced the development of VR gaming experiences.

There remained strong interest from academics to explore what VR, along with augmented reality and other mixed reality systems, could bring to video games, through the 2000s, but these games were mostly prepared for research proof-of-concepts to demonstrate the interaction of VR hardware, software, and human motion rather than for commercial release, since hardware costs were still high. Therefore, there was not much progress in the research of VR games in the first decade of the 21st century.

After decades of attempts from its introduction, low-cost, consumer-grade VR hardware began to appear in the 2010s. In 2012, Oculus VR launched a Kickstarter campaign for the Oculus Rift [95], a consumer-oriented VR headset that spurred a resurgence of interest in HMDs and VR technology. In 2014, Google introduced Google Cardboard [33], an affordable, smartphone-based VR headset that aimed to make VR experiences more accessible. In 2016, Sony released the PlayStation VR [96], a console-compatible VR headset that expanded the market for VR gaming. In 2016, HTC and Valve Corporation launched the HTC Vive [93], a PC-based VR system with room-scale tracking capabilities. Throughout the 2010s, VR game development accelerated, with popular titles such as Beat Saber [1], Superhot VR [2], and Half-Life: Alyx [3] capturing the attention of gamers worldwide.

In 2020s, Standalone VR headsets like the Oculus Quest [94], Oculus Quest 2 [60], Vive Pro 2 [86], and Oculus Quest Pro [59] have become more popular, offering wireless, all-in-one VR experiences without the need for a separate computer or gaming console. Augmented reality (AR) headsets, such as the Microsoft HoloLens and Magic Leap One, have started to gain traction for enterprise and industrial applications. Ongoing research and development efforts aim to improve HMDs in terms of display resolution, field of view, comfort, and tracking capabilities. Figure 1 shows the development process of VR technology.

[1] https://store.steampowered.com/app/620980/Beat_Saber/
[2] https://store.steampowered.com/app/617830/SUPERHOT_VR/
[3] https://store.steampowered.com/app/546560/HalfLife_Alyx/

Fig. 1.1 History of VR game development (From 1980s).

With the release of consumer-grade Head-mounted Display devices, VR games have also ushered in explosive growth, taking the Steam platform as an example, as the figure 1.2 demonstrates, there was only one VR Only game releasing in 2012, named "Curious Alice" [4]. In 2013 and 2014, there was no VR Only Games released on Steam, and only six VR Only

[4]https://store.steampowered.com/app/1424190/Curious_Alice/

games released in 2015. Starting in 2016, VR games ushered in a blowout, reached its peak in 2017, and then began to decline slowly. The releases in 2021 and 2022 are basically the same.

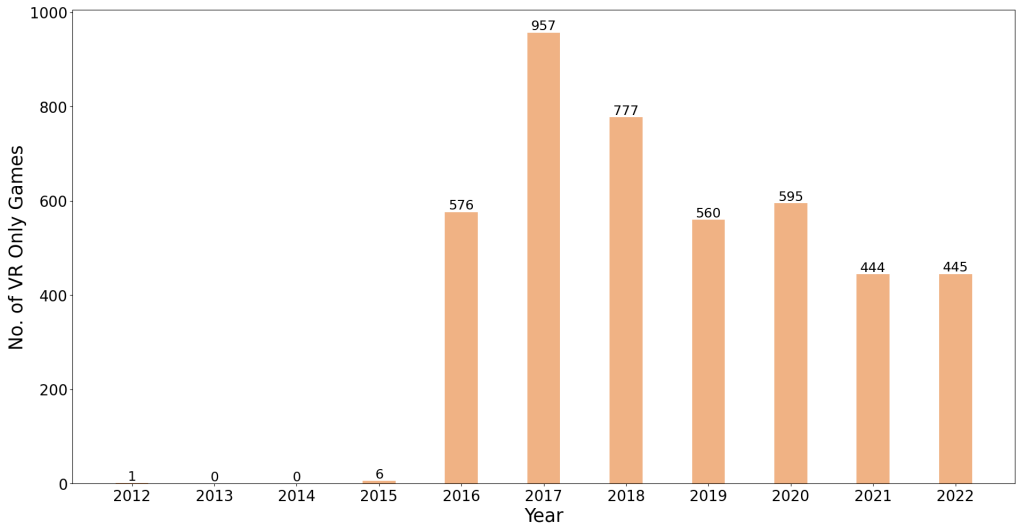


Fig. 1.2 The trends in the number of *VR Only* games released on the Steam platform.

1.1.2 The User Experience in VR Games

User experience (UX) in VR games is a critical aspect of game design and development, as it determines the overall satisfaction and enjoyment players derive from the game. VR games offer unique and immersive experiences compared to traditional video games, but also present distinct challenges and considerations when designing UX. As Figure 1.3 shows, some key factors contributing to user experience in VR games include:

Immersion: Immersion is essential to the success of VR games, as it enables players to feel fully engaged within the virtual environment. Factors that contribute to immersion include realistic graphics, high-quality audio, consistent game physics, and seamless interactions with game elements. A high level of immersion can lead to a heightened sense of presence and greater emotional connection to the game world.

Comfort: Comfort is a major concern in VR game design, as physical discomfort or motion sickness can severely impact the player experience. To ensure user comfort, developers must consider factors such as movement mechanics, field of view, refresh rate, and ergonomics. Techniques such as teleportation, snap turning, or maintaining a stable horizon can help reduce motion sickness in VR games.

Interaction: Interaction in VR games often relies on novel input methods, such as motion controllers, gesture recognition, or voice commands. These interactions should

be intuitive, responsive, and satisfying, providing players with a sense of agency within the virtual environment. Developers must carefully design user interfaces and interaction mechanics to ensure that they are accessible and enjoyable for players with varying levels of VR experience.

Accessibility: VR games should be accessible to players with different abilities and preferences. This can include options for adjusting movement speed, controller configurations, and text size, as well as incorporating features that accommodate players with color blindness, hearing impairments, or limited mobility.

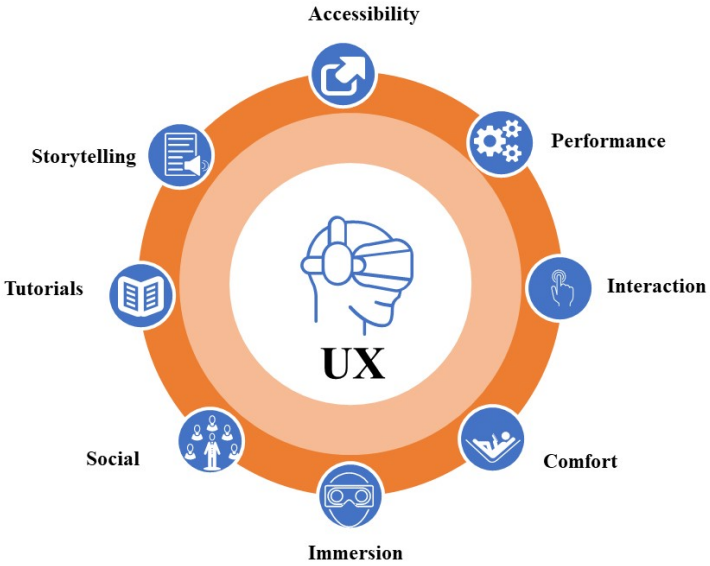


Fig. 1.3 Factors for UX.

Storytelling: The immersive nature of VR games presents unique opportunities for storytelling and narrative engagement. Developers should consider how to create compelling stories that take advantage of the immersive medium, offering players a sense of purpose and motivation to explore the game world.

Social: Multiplayer and social VR games can offer shared experiences that foster a sense of community and camaraderie among players. Designing these experiences requires careful consideration of communication tools, shared spaces, and collaborative gameplay mechanics to create a positive and enjoyable social environment.

Performance: VR games demand high-quality graphics and smooth performance to maintain immersion and minimize discomfort. Developers must optimize their games for various hardware configurations to ensure consistent frame rates and avoid performance-related issues that could negatively impact user experience.

Tutorials: Given the unique nature of VR interactions and mechanics, it is crucial to provide clear and engaging tutorials that help players acclimate to the virtual environment and learn the game's controls. This can include interactive demos, visual cues, or guided experiences that familiarize players with the game mechanics in an intuitive manner.

In summary, the user experience in VR games depends on a delicate balance of various factors, including immersion, comfort, interaction, and accessibility. By carefully considering these elements, developers can create engaging and enjoyable VR experiences that appeal to a wide range of players.

1.2 Research Problems

In this section, three major research problems in the dissertation are briefly introduced, and the following chapters will discuss these research problems in detail. Figure 1.4 shows the research outline of this dissertation.

1.2.1 The Tendency of VR Games and Player Concerns in Different Languages Regions

As VR technology continues to advance and becomes more widely adopted, the global gaming industry has seen a rapid expansion, attracting players from various linguistic and cultural backgrounds. Consequently, it has become increasingly important for game developers to create content that appeals to this diverse player base, ensuring that VR gaming experiences are engaging, accessible, and culturally relevant.

In my dissertation, the study of cross-linguistic player preferences in VR gaming is rooted in several research domains, including:

Game Localization: As the gaming industry has grown into a global market, the need for effective game localization has become apparent. Localization involves adapting game content to suit the linguistic, cultural, and regional preferences of target audiences. This includes not only the translation of in-game text but also the adaptation of visuals, sounds, and game mechanics to create a seamless experience for players from different cultural backgrounds.

Player Behavior and Gaming Preferences: There is a rich body of research exploring the relationship between player behavior, gaming preferences, and cultural background. Studies in this area have investigated various aspects of gaming, such as player motivations, game genres, playstyles, and social interactions, and how these are influenced by culture and language.

As the VR gaming market continues to expand and attract a more diverse player base, it becomes crucial for developers to understand the impact of language and culture on player preferences. The research background of "Cross-Linguistic Analysis of Player Preferences in Virtual Reality Gaming" provides a foundation for exploring these complex relationships and offering insights that can be applied to create more inclusive and engaging VR gaming experiences.

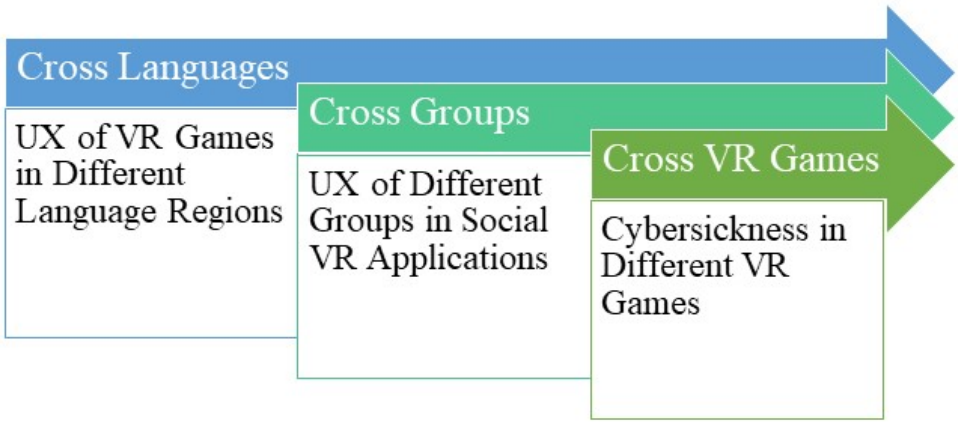


Fig. 1.4 The research outline of UX in VR games.

1.2.2 User Experience of Different Groups in Social VR Applications

Virtual Reality (VR) technology has transformed the gaming landscape, providing immersive and interactive experiences that appeal to a broad range of players. As VR gaming continues to gain popularity, it is essential to understand how these gaming experiences impact various user populations. This investigation aims to explore the effects of VR gaming on different user groups, considering factors such as age, gender, cultural background, and gaming preferences.

The rapid growth of the VR gaming industry has led to an expansion in the types of games and experiences available, catering to a diverse range of players. This has raised questions about the potential benefits and drawbacks of VR gaming for various user groups, as well as the need for game developers to create inclusive and accessible experiences that cater to the unique needs and preferences of different players. By examining the impact of VR gaming on different user populations, researchers and developers can gain insights into the factors that contribute to positive and negative outcomes, and make informed decisions about the design and implementation of VR games.

In Chapter 3, we will delve into the existing research on the effects of VR gaming on user populations, conduct empirical studies to collect new data, and analyze the results to uncover patterns and trends. By investigating the impact of VR gaming experiences on varied user populations, we hope to contribute to the broader understanding of how VR technology can be harnessed to create inclusive, engaging, and beneficial gaming experiences for all.

1.2.3 Cybersickness in VR Games

VR technology has rapidly advanced in recent years, offering increasingly immersive and interactive gaming experiences. However, with this growth comes a challenge that affects a significant portion of users: cybersickness. This phenomenon, akin to motion sickness, occurs when individuals experience discomfort or adverse symptoms while engaging with VR games or simulations.

Cybersickness, also known as VR sickness or simulator sickness, is a condition characterized by a range of symptoms that some individuals experience during or after exposure to VR games. These symptoms resemble those associated with motion sickness and can include: Nausea, Dizziness, Headaches, Disorientation, Fatigue, Eyestrain, Sweating, Pallor. In extreme cases, these symptoms can lead to vomiting and loss of balance. The severity of cybersickness varies among individuals, with some experiencing mild discomfort, while others may find it debilitating.

The primary cause of cybersickness lies in the sensory conflict that occurs when the brain receives conflicting information from the visual and vestibular systems. The vestibular system, located in the inner ear, is responsible for maintaining balance and spatial orientation. In a VR environment, users perceive motion through their visual system while their vestibular system might not detect any corresponding physical movement, leading to a sensory mismatch that can result in the onset of cybersickness symptoms.

The prevalence of cybersickness in VR games has implications for both users and the broader VR gaming industry. For users, cybersickness can negatively impact their enjoyment of VR games, leading to reduced playtime or even avoidance of VR gaming altogether. This, in turn, can hinder the adoption of VR technology and limit the growth of the VR gaming market.

Moreover, cybersickness has the potential to exacerbate existing health conditions or create new ones, such as chronic headaches, vestibular disorders, or anxiety related to VR experiences. It is crucial to address the issue of cybersickness to ensure that VR gaming remains an accessible and enjoyable form of entertainment for all users.

To better understand and address cybersickness in VR games, it is essential to explore the factors contributing to its development, its impact on users, and the potential strategies for mitigating its occurrence.

1.3 Organization

The rest of this dissertation is organized as follows. We briefly introduce the trendency of VR games in Chapter 2. This chapter also includes the analyzation of user concerns of different language regions. We discuss the UX in VR games of different age groups in Chapter 3, which considers the avatar, self-presentation, harassment behaviors, and physical effects. Chapter 4 shows the exploration of Cybersickness in VR games. We conclude this dissertation in Chapter 5.

Chapter 2

The Tendency of VR Games and Player Concerns in Different Languages Regions

2.1 Motivation

In recent years, the rise of Virtual Reality (VR) technology has suggested promising applications in a variety of industries, including education [66, 65], tourism[74, 57], industry[72, 37], animation [30], entertainment [38], and to name a few. VR games are video games played on VR hardware and provide an immersive experience to gamers. Most VR games require wearing a Head Mounted Displays (HMDs) device and one or more controllers to manipulate game characters. The first consumer-ready VR HMDs was Oculus Rift, released in 2016 by Oculus VR. The release of the Oculus Rift has ushered in a new era of VR games, and led to more hardware developers releasing new VR devices, such as HTC Vive (released by Valve partnered with HTC), Valve Index (developed by Valve), Oculus Quest (released by Meta), and Gear VR (released by Oculus and Samsung).

With the release of VR devices, VR games have also ushered in explosive growth. Before 2016, there were only nine VR games released on Steam, and after the releases of Oculus Rift, HTC Vive, and Windows Mixed Reality, from 2016 to 2021, the number of annual released VR games on Steam was 591, 961, 783, 555, 616, and 481, respectively. The global VR games market is projected to grow from $7.92 billion in 2021 to $53.44 billion in 2028 at a CAGR of 31.4% in the 2021-2028 period [39]. Therefore, it is necessary to study the development trend of VR games and what points of concern for VR game players. In [23], the authors analyzed the trends of popular VR games on Steam, but they used data as of April 2019. After April 2019, VR games have flourished again, especially in July 2020, after the president of Facebook (i.e., Meta) announced that the company's future business will focus

on the metaverse, the metaverse concept has received increasing attention from academia and industry. Hence, it is essential to integrate the data after April 2019 and analyze the tendency of the VR game and the concerns of VR game players.

The player's review information contains the player's attitude towards the games and feedback to developers. VR game developers can leverage reviews of their games to understand the players' needs. The valuable feedback from players' experiences could help game developers design and develop high-quality VR games. Hence, analyzing and understanding the concerns of gamers on VR games is a crucial element in promoting the development of VR games.

Therefore, a large body of virtual reality research has studied the reviews of VR games. Farič *et al.* [25] conducted a thematic analysis of 498 reviews of the 29 most popular exergames sold in the top 3 VR marketplaces: Steam, Viveport, and Oculus. They categorized reviews as positive and negative as they appeared in the marketplaces and identified the most common themes using inductive thematic analysis. They identified common features that players liked or disliked to inform future VR exergame design. Fagernäs *et al.* [24] analyzed 1379 published reviews (including star ratings) of 30 different VR relaxation applications available for the Oculus Go and Gear VR. They found that the users have an overall positive view of VR relaxation applications. Sweetser *et al.* [81] studied the players' reviews of VR and non-VR versions of the same games to identify differences in enjoyment. Gao *et al.* [32] analyzed the emotional tendency and syntactic properties of VR game reviews. Epp *et al.* [23] made an empirical study to analyze the trends of popular VR games and the players' complaints.

In this paper, we build large-scale research of 1362 VR games and 484070 reviews in three languages (English, Simplified Chinese, French) on the Steam platform. We first conduct a preliminary analysis of the characteristics of VR games on Steam. We then examine those games' positive and negative reviews and cluster them to different topics to identify common advantages and disadvantages of current VR games. Hence, we perform an in-depth analysis of the VR game reviews on the Steam platform along with the following research questions (RQ)s:

RQ1: What is the tendency of VR games?

RQ2: What frequency do players review a VR game and how helpful to other players?

RQ3: What do players praise about VR games in the reviews?

RQ4: What do players complain about VR games in the reviews?

In summary, our contributions are concluded as follows:

- Our study is the first to explore the tendency of VR games from 2016 to March 2022. We analyze the tendencies of VR games releases, support HMDs, play areas, input devices, etc.
- Secondly, Our study is the first to explore multilingual reviews (including English, Simplified Chinese, and French) on Steam to research the players' perception of VR games.
- Additionally, we demonstrate that the player reviews on Steam are a valuable source of player experience data and a broadly meaningful contribution to player experience research.

2.2 Related Work

User reviews can provide valuable feedback to developers and producers or sellers. For example, Chen *et al.* [15] studied more than 3 million UI-related reviews of apps in Google Play to explore the users' complaints about the UI. Ehsan *et al.* [22] conducted an in-depth analysis of developer discussions in the Gitter platform to analyze the discussion thread. Gao *et al.* [31] proposed a novel framework (CoRe) to generate accurate responses to user reviews of apps. In [36], the authors proposed a supervised learning model to accomplish sentiment analysis of large-scale product reviews on Amazon.

User reviews are also crucial for game developers to obtain positive or negative feedback to maximize the chance of success. For example, player reviews provide the positive feedback that the developer should keep and the negative feedback that the developers should maintenance or avoid the next time. In [21], the authors conducted a study of 64 games with 132013 reviews on Steam to investigate the helpfulness of reviews. They found that review length and time spent playing a game strongly influence the helpfulness of reviews. Tong *et al.* [83] used the independent game No Man's Sky as an example to analyze the 158083 reviews between August 2016 and October 2020, investigated the influence of online reviews on the development of video games, and assess the interdependent relationship between online reviews and video games. Lin *et al.* [45] studied the characteristics of 1182 Early Access Games (EAGs) on Steam, including reviews, release notes, and discussions. They found that the smaller development studios mostly used the early access model and 15% of games on Steam made use of the early access model as of that time. Furthermore, they indicated some lessons learned from a failed early access game: the Spacebase DF-9 [1]. Guzsvinecz [35] studied the correlation between positive reviews, playtime, design and

[1] https://store.steampowered.com/app/246090/Spacebase_DF9/

game mechanics in "Souls-like" role-playing games. The author analyzed 21 "Souls-like" games on Steam, which have 993932 reviews as of the middle of April 2021. Wang *et al.* [89] employed text analytics to automatically elicit components of the game experience from online reviews and examined each component's relative importance to user satisfaction.

Video games may also be utilized to help gamers improve their mental health. Phillips *et al.* [68] explored the game reviews to expeditiously identify games with potential benefits for mental wellbeing. Their work contributed to an emerging research agenda of commercial video games as therapy (VGTx), by providing a technique for rapidly identifying games with therapeutic potential. However, spam reviews increasingly appear on the internet, confusing users' decisions. These fake reviews are widespread, dangerous, and difficult to detect manually. Bian *et al.* [11] proposed a semi-supervised method to detect spam game reviews on Steam.

With the popularity of VR games, a large body of reviews research has explored the sentiment of players, emotional tendency [32], and the enjoyment of VR games [81]. Epp *et al.* [23] conducted an empirical study of players' complaints about VR games on Steam. They analyzed 17635 English reviews of 750 VR games on Steam to understand VR games and user complaints. Faric *et al.* [25] researched the features that players liked or disliked of VR exercise games, they extracted 498 reviews of 29 games from the three most popular platforms: Steam, Viveport, and Oculus. The main limitation of their study is the small number of sample reviews. Qian *et al.* [71] developed a topic model to identify the critical features of VR applications using 198301 user reviews from the Oculus Quest Store.

Compared to the literature mentioned above, our research collected newer and larger datasets containing 1362 VR games with 480970 reviews on the Steam platform as of March 3, 2022. We also studied multilingual reviews rather than only English reviews to explore the users' points of concern about VR games.

2.3 Study Setup

2.3.1 Data Collection

In this subsection, as Figure 2.1 shows, we describe our steps for collecting VR games data and reviews data from the Steam platform. Then we preprocess the reviews using natural language processing (NLP) techniques. Finally, we cluster the topics of reviews using the Transformer-based method.

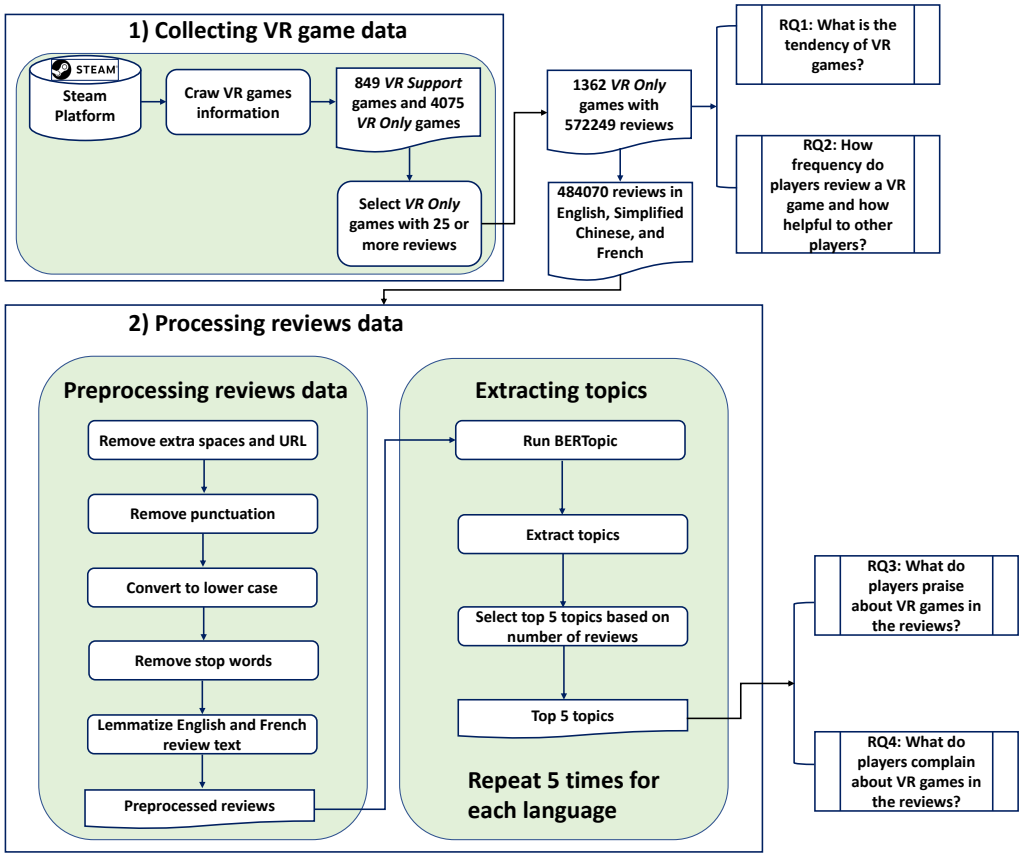


Fig. 2.1 The overview of our approach for collecting review data and topics clustering

VR Games Data Collection

We design a customized Python crawler to collect information for all VR games (including *VR Support* and *VR Only*) on Steam as of March 3, 2022. *VR Support* means a game has both VR and non-VR versions, and *VR Only* means a game has only a VR version. For each game, the crawler gathers the game id, game name, developer, release date, price (undiscounted, in Japanese yen), support HMDs, support input devices, support play areas, genre, support languages, and VR required properties (*VR Support* or *VR Only*). As of March 3, 2022, there are 4453 *VR Only* games and 849 *VR Support* games on Steam. We wish to analyze the advantages and disadvantages of VR games, the reviews of these *VR Support* games contain reviews that players play in non-VR modes, which may affect the analysis results. Therefore, we only analyze the *VR Only* games in this paper. Among the 4453 *VR Only* games, the release date of some games is before March 3, 2022, but the state of these games is still "Coming soon", which means these games are not yet available and do not have reviews, we delete these games from our dataset. After this pre-processing step, the rest number of VR games is 4084. Before 2016, only nine *VR Only* games were released on Steam. These

games have only 197 reviews and will not have much impact on our analysis results. This paper mainly focuses on *VR Only* games released from January 2016 to March 2022. Hence, we also delete these nine games from our dataset. Then, considering the popularity of games, we select the games with 25 or more reviews to research players' concerns about VR games.

Fig. 2.2 A review example on Steam

Reviews Data Collection

Among the 4075 *VR Only* games, 1362 games have 25 or more reviews. We design another Python crawler to collect reviews of the 1362 games. Figure 2.2 is a review example, a review contains six main messages:

- **A:** the number of users that found this review helpful.
- **B:** the number of users that found this review funny.
- **C:** *Recommended* means this is a positive recommendation and *Not Recommended* means this is a negative recommendation.
- **D:** playtime tracked in the past two weeks for this game; lifetime playtime tracked in this game; playtime when the review was written.
- **E:** date the review was created.
- **F:** text of written review.

In addition to these six messages, we also collect the Steam ID of the user who wrote this review, the number of games owned by the user, the number of reviews written by the user, and the language the user indicated when authoring the review.

The 1362 *VR Only* games have 572249 reviews in 28 languages, of which recommended reviews are 505154, and not recommended reviews are 67095. The top five languages with the most reviews are English (78.35%), German (4.03%), Simplified Chinese (3.91%), Russian (3.15%), and French (2.34%). For RQ3 and RQ4, we analyze the English, Simplified Chinese, and French reviews. Table 2.1 shows the summary of English, Simplified Chinese, and French reviews of 1362 *VR Only* games. Compared to the study in [23], we analyze more *VR Only* games (1362 vs. 750) with more reviews (484070 vs. 17635).

Table 2.1 The summary of English, Simplified Chinese, and French reviews of 1362 *VR Only* games

Language	**No. of Reviews**	**No. of Recommended**	**No. of Not Recommended**	**No. of Helpful**	**No. of Funny**
English	448355	396315	52040	1155742	25770197361
Simplified Chinese	22349	19536	2813	179066	117063
French	13366	11702	1664	17169	3427

2.3.2 Data Preprocessing

A data cleansing step is necessary before analyzing the game reviews data. In this subsection, we explain the preprocessing steps using NLP techniques. Each review data is preprocessed as follows:

- Firstly, we remove the extra spaces and URLs in the reviews. Some reviews contain un URL to a video review, such as a YouTube link.
- Secondly, we remove punctuation from each review and then converted the text to lowercase.
- Thirdly, we apply Python package nltk [12] to remove the stop words from each English and French review text and package Jieba [80] to remove the stop words from each Simplified Chineses review text.
- Finally, we apply the nltk library to lemmatize the English and French review text.

Table 2.2 The brief summary of the VR games reviews collected on Steam

No. of *VR Supported* games	849
No. of *VR Only* games	4075
No. of reviews of 4075 *VR Only* games	594022
No. of *VR Only* games with 25 or more reviews	1362
No. of reviews of the 1362 *VR Only* games	572249

2.3.3 Topic Modeling

After preprocessing the reviews data, we conduct an in-depth analysis of all reviews in 3 languages to explore the concerns of VR game players. We use the Python package BERTopic [34] to cluster the reviews for extracting topics. BERTopic is designed to create dense clusters that make it simple to assign topics while maintaining essential keywords in the topic descriptions. Guided, supervised, semi-supervised, and dynamic topic modeling are all supported by BERTopic. It also has visualizations comparable to LDAvis [78]. In this step, each review was assigned to one topic. In this paper, we did not fine-tune the model and took advantage of the better off-the-shelf sentence transformers from the sentence-transformer library [73] to cluster reviews topics.

After performing the BERTopic model on the reviews, the clustered topics were sorted according to the number of reviews assigned to each topic. Because BERTopic is nondeterministic, the results will vary from run to run. As a consequence, we run the model five times for each language, and for each run, the hyperparameters of the BERTopic algorithm are not always set the same. The detailed steps of topics categorization are as follows:

1. For each run, we set the topic parameter of the BERTopic model to 10. The first two authors sorted the topics according to the keywords and the number of reviews. After five runs, the two authors manually grouped the top 10 topics of all five runs.

2. After the BERTopic model run, the first two authors each had 10 topics, then the two authors discussed and selected the top 5 topics. During the discussion, each author gave a rationale for every disagreement. Two authors adopt reasonable results for most of the disagreements. The third author participated in the discussion for the few remaining disagreements to obtain a final consensus.

We run this step separately for positive and negative reviews of each language. After completing this process, we got the top 5 topics for each type of review in each language.

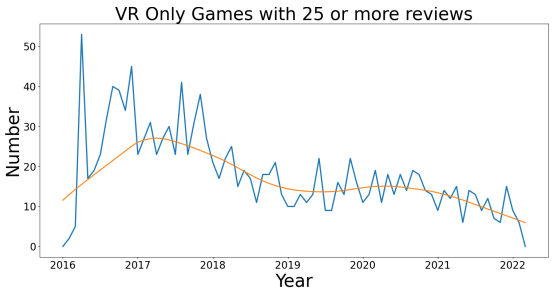


Fig. 2.3 The distribution of release date of 1362 *VR Only* games. The Year axis is grouped into months. The line is a LOWESS trend line which provides a smoothed estimate of the number of games.

2.4 VR Games Trends and Users' Concerns

This section introduces four research questions (RQs) and our findings. First, we comprehensively analyzed the essential characteristics of VR games and a quantitive study of users' playtime. Furthermore, we analyzed three language reviews: English, Simplified Chinese, and French, to discover players' concerns in different language regions.

2.4.1 RQ1: What Is the Tendency of VR Games?

In this research question, we analyze the essential characteristics of VR games, including release date, price, game genre, support language, headset, controller, and play areas. It is crucial to analyze these fundamental characteristics of VR games before exploring their reviews for games because these factors will affect the player's evaluation of the game. In [46], the authors found that players write longer reviews for games for which they paid. Therefore, we firstly analyzed the basic characteristics of these *VR Only* games.

RQ1.1 What Are the Release Date and Price Distribution of VR Games on Steam?

Release Date The first *VR Only* game on Steam is Curious Alice[2] released on February 23, 2012. Subsequently, the commercial VR devices boom has made VR games flourish. From 2016 to 2021, the annual number of *VR Only* games released on the Steam platform is 591, 961, 783, 555, 616, and 481. 2017 and 2018 were the peak years for *VR Only* game releases, then the number of releases each year began to decline, Figure 2.3 shows the number of *VR Only* games released monthly from January 2016 to March 2022.

[2]https://store.steampowered.com/app/1424190/

Price The mean, median, and mode price values of 4075 *VR Only* games are 1099.96 yen, 930.00 yen, and 1010.00 yen, respectively. 870 (21.35%) of these games are free to play. The mean, median, and mode price values of the 1362 *VR Only* games with 25 or more reviews are 1449.51 yen, 1280.00 yen, 2050.00 yen, respectively. 381 (27.97%) of these games are free to play. The VR games with more reviews are more expensive than those with fewer reviews. One possible explanation is that the more players spend on games, the more willing they are to review games. Figure 2.4 shows the price trends of *VR Only* games on Steam. We collected the undiscounted price of each *VR Only* game on Mar 3, 2022.

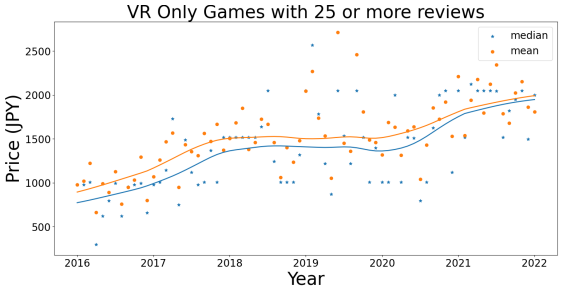


Fig. 2.4 The price trendency of 1362 *VR Only* games on Steam. The Year axis is grouped into months. The line is a LOWESS trend line which provides a smoothed estimate of the mean and median price of *VR Only* games over time.

RQ1.2 What Genres and Languages Do VR Games Support on Steam?

Game genre In [46], the authors found that players typed longer reviews for indie games than non-indie games. In our statics, 60.76% (830 of 1362) are indie games, which is bigger than the indie game fraction of all *VR Only* games (2383 of 4075, 58.48%). The most popular genre of VR games is the Action game, the top 5 genres of *VR Only* games are Action (669, 49.12%), Casual (507, 37.22%), Adventure (487, 35.76%), Simulation (457, 33.55%), and Sports (137, 10.06%). We exclude generic genres reported by Steam, such as Early Access, Free to Play, and Indie [85].

Support Language All the studied 1362 *VR Only* games support English, and 869 (63.80%) games only support English. The top 5 support languages of the 1362 *VR Only* games are English (100.00%), Simplified Chinese (22.98%), German (21.66%), French (21.00%), and Japanese (19.53%). In RQ3 and RQ4, we only analyze the English, Simplified Chinese, and French reviews based on these statistics. However, it is not mean other language reviews are worthless valuable, reviews in other languages are also an attractive research direction. For instance, Barbosa *et al.* [9] designed a prediction network to study

the helpfulness of game reviews based on the Brazilian Portuguese reviews on the Steam platform.

RQ1.3 What Are the Support Play Areas, Input Devices, and HMDs Tendency of VR Games?

Play area The top two supported play areas of 1362 *VR Only* games are standing (1098, 80.62%) and room scale (1038, 76.21%). Some VR games only support one kind of play area, in the 1362 VR games, 55 games only support standing, 86 games only support seated, and 169 games only support room scale. Figure 2.5 shows the distribution of supported play areas for these 1362 games. For the 1362 VR games, the support for room-sacle is up and down, but the overall trend is still down. From 2016 to early 2021, support for standing and seated was on the rise but has been trending downward recently.

Table 2.3 Top 5 genres of 1362 *VR Only* games on the Steam platform

	All VR Only Games	**VR Only Games with 25 or more reviews**
Action	1943 (47.68%)	669 (49.12%)
Casual	1719 (42.18%)	507 (37.22%)
Adventure	1250 (30.67%)	487 (35.76%)
Simulation	1285 (31.53%)	457 (33.55%)
Sports	494 (12.12%)	137 (10.06%)

Table 2.4 Top 5 support languages of 1362 *VR Only* games on the Steam platform

	No. of Games
English	1362 (100.00%)
Simplified Chinese	313 (22.98%)
German	295 (21.66%)
French	286 (21.00%)
Japanese	266 (19.53%)

Input device Among the 1362 games, 1308 (96.04%) games support tracked motion controllers, 124 games support gamepad, 131 games support keyboard & mouse, and 1168 games only support tracked motion controllers, 11 games only support gamepad, 25 games only support keyboard & mouse, and 61 games support all three type of input devices. Figure 2.6 shows the distribution of supported input devices of *VR Only* games. The support for tracked

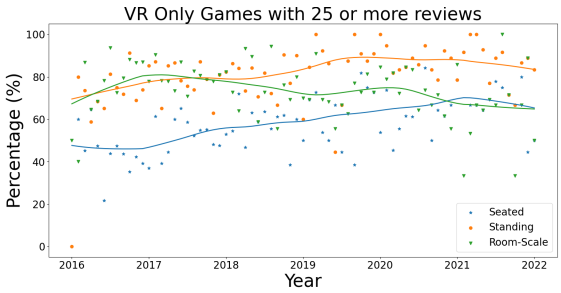


Fig. 2.5 The supported play area distribution of 1362 *VR Only* games. The trend line is a LOWESS trend line which provides a smoothed estimate of the released games.

motion controllers is increased from 2016 to 2017, and after reaching 98% in December 2016, the device's support rate has been above 90%, and the last three months have reached 100%, while the support for other two control schemes is decreasing month by month, and the last three monthly approval rate dropped to 0.

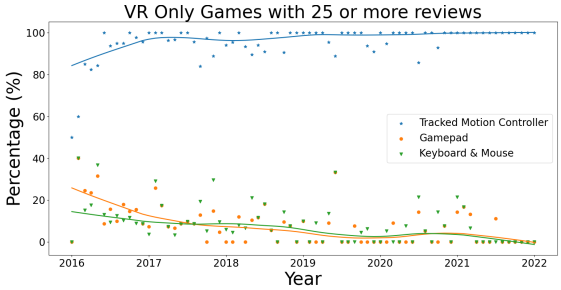


Fig. 2.6 The input device distribution of 1362 *VR Only* games. The trend line is a LOWESS trend line which provides a smoothed estimate of the percentage.

Head-mounted Displays HTC Vive is the most widely supported HMDs on Steam, 1353 of 1362 (99.34%) *VR Only* games support this VR device. HTC Corporation released HTC Vive in April 2016 and cooperated with Valve Corporation, implementing its SteamVR hardware and software ecosystem. Valve Corporation terminated cooperation with HTC Corporation and released its own VR headset Valve Index on June 28, 2019. Valve Index is the second supported headset, which gets 95.45% (1300 of 1362) supported rate. In [23], the authors analyzed three kinds of VR headsets except Valve Index, because they used information of studied games on Steam as of April 4 2019. Figure 2.7 shows that some *VR Only* games released before June 28 2019 also support Valve Index, which means these games had added support for Valve Index after its release. The third supported VR device is Oculus series devices (83.11%, 1132 of 1362), including Rift, Quest and Quest 2. Oculus Rift was released in March 2016. Windows Mixed Reality was released in November 2017, it gets 44.13% (601 0f 1362) support, respectively. The Figure 2.7 shows the support trend for

four VR devices of 1362 *VR Only* games. The support rate for Oculus and Windows Mixed Reality has been on an upward trend, while for the other two devices has remained high.

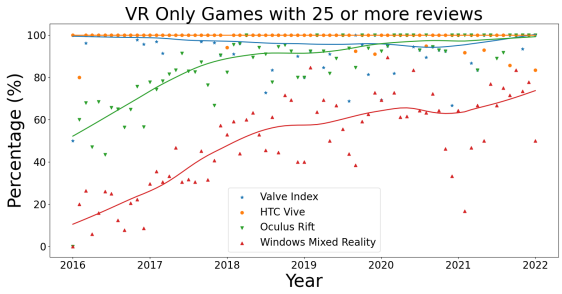


Fig. 2.7 The supported HMDs distribution of *VR Only* games. The trend line is a LOWESS trend line which provides a smoothed estimate of the released games.

RQ1.4 How Many VR Games Does Each Developer Release on Steam?

Developer The 1362 *VR Only* games are developed by 1096 developers, of which 653 (59.58%) only focus on developing VR games, and 465 (42.43%)developers only released one VR game. The remaining developers also develop non-VR games.

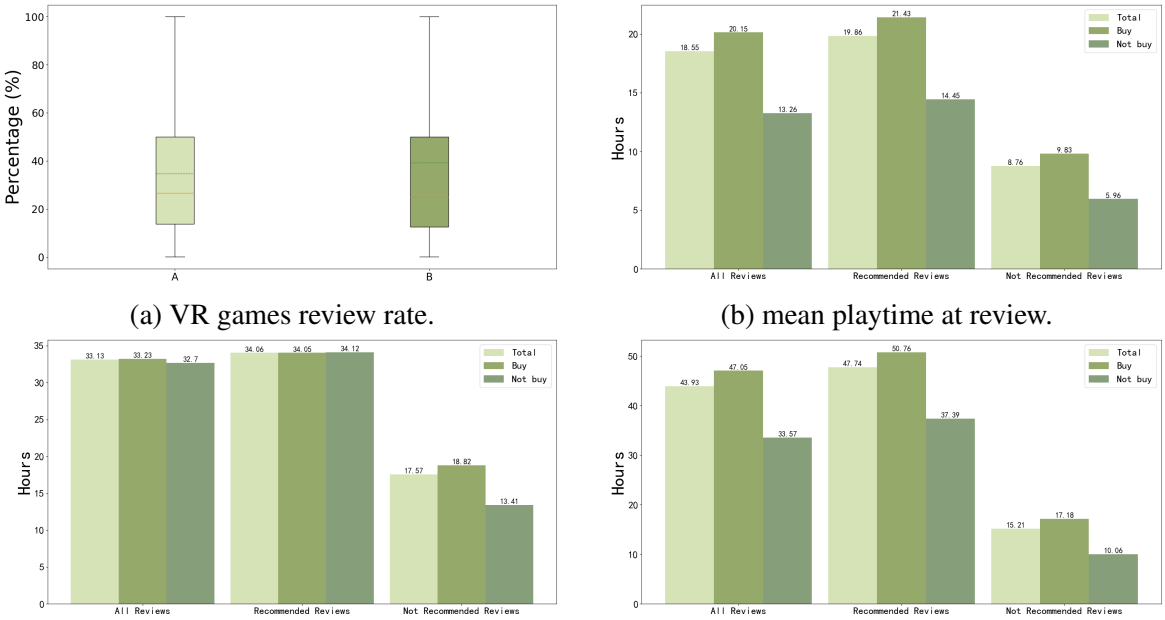
Summary of RQ1

We analyze the essential elements of VR games, including release date, price, game genre, support language, play areas, headset, controller, and developer. We found that VR games have boomed in recent years, especially in 2017 and 2018 and most VR games are indie games. Action, casual, and adventure are the top three VR game genres. All VR games support English, but support for other languages needs to be improved. The tracked motion controller is the most supported input device, and the HTC Vive is the most supported Head-mounted Displays.

2.4.2 RQ2: What Frequency Do Players Review a VR Game and How Helpful to Other Players?

RQ2.1 What Is the Popularity of VR Games among Gamers?

Every user has a Steam ID on Steam, and we also collected the message when we crawled reviews. We found that out of these 572249 reviews, 229049 players posted only one



(a) VR games review rate.

(b) mean playtime at review.

(c) mean playtime after review.

(d) mean playtime forever.

Fig. 2.8 Quantitative analysis of the proportion of *VR Only* games review, mean playtime at review, mean playtime after review, and mean playtime forever. (In (a), A: more than one VR games reviews; B: only one VR games review.)

comment about the *VR Only* game, and 92536 players posted the remaining 343200 reviews, accounting for 59.97%, and we counted the total number of reviews posted by each of these 92536 players. Among the 229049 players, 49077 players (21.43%) only posted one comment on Steam, and this comment was about *VR Only* games, such as one player had 6820 games but only posted one comment about *VR Only* games, and we also counted the total number of reviews posted by each of these 229049 players. We then calculated the percentage of VR game reviews posted by each player as a percentage of the total number of reviews. Figure 2.8a illustrates the distribution of these values, among these 92536 players, the mean proportion of VR games review is 34.67%, and among these 229049 players, the value is 39.27%. This shows that VR games are attracting players' attention, but are not very popular yet.

RQ2.2 How Long do Players Play a VR Game before and after Posting a Review?

The playtime at review is an important indicator, we conducted a quantitative analysis of playtime among three categories of reviews (all reviews, all recommended reviews, and all not recommended reviews). As Figure 2.8 illustrates, we compared the mean playtime at

review, mean playtime after review, and mean playtime forever of the three categories of reviews. We also compared the difference in playtime between paid and free games.

Mean playtime at review: In total, the mean playtime of the recommended reviews is the highest, whether total or separately (paid, free), meaning players tend to make positive comments the longer they play. Players who purchased the games played an average of 20.15 hours before commenting, which was 51.95% more than those who played the free games (20.15h vs. 13.26h). In players who posted recommended reviews, players who bought the game played longer before posting a review than those who did not (21.43h vs. 14.45h). Even among players who posted negative reviews, those who bought the game also played longer before posting a review than those who did not (9.83h vs. 5.96h).

Mean playtime after review: After a player leaves a comment, whether they continue to play the game and its duration are also meaningful indicators for evaluating the player's liking for a game. In recommended reviews, 81.99% (414155) of players continue to play the games, in which, 81.39% (337075) of the players purchased the games, and 18.61% (77080) of the players did not purchase the games. However, only 36.75% (24642) of players continue to play the games in negative reviews, and 63.27% (42453) of players never play the games again, even though 69.65% of them paid for the games.

As Figure 2.8c shows, for players who posted positive reviews, those who bought the game played about the same amount of time as those who did not (34.05h vs. 34.12h). However, among players who made negative reviews, those who purchased the game continued to play 40.34% more time than those who did not purchase the game (18.82h vs. 13.41h). Furthermore, players who post positive reviews are more likely to keep playing the game (34.06h vs. 17.57h).

Mean playtime forever: The players with positive reviews tend to play more time than others, nearly 47.74 hours, and those who bought the game played longer than those who did not (50.76h vs. 37.39h). The players with negative reviews only play 17.18 hours (buy games) and 10.06 hours (not buy games).

RQ2.3 Are Reviews Useful for Other Players?

On the Steam platform, if a player thinks a comment is helpful, he can click "Yes" or "Funny". We also conducted a quantitative analysis of these two facets. As Table 2.5 shows, the not recommended reviews got the most "Yes" (66.81%), and "Funny" (33.12%) tags, meaning negative comments could bring valuable information to other players and resonate with other players. Game developers should pay more attention to negative comments.

Summary of RQ2

We quantitatively analyzed the proportion of reviews of VR games, the total playtime, the playtime when the review was posted, and the playtime after that, as well as the number of "Yes" or "Funny" tags obtained by the reviews. We find that VR games are getting a certain level of attention among players, and if players purchased the VR game, they would play longer after commenting. However, after commenting, among players with positive comments, paying players and free players play almost the same time, and among players who made negative comments, paying players continue to play longer. Furthermore, VR game developers should pay more attention to negative comments, which generally contain valuable information.

Table 2.5 Quantitative comparison of the number of "Yes" and "Funny" tags

	All Reviews	**Recommended Reviews**	**Not Recommended Reviews**
No. of "Yes"	228647 (39.96%)	183823 (36.39%)	44824 (66.81%)
No. of "Funny"	82189 (14.36%)	59967 (11.87%)	22222 (33.12%)
No. of "Yes" and "Funny"	60323 (10.54%)	42374 (8.39%)	17949 (26.75%)
No. of "Yes" or "Funny"	250513 (43.78%)	201416 (39.87%)	49097 (73.18%)

2.4.3 RQ3: What Do Players Praise about VR Games in the Reviews?

RQ3.1 What Do Different Language Region Players Praise Most for VR Only Games?

English As the Table 2.6 shows, Music is the first topic that players praise mostly in English-speaking region. The excellent music can add a fantastic atmosphere and bring them a more immersive feeling. The second topic is community. The Steam Community is an online discussion and forum-based site used by Steam for users to communicate with each other. Players can exchange game experiences, find the game mods, new maps, tutorials, and so forth. Someone praised VR game with great community, such as *"It's well done and now has a strong modding and mapping community"*. Exercise or fitness is the third topic that players talk about most in reviews. Due to the COVID-19 epidemic, People has been isolated at home for most of the past two years and cannot exercise outdoors or go to the gym. VR sports games can provide fitness functions and are becoming increasingly popular. Players also exchanged the fitness effects of VR sports games in reviews. The game experience and gameplay are the fourth and fifth topics that players talked about more frequently. The

gameplay is more important for players, good gameplay can bring players a better gaming experience. For example, one player reviewed as *"Amazing VR experience, great idea, love the gameplay"*.

Table 2.6 The top 5 topics in English positive reviews of *VR Only* games on Steam

Topics	**Examples**
Music	"Very immersive with good music, tension and feelings of isolation", "All this is accompanied by pleasant music".
Community	"This game has an awesome community and helped me figure out modding it to turn off 99% of effects", "with great mapping tools by the community"
Exercise	"Lots of fun! AND good exercise!", "It's cool and a good exercise".
Experience	"A wonderful gaming experience", "It is one of the best and most satisfying VR experiences I've had by a long shot".
Gameplay	"Amazing VR experience, great idea, love the gameplay", "Good game, fun gameplay", "Great workout and addictive gameplay".

Simplified Chinese As the Table 2.7 shows, the most discussed advantage of VR games in the Simplified Chinese region is the game experience. Players are not stingy with their praise for a good game: the game is entertaining, this is a masterpiece, and the storyline is perfect. The second topic is music, players praised the game's beautiful background music and good rhythm, and they looked forward to more songs. The third topic is fitness, rhythm games (such as Beat Saber) require players to move, swing two handles or move to avoid obstacles, players think these VR games can be used for fitness. The weapon system is the fourth top topic that players were concerned about. The game content is the fifth topic that Simplified Chinese players paid more attention, they praised the game for being fun but also pointed out that the content of the game was too short.

French For French-speaking gamers, the gameplay is the most topic discussed in the reviews. Music and experience are the second and fourth topics they talk about most. Furthermore, French gamers are also concerned about game graphics and price, unlike English and Simplified Chinese players. The details show in the Table 2.8.

RQ3.2 What Are the Differences between Players in Different Language Regions?

In English, Simplified Chinese, and French-speaking region, the music and game experience are mostly the common topics that players praise. Simplified Chinese and English players also pay attention to VR sports games. French players also care more about the gameplay like English players. In addition, English players also pay attention to game community

Table 2.7 The top 5 topics in Simplified Chinese positive reviews of *VR Only* games on Steam

Topics	**Examples**
Experience	“非常喜欢这款游戏。很好玩”，“绝对的VR神作, 可以说是VR必玩的作品”. “Like this game very much. Very fun", “Absolute VR masterpiece, it can be said that it is a must-play work in VR”.
Music	“完美的剧情，优秀的音乐”，“强力推荐，非常好玩的音游，还支持本地歌曲，戴上头盔后场景非常酷”. “Perfect plot, excellent music", “Highly recommended, very fun audio game, also supports local songs, the scene after wearing the helmet is very cool”.
Fitness	“每天用来健身”，“真的好玩，真的健身”，“真的挺不错，锻炼身体，训练反应能力，练习身体协调能力，很好的运动游戏”. “Use it for fitness every day", “Really fun, really fitness", “Really good, exercise, train reaction ability, practice body coordination, very good sports game".
Weapon	“这个版本新加入的武器也很有特色，还可以使用飞剑。”，“做的不错，就是武器地图和敌人有点单一”，“武器升级系统很有意思”. “The newly added weapons in this version are also very distinctive, and flying swords can also be used.", “It’s done well, but the weapon map and enemies are a bit monotonous", “The weapon upgrade system is fascinating".
Content	“神作，就是剧情有点短”，“不足点是流程太短，刚到高潮部分却戛然而止”，“但剧情流程太短，希望流程更长”. “A masterpiece, but the plot is a bit short", “The shortcoming is that the process is too short, and it stops abruptly when it reaches the climax", “But the plotting process is too short, I hope the process is longer".

Table 2.8 The top 5 topics in French positive reviews of *VR Only* games on Steam

Topics	Examples
Gameplay	"Le gameplay est plutôt fun et les musiques sont très bonne. Que demander de plus", "le gamplay est nerveu". “The gameplay is quite fun and the music is very good. What more could you ask for", “the game-play is nervous".
Music	"Les musiques sont sympas", " Les musiques sont très bonnes“, ”les musiques sont vraiment bien". “The music is nice", “The music is very good", “The music is really good".
Graphics	"Les graphismes de très bonne qualité", "les graphismes époustouflants". “The graphics of excellent quality", “the stunning graphics".
Experience	"Bonne expérience, je le recommande!", "l'expérience encore plus fantastique". “Good experience, I recommend it!", “the even more fantastic experience".
Price	"il vaut bien son prix", "Très bon jeu ! A ce prix ça serait dommage de le louper". “it is well worth its price", “Very good game! At this price it would be a shame to miss it".

platforms, Chinese players care about game weapon systems and game content, and French players take notice of game graphics and prices.

Summary of RQ3

We cluster the top 5 topics from the positive reviews of VR games in English, Simplified Chinese, and French. We find that music, experience, gameplay, and exercise are the most talked about topics. Furthermore, community platform, weapon system, game content, graphics, and game price are related topics that VR game players pay more attention to.

2.4.4 RQ4: What Do Players Complain about VR Games in the Reviews?

RQ4.1 What Do Different Language Region Players Complain about primarily for VR Games?

English As the Table 2.9 shows, English players care about mostly weapon systems, and

Table 2.9 The top 5 topics in English negative reviews of *VR Only* games on Steam

Topics	Examples
Weapon	“I could barely unjam my weapon, attach weapon attachments”, “weapons disappear during engagement”.
Crash	“This game is dog ass the watch menu system is buggy and often find yourself accidentally restarting the game”, “Game has potential but is buggy on the valve index”.
Content	“game needs a lot more content its very unfinished good gore but not to much and not enough weapons etc”, “pricey for a game with very little content, polish... and gore”.
DLC	“very disappointed they didn’t add the time lord victorious DLC to the steam version", “DLC would not work for me on Oculus Quest 2 via steam".
Sickness	“the movement gives me motion sickness”, “I’ve played so many FPS/TPS/VR games and ONLY this game gave me 3D motion sickness”.

point out their complaints about weapons in the reviews, such as lack of weapon detail, the weapons do not have sound effects, and uncomfortable way of operating the weapon. The second complaint is crashing, including restarting the game, unloading, and duplicate game content, to name a few. Game with short content or overpriced is also complained about by players. The DLC (Downloadable Content) is also a topic that players often complain about. Some DLCs do not work on a specific HMD, or the players request to add DLC to the Steam version. Motion sickness is a longstanding research topic in VR games and 360-degree immersive video scenarios [70, 63, 19, 87, 88]. In English reviews, the players also complain about sickness, and movement often causes players to get sickness. Certain HDMs also sometimes cause the player to get cybersickness.

Simplified Chinese The most common complaint of Simplified Chinese region is game experience, such as *“very bad game experience", “The operation is too awkward", “Poor walking operation, easy to get sickness"*. The second complaint is the game does not support Simplified Chinese. As of February 2021, Simplified Chinese was the second most used language on Steam (19.80%) [FinancesOnline], the game developers should consider supporting Simplified Chinese. The price was also complained mostly. Such complaints are all about the game being overpriced and the content is short. The fourth complaint is bug and the fifth is multiplayer. Game bugs are varied, including black screen, cannot enter the game, and flashback. The complaint about multiplayer is that cannot find other players to play, or the game crashes when connected. More details are shown in Table 2.10.

Table 2.10 The top 5 topics in Simplified Chinese negative reviews of *VR Only* games on Steam

Topics	**Examples**
Experience	“游戏体验极差”，“游戏体验很不好”，“操作太别扭了”，“走路操作差，易头晕”，“糟糕的操作体验和近乎为零的物理引擎”. “The game experience is extremely bad’, “The game experience is very bad’, “The operation is too awkward’, “The walking operation is poor, easy to dizzy”, “Bad operation experience and almost zero physics engine".
Language	“只希望游戏有中文”，“我们需要中文”，“游戏不错，可惜没中文”. “I only hope the game has Chinese", “We need Chinese", “The game is good, but unfortunately there is no Chinese".
Price	“游戏做得很粗糙，退款了”，“不值这个价格”，“讲道理我觉得不值这个价钱”，“不值这个价，互动性不强，剧情很短。。。基本就是个DEMO”. “The game is very rough, and I have refunded’, “Not worth the price’, “To be reasonable, I don’t think it is worth the price’, “Not worth the price, not very interactive, short plot. . . It’s basically a DEMO".
Bug	“bug太多了”，“黑屏进不了”，“LOGO过后一直黑屏，进不了游戏”. “Too many bugs”, “The black screen can’t enter”, “The screen is always black after the LOGO, and I can’t enter the game’.
Multiplayer	“无法联机”, “联机也没人"，“为什么不能联机，我和朋友买了这个游戏一联机就崩溃"，“根本没人玩、无法组到人联机". “Unable to connect", "No one connected", “Why can’t connect, my friend and I bought this game and it crashed as soon as we connected", “There is no one to play at all, and no one can be connected online".

Table 2.11 The top 5 topics in French negative reviews of *VR Only* games on Steam

Topics	Examples
Graphics	“graphiquement, c’est flou et dégueulasse", “graphisme pas top et flot", “graphismes moins bon". “graphically it’s blurry and disgusting", “graphics not great and flowing", “less good graphics".
Controllers	“des contrôles très mal faits", “Peut-être que c’est bien mais les contrôles sont inutilisables avec Oculus Quest". “very poorly made controls", “Maybe it’s good but the controls are unusable with Oculus Quest".
Interface	“impossible d’utiliser ma manette et mon clavier l’interface menu", “Les éléments d’interface qui se font cacher par les modèles 3D". “can’t use my gamepad and keyboard the menu interface", “Interface elements that are hidden by 3D models".
Bug	“Le jeu est plein de bug", “il y a un bug de son". “The game is full of bugs", “there is a sound bug".
Content	“C’est vraiment trop court...donc non même pour 0,99€, je ne recommande pas". “It’s really too short...so not even for 0.99€, I don’t recommend".

French The French-speaking players complained mostly about the graphics. They complained that the graphics of some VR games are blurry and disgusting. The second topic is controllers. Some VR games are not well adapted to specific control devices, such as Oculus Quest, resulting in players being unable to operate the VR game. The third complaint topic is about the interface. The interface elements are hidden by 3D models or do not adjust to the resolution of specific HMDs. The players also complained about some bugs in their reviews, such as sound bugs, mission crashes, clipping bugs, etc. Like English players, French players also talk about some VR games’ content are short and overpriced, or the game is just a demo. More review examples are shown in Table 2.11.

RQ4.2 What Are the Differences between Players from Different Language Regions?

In English, Simplified Chinese, and French-speaking regions, the crash is the most common topic that players complain about. English and French players also pay attention to the VR games content. Furthermore, English players complain about the weapon system, game DLC, and sickness. Simplified Chinese players also pay attention to the game experience,

price, support Chinese, and multiplayer. The French players take notice of game graphics, controllers, and interfaces.

Summary of RQ4

We cluster the top 5 topics from the negative reviews of VR games in English, Simplified Chinese, and French. We find that crash, game content, experience, graphics, and weapon system are the five most talked about topics. Furthermore, sickness, price, interface, controllers, and multiplayers are also topics that VR game players pay more attention to. In particular, Chinese support is more critical for Chinese players.

2.5 Implications

Grounded in the analysis of the essential elements of VR games, our findings indicate that the development of VR games has stabilized after the explosion in 2017 and 2018. However, the price of VR games has gradually increased, which has also caused some players to complain that some VR games are overpriced or do not have enough game content.

All VR games support English on Steam. Although the support rate for Simplified Chinese ranks second, it is only 22.98%. Many Chinese players complain in the reviews that the game does not support Chinese. Considering that the Chinese game market is getting bigger and bigger, VR game developers should strengthen support for Simplified Chinese in the future.

At present, the newly released VR games can support almost all mainstream HMDs, Valve Index, HTC Vive, and Oculus are the three devices with the highest support rate, and the support for Windows Mixed Reality is gradually increasing. However, VR game developers should pay attention to the compatibility of different devices because players complain that specific devices have bugs.

VR games are gaining acceptance among players, the average VR game time of gamers is 18.55 hours before posting a review and 33.13 hours after that. Players in different regions pay different attention to the VR game, but in general, good background music, gameplay, and graphics can win the praise of players. If game developers want to attract players, they should take notice of the gameplay, content, and game experience.

2.6 Threats to Validity

In this section, we discuss the potential threats to the validity of our study and findings.

2.6.1 Construct validity

We analyze the VR game reviews only from the Steam platform, as we all know, HTC Corporation has its own game distribution platform VIVEPORT [17], and Meta has Meta Quest platform [58]. As of May 23, 2022, there are 1607 VR games on VIVEPORT and 2444 games on Oculus Quest Store. The Steam platform has more than 4000 VR games. Considering the number of users the platform popularity, we only analyze the reviews from Steam. The VR game reviews from VIVEPORT and Oculus Quest Store platforms are also worth looking into in future research. Furthermore, console game platforms such as PlayStation VR or mobile-based platforms (Samsung Gear VR) are also worth investigating in the future.

By combining the release date of each VR game with the declared support on Steam, we calculated trends in supporting language, play area, input device, and headset. However, as the finding by Epp *et al.* [23], the VR game developers could update the support information at any time. For example, Windows Mixed Reality was released in November 2017, and we found 162 games supporting it, which were released before November 2017; Valve Index was released on June 28, 2019, and we found 898 games released before that time also support this headset.

In this paper, we apply the BERTopic library to cluster the reviews into several topics. However, this library can only cluster a review into one topic, even though some reviews may belong to multiple topics. This is a multi-label classification problem and it's a tedious and time-consuming task to manually label reviews for conducting train datasets. In future research, we will focus on conducting a large-scale dataset to study this problem.

2.6.2 Internal validity

We excluded games with less than 25 reviews according to VR game popularity, but newly released VR games may be excluded because they have not had enough time to accumulate 25 reviews. VR games with less than 25 reviews are also a topic worthy of study.

In order to categorize user complaints, we studied multilingual reviews, including English, Simplified Chinese, and French. We also examined the positive and negative reviews. However, the number of reviews in English is much larger than those in the other two languages, and the distribution of reviews in the other two languages is uneven, with more popular VR games having a higher percentage of reviews. For example, Beat Saber[3] and Half-Life: Alyx[4] are the two most popular VR games on Steam. Their comments account for

[3]https://store.steampowered.com/app/620980/
[4]https://store.steampowered.com/app/546560/

11.23% and 18.35% of Chinese comments, respectively, and account for 10.24% and 13.80% of French comments. The potential threat is that the proportion of reviews of a particular game is too high, affecting the topic classification results. We extract players' complaints from negative reviews and players' praises from positive reviews. However, positive reviews may also contain complaints and vice versa. Since the proportion of positive reviews containing complaints and negative reviews containing praise is small, it is challenging to automatically extract complaints and praises from these reviews. Future research should investigate the category of complaints in positive reviews of VR games and the category of praise in negative reviews of VR games.

2.6.3 External validity

A threat to validity is that there may exist inconsistent reviews. Some players' comments contain negative content but are marked as *Recommended* and vice versa. As an example, we found "The game is buggy and sometimes janky as fu**" associated with *Recommended*. The inconsistent user reviews can affect the accuracy of the findings. We will explore the impact of inconsistent reviews for VR games in the future to bridge this gap.

We only look at *VR Only* games, excluding games with both VR and non-VR modes, so our findings may not generalize to those games. Unfortunately, this limitation was inevitable since games with optional VR compatibility may include reviews for both VR and non-VR content, with no way to distinguish between the two. In [23], the authors also pointed out this issue. We encourage future studies to design a classifier for classifying the reviews of VR and non-VR versions of the same games and then explore the differences in enjoyment.

2.7 Conclusion

In this article, we conducted an empirical study to analyze VR game tendencies and players' concerns using 1362 VR games data from the Steam platform. We explored the VR game tendencies grounded in the analysis of release frequency, price, genre, support language, play areas, input devices, HMDs, and game developers. We also clustered the top five praise and complaint topics of each language from reviews in three different languages (English, Simplified Chinese, and French). The most important findings of our study are:

1. English is the first language supported by VR games, and developers should add support for other languages, especially Simplified Chinese.

2. The majority of recently released VR games have support for multiple categories of HMDs and play areas. However, for input devices, almost all VR games support

tracked motion controllers, and the support rate for gamepad, keyboard & mouse is almost zero.

3. The music, game experience, and gameplay are the three aspects that players praise most.

4. In the meantime, the game bugs, not enough content, and overprice are the three areas that players complain about most.

Our study is helpful for VR game developers who wish to develop VR games with high user satisfaction and value for VR field researchers who want to study user behaviors. In particular, these VR game developers can leverage our findings as a reference to improve game quality.

In the future, we would like to extend our work vertically and horizontally. First, we will collect more VR game data from other VR game digital distribution platforms, such as Oculus and VIVEPORT. Second, apart from clustering complaints from negative reviews, we will also study the complaints in positive reviews and the positive factors about VR games in negative reviews.

Chapter 3

User Experience of Different Groups in Social VR Applications

3.1 Motivation

Social virtual reality (VR) is an emerging online social platform that enables players to interact with each other in virtual space through Head-Mounted Displays (HMDs). Social VR applications have attracted increasing users to join, especially during the epidemic of COVID-19, people could not do outdoor activities due to the strict lockdown measures. Many people went into social VR applications to enjoy VR games, travel in virtual worlds, or communicate with others. Commercially available social VR applications include VRChat, Rec Room, Altspace VR, and PokerStars VR, to name a few.

A significant body of literature on social VR has resulted from the popularity of these commercial social VR applications. These studies have focused on design strategies [79, 40, 56], user experiences of different age groups [50–52, 103, 4–6], self-presentation and avatars [27, 1, 7, 82], and harassment in social VR platforms [13, 77, 28].

However, prior research has two limitations in studying the UX of social VR. First, the vast majority of earlier studies are based on interviews [53, 69, 49]. Maloney *et al.* [53] recruited 30 interviewees to explore Non-Verbal communication in Social VR. Piitulainen *et al.* [69] interviewed 17 participants to explore what kind of experiences people currently have with dancing in social VR. Maloney *et al.* [49] designed a research to investigate what made activities meaningful to users on social VR platforms and users' recommendations. Although these interview-based researches have provided relevant insights into the UX, the sample size could be easily extended by using reviews as data. Second, some prior social VR literature focused on specific groups, such as Baker and his colleagues paid attention to

older adults in social VR [6, 5, 4, 7], Divine Maloney's team concentrated on the influence of social VR on children and teenagers [50–52]. Little work has explored a holistic study of social VR experience on different age groups.

Therefore, to bridge the above mentioned gaps, we conduct an empirical study based on large-scale user reviews of social VR applications. Specifically, we collect 105757 English reviews of nine different social VR applications from two digital distribution platforms (Steam and Oculus) to study the following research questions (RQs):

RQ1: What do users think of avatar and self-presentation in social VR?
RQ2: What are the harassment behaviors in social VR?
RQ3: What is the impact of social VR on different groups of people?
RQ4: What are the physical effects of social VR platforms?
RQ5: What are the benefits of social VR during the COVID-19 pandemic?

In summary, this paper makes a number of contributions to UX research in social VR:

- First, to the best of our knowledge, this is the first study to explore the UX of social VR based on large-scale user reviews from digital distribution platforms.
- Second, we offer a large-scale dataset of user reviews collected from nine social VR applications, which could be used in future research about the UX of social VR.
- Third, our study shows the valuable feedback of user reviews, which can help social VR developers better meet users' needs.

3.2 Related Work

3.2.1 Social VR applications

With the advent of commercial-grade HMDs like Oculus Rift, Quest, and Vive Index, VR applications have blossomed in recent five years, including games, tourism, education, social, and so forth. Social VR platforms provide an immersive virtual environment where multiple users chat, play games, watch movies, and do other social activities together through VR HMDs. Some representatives of the more popular social VR applications among players are as follows:

- **VRChat** was released on Steam on February 1, 2017. Players can design their own virtual worlds where they can interact with other players using virtual avatars. Players can also create or import character models for using in VRChat thanks to a software development kit for Unity.

- **Rec Room** was released in June 2016, it consists of separate built-in multiplayer games, such as paint ball, co-op adventures games, 3D charades, and various sports games. Therefore, Rec Room attracts a lot of minors.

- **Altspace VR** was released in May 2015. Users create their own worlds in the platform, which can be visited by other players. And the platform also hold a wide variety of live virtual events such as VR church, LGBTQI+ meetups, magic shows, and large business conferences.

- **PokerStars VR** is a free play VR poker game that was released in November 2018. Players can play Texas holdem, Blackjack, slots, roulette, and sports betting. It's popular on Meta Quest.

According to SteamDB[1], the two most popular social VR applications on Steam are VRChat and Rec Room. Figure 3.1 shows the average number of weekly online players of these two social VR platforms from January 2018 to April 2022. As Figure 3.1 illustrates, before 2020, the number of players in VRChat has been hovering around 7,500. Since 2020, the number of players has continued to grow. On the one hand, during the COVID-19 epidemic, people are locked down at home and cannot perform outdoor activities, social VR platforms can provide players with immersive virtual worlds where people can interact with friends, families, and strangers. On the other hand, the release of new affordable HMDs has also attracted a large number of players, such as the Oculus Quest 2, which was released on October 13, 2020

With the popularity of social VR platforms, more and more researches focus on the UX of social VR. Such studies have focused on old adults' [6, 5, 4, 7], children and teenagers' experience in social VR [50–52], avatars [27, 1, 7, 82], and harassment in VR platforms [13, 77, 28].

Baker and colleagues conducted a broad research project on social VR experiences for older adults [6, 5, 4, 7], their studies demonstrated that social VR provides a promising avenue for supporting social connectedness in later life. For example, older adults could use social VR as a comfortable environment to communicate face-to-face [7], or as a reminiscence tool to stimulate memories [4]. Maloney and colleagues paid attention to children and teens in social VR. In [50], they focused on how people interact with young users across various social VR applications based on interviews with 30 adults. They also applied a participatory observation study to enhance this research [51]. In addition to the perspective of adults, the authors also interviewed 20 teenagers to explore why teenagers engage in social VR [52].

[1] https://steamdb.info/

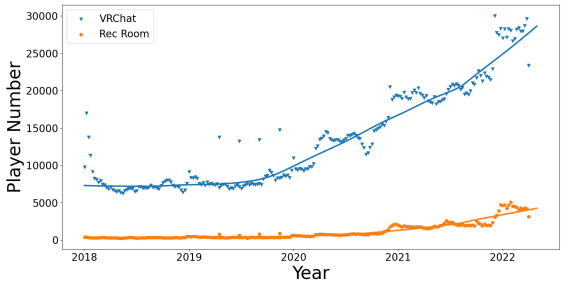


Fig. 3.1 The trends of average weekly online players of VRChat and Rec Room on Steam from January 2018 to April 2022.

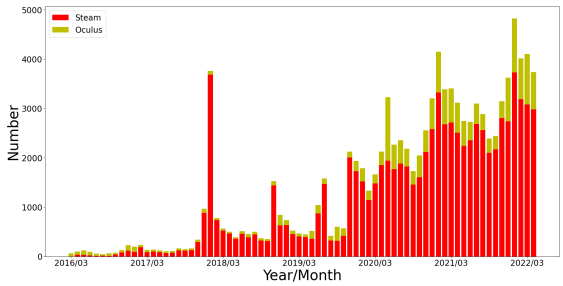


Fig. 3.2 Monthly distribution of English reviews of social VR platforms on Steam and Oculus.

Freeman *et al.* [27] conducted interview-based research on 30 social VR users to explore self-presentation on commercial social VR platforms. They found that social VR users tend to construct platform-specific self-presentation. Based on eight interviews and two months of participatory observations, Acena *et al.* [1] explored how LGBTQ users participate in social VR and how social VR has the potential to support them by affording a range of inclusive interactions. In a five-month study, Baker *et al.* [7] evaluated a social VR prototype with 16 older adults. Their findings showed that older adults are excited by the possibility of customizing their avatars to match various virtual environments.

However, these prior studies are usually based on interviews, and the number of interviewees is usually less than 50. The limitation is that the sample size is too small. User reviews of social VR platforms are also a considerable treasure, and little existing literature utilizes this resource. Therefore, in this paper, we collect user reviews of nine social VR applications from two digital platforms to explore the UX of social VR.

3.2.2 User Reviews

User reviews are crucial for game developers to obtain positive or negative feedback to maximize the chance of success. For example, player reviews provide positive feedback that the developer should keep and negative feedback that the developers should maintain or avoid

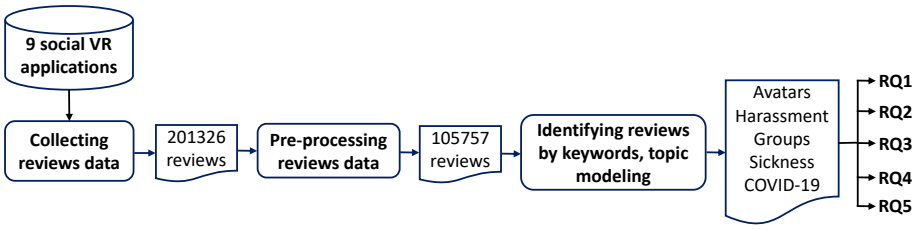


Fig. 3.3 Overview of review data collection and data processing steps.

the next time. In [21], Eberhard *et al.* conducted a study of 64 games with 132013 reviews on Steam and found that review length and time spent playing a game strongly influence the helpfulness of reviews. Lin *et al.* [45] studied the characteristics of 1182 early access games on Steam, including reviews, release notes, and discussions. They found that the smaller development studios mostly used the early access model and 15% of games on Steam made use of the early access model as of that time.

With the popularity of VR games, a large body of reviews research has explored the sentiment of players, emotional tendency [32], and the enjoyment of VR games [81]. Epp *et al.* [23] conducted an empirical study of players' complaints about VR games on Steam. They analyzed 17635 English reviews of 750 VR games on Steam to understand VR games and user complaints. Qian *et al.* [71] developed a topic model to identify the critical features of VR applications using 198301 user reviews from the Oculus Quest Store.

However, there is still very little literature on social VR based on user reviews. Figure 3.2 presents the monthly distribution of English reviews of social VR applications on Steam and Oculus platforms. It illustrates that many user reviews are published monthly, which is a treasure to be unearthed. Compared with Figure 3.1, as the number of players increases from 2020, the number of user reviews also increases. The Steam platform is the most popular, and the number of reviews on Steam is much more than the Oculus platform. In this paper, we study the user experience of different groups regarding social VR applications from different aspects, including the virtual avatar, harassment in social VR, physical effects, and the benefits of social VR during the COVID-19 pandemic based on analyzing user reviews.

3.3 Methodology

In this section, we outline the strategy utilized to collect the user reviews from Steam and Oculus platforms and the steps followed in processing the reviews. Figure 3.3 depicts our strategy in broad strokes. The following subsections describe the details of our approach.

3.3.1 Data Collection

We design two customized Python crawlers to extract user reviews from the Steam and Oculus digital distribution platforms as of April 30, 2022. There is a "Social" option in the game genres on the Oculus platform, hence, we could directly find social VR games to crawl user reviews. Because there is no "Social" option for VR games on Steam, after we crawled the Oculus platform, we had a game list, and then we followed the list to crawl reviews on Steam if games exist on Steam. Finally, we selected 9 social VR platforms/games based on the number of reviews. The games details are as follows:

- **Steam:** VRChat, Rec Room, PokerStars VR, Altspace VR, Sansar.
- **Oculus:** VRChat, Rec Room, Echo VR, PokerStars VR, Real VR Fishing, Poker VR, Altspace VR, vTime VR.

In summary, we collected 201326 user reviews of the nine social VR games, of which, 180384 reviews from Steam, 20473 from Oculus. In addition, we did not collect the personal information, such as user name, user id for the data protection and privacy,

3.3.2 Keyword Selection

In order to extract the most relevant reviews for each topic from the review dataset, we construct a keywords bag. We first build a simple initial set of several keywords for each topic based on the authors' experience. To expand the keywords bag and avoid bias in perspectives, we first extract related reviews of each topic from the collected review dataset using the initial keyword bag. Second, we remove the stop words of each review and then apply Word2vec [61, 62] technique to learn word associations. We calculate the similarity between initial keywords and words, and we choose the top 200 most similar words to each initial keyword. Finally, the three authors read through the 200 words and select the most related keywords for each topic and add them to the keywords bag.

3.3.3 Preprocessing Data

In this subsection, we present the pre-processing steps using natural language processing techniques.

Filtering English User Reviews

In this paper, we aim to analyze the English reviews. We apply Lingua library to remove non-English reviews and finally we get 105757 English reviews. The table 3.1 shows the total English review numbers of each social VR platform.

Table 3.1 The review numbers of each social VR platform.

	VRChat	Rec Room	Echo VR	Real VR Fishing	PokerStars VR
No. of reviews	69553	24450	3620	2534	2103
	Poker VR	Altspace VR	vTime VR	Sansar	**Total**
No. of reviews	1321	1055	732	389	**105757**

Extracting Key Sentences

The 105757 user reviews are a large amount of data, and it is impossible to obtain accurate information by directly clustering it. Therefore, we design a keywords bag for each RQ to extract key sentences from the collected review dataset. Table 3.2 shows the keywords bag for each RQ.

Cleaning Reviews

Stop words are frequently occurring words that hardly carry any information in user revires, and some user reviews may contain distracting text, such as hyperlinks to advertisements. Therefore, it is necessary to clean the reviews data for more accurate topic clustering. The cleaning steps are as follows.

- First, we remove the extra spaces and URLs in the reviews. Some reviews contain un URL to a video review, such as a YouTube link. And we also remove punctuation from each review and then convert the text to lowercase.
- Second, we apply Python package nltk [12] to remove the stop words from each review text and then lemmatize the review text.

Topic Modeling

After cleaning the review data, we use the Python package BERTopic [34] to extract hot topics the players talk about for the RQs. BERTopic is designed to create dense clusters that make it simple to assign topics while maintaining essential keywords in the topic descriptions. In this step, each review was assigned to one topic.

After performing the BERTopic model on the reviews, the clustered topics were sorted according to the number of reviews assigned to each topic. Because BERTopic is nondeterministic, the results will vary from run to run. As a consequence, we run the model five times for each research question and sub-question.

For each run, we set the topic parameter of the BERTopic model to 10. The first two authors sort the topics according to the keywords and the number of reviews. After five runs, the two authors manually group the top 10 topics of all five runs. Then, the two authors discuss and select the top 5 topics. During the discussion, each author give a rationale for every disagreement. Two authors adopt reasonable results for most of the disagreements. The third author participate in the discussion for the few remaining disagreements to obtain a final consensus.

3.4 Findings

In this section, using user reviews of social VR applications, the following five themes are discussed: (1) how users think of avatars in social VR; (2) the harassment behaviors in social VR; (3) the influence of social VR on different age groups; (4) the physical effects of social VR; (5) the benefits of social VR during COVID-19 pandemic. Note that a user review could be labeled to more than one theme (e.g., *"there were some kids in the lobby who were just nasty in trying to do sexual things to my avatar"* could be labeled as the theme (2) and (3)).

3.4.1 RQ1: What do users think of avatar and self-presentation in social VR?

Self-presentation in online social platforms has been a long-standing research topic. Compared to other forms of media where users present themselves by creating online profiles using text, images, and videos, social VR introduces an entirely new form of self-presentation that combines a person's body and avatar. In these novel social VR platforms, how users experience and understand avatars and how to perceive the self-presentation of others is a topic worthy of research.

In this paper, we collect 5298 avatar-related reviews by using keywords to filter user reviews. Then, we use TextBlob[2] tool to label the emotional sentiment of the reviews into positive, neutral, and negative. TextBlob tool indicates a sentence's attitude by calculating the score as a polarity in [-1, 1]. When the polarity of a review is less than -0.4, its sentiment is regarded as negative. The review is considered positive when it is more than 0.4. The

[2]https://textblob.readthedocs.io/en/dev/

polarity of neutral review lies in [-0.4 0.4]. After this process, the final distribution of the avatar-related reviews is: positive (759,14.33%), negative (116, 2.19%), and neutral (4423, 83.48%).

We apply the BERTopic model to cluster the topics among the positive and negative reviews to explore what players care about most. In the positive reviews, the vast majority of players expressed their love for the avatars that social VR applications provide. Furthermore, the second topic is avatar customization. The avatar customization impresses the social VR players, and they can design their avatar according to their liking and even make a great comedic situation. Players are generous with their compliments in reviews for avatar customization:

> *"The avatar customization is surprisingly robust!"; "Especially the avatar custom system is wonderful."; "Would be very willing to spend money for more avatar customization."; "I love the new version it has more avatar customization."*

The number of avatar types is also a topic that players are more concerned about, some games have rich avatars for players to choose from: *'There are so many avatars to choose to represent yourself'"*; but in some games, the number of avatars is limited, users require more avatars: *"It's good but they need to make more avatars."* Avatar diversity should be a concern for social VR developers in the future.

In the negative reviews, the most common complaint from users is the way avatars are displayed. Some users would like to see all avatars: *"Cannot see all avatars, which is annoying"; "I have to go to the menu to show avatar, it's so annoying."* On the other hand, compatibility is also an important issue: *"the incompatibility of a lot of avatars with the PC version and the 'perf blocking' of avatars is highly annoying"*. In addition, the NSFW (Not Safe For Work) avatar also caught users' attention: *"Be warned there are NSFW avatars on the game"; "banning NSFW avatars, please protect the kids"*.

In the neutral reviews, the first topic in neutral reviews is avatar creation. Users like to create their avatars. The second is anime avatar, females users usually like anime avatars, but some users do not like: *"I love the virtual socialization idea but I hate the furry anime avatars."* Privacy is also a topic that players are more concerned about. Some players discuss in the reviews that the developers do not pay attention to player privacy: *"They do not do anything to protect user privacy." "the devs of this game should be ashamed, that my privacy and security was violated."*

Table 3.2 Overview of keywords of topics and number of reviews.

Topics		Keywords	No. of Reviews
Avatar		avatar, perception, presentation, disclosure, privacy, self-disclosure, anonymity	5298
Harassment		sex, sexy, sexual, sexually explicit, sexist, sexism, attack, harassment, bullying, abuse, abusive, discomfort, violent, ableism, racism, racist, black people, color people	2034
Different groups of people	Children & Teenagers	children, kid, youth, adolescence, adolescent, teenager, teens, pedophile	5988
	Couples	couple, husband, wife, girl friend, boy friend, e-couple	233
	Old adults	old adult, grandpa, grandma, grandfather, grandmother, granny	150
	LGBTQ	lesbian, gay, bisexual, transgender, queer, lgbtq	498
	Introvert	shy, introvert, introverted, anonymity, social phobia, social anxiety disorder, SAD, nervous	564
Motion sickness		sick, sickness, cybersickness, nausea, nauseous	265
COVID-19		covid, covid-19, pandemic	466

3.4.2 RQ2: What are the harassment behaviors in social VR?

Similar to traditional social media applications, harassment and other forms of abuse occur in social VR and received increasing attention from researchers. Shriram *et al.* [77] conducted an interview study about 15 participants' experiences and behaviors in the social VR application: VTime, and found that females reported more harassment than males. Blackwell *et al.* [13] interviewed 25 VR users about their experiences with harassment, abuse, and discomfort in social VR and found that the harassment in social VR fell into three categories: *verbal harassment, physical harassment, and environmental harassment.* Many participants felt that particular groups of individuals were more likely to be harassed in VR than others, such as women, children, color people, and persons with non-typical American accents.

Grounded in prior scholarships on harassment research in social VR, we conduct a study to explore what kind of harassment social VR users complain about more in reviews. We apply keywords to filter harassment-related reviews and get 2034 reviews. Among these reviews, the most common harassment is "sexual" (44.99%), the second is about "racism" (34.46%) and the others are about "abuse" (10.57%), "bullying" (7.82%), "attack"(6.24%), and "sexism"(2.36%).

Players frequently mentioned being sexually harassed by others in the reviews about "sexual". In addition, some users described the sexual content for kids and the sexual harassment from kids. Some example reviews are as follows:

> *"I was shocked to see people attacking me sexually. The game could be really fun if it wasn't for nasty people sexually abusing me"; "Got on to this game and there were some kids in the lobby who were just nasty in trying to do sexual things to my avatar."*

Racism is also the main problem on social VR platforms. Typically, racism is harassment to color people:

> *"Rec Room is full of little white supremacist kids and racism, homophobia is the main problems of this game"; "This is a racist app! whites only"; "There were several white people around us calling us "Niggers", so we both told them to stop being F**ing racist"; "too many racist players so there should be some more moderators."*

Bullying is another type of harassment, in general, bullying is bilateral between adults and children: *"The thing that bothers me is the bullying how so many people and I mean adults and kids, turn to bully."* In addition, as mentioned in [13], sexism also exists in social VR: *"There is ton of racial, sexist and rude behavior on the platform."* Some players complain about more than one kind of harassment: *"I have seen many accounts of sexual harassment, racism, and bullying, all in the same time playing the game I was even bullied."*

Harassment is a widespread problem in social media. Although social VR platforms follow the video game content rating system and require parental guidance, there are still many children. The social VR platforms could create different rooms to separate adults and children and add more moderators to avoid harassment between adults and children.

3.4.3 RQ3: What is the impact of social VR on different groups of people?

Social VR has attracted users of different groups, and in this subsection, we discuss the impact of social VR on groups of children, old adults, couples, LGBTQ, and introverts.

Children and Teenagers

In our study, we collect 5988 reviews about children (5208) and teenagers (780) of social VR applications. The majority of these reviews are from adults and almost are negative.

We cluster the topic of these reviews using model BERTopic. The most discussed topic in the 5988 reviews is the annoying behaviors of kids. Many mature users complained about annoying kids, such as *"Kids really made me hate the game because of how annoying they are and they are very toxic." "However, the game is pretty much unplayable because there are too many kids and frankly just hearing their voices is extremely annoying. And then if a kid sneaks in we could do a unanimous vote to remove them."* These quotes well explained the distress annoying kids bring to adult players, the co-existence of adults and minors on the same social VR platform leads to potential tensions. The minors often try to get attention from others by yelling or screaming, but this is disturbing for adults. In this situation, creating separate spaces or adding moderators could better cater to different age groups.

The second topic in these reviews is bullying: kids bullying and bullying kids. On the one hand, children or teenagers bully other players and get disgusted by them: *"Kids bullying and cursing and not letting anyone play!" "I was playing paintball then this random kid just starts bullying me for no reason."* One user gave advise to avoid kids bullying, *"I know lots of people complain about kids bullying so just mute all non-friends it's simple it's what I do."*

On the other hand, our findings also reveal that adults bully kids on social VR platforms compared to traditional media platforms. Some players even showed off in reviews and taught others to bully children: *"I like bullying children." "Is bullying these small children in Rec Room funny? yes!" "Play this if you like bullying children." "Incredibly boring if you do not like bullying kids."* Moreover, one parent commented that his child would commit suicide after being bullied: *"My child tried to commit suicide because of the bullying going on in [social VR platform]. It's a total hangout for bully's and aholes that have nothing better to do then spew hate towards others and especially children."* Some players warning to children and their parents: *"a lot of bullying, do not recommend for 13 or younger."*

In addition, the social VR platforms can potentially be a grooming platform for pedophiles as kids and adults seem to mix freely and there's no way to control what goes on. Some players have pointed out the phenomenon and expressed their concern: *"Too many little kids and pedophiles on the game it's actually quite concerning." "The game is literally filled with pedophiles that expose children to adult avatars."*

Couples

How VR technology supports Long Distance Relationships (LDRs) is also a topic worthy of study. Zamanifard *et al.* [103] used 650 social media posts and comments to explore the influence of social VR in LDRs. In our study, we filter out 233 user comments about LDRs from the social VR dataset. We find that the first hot topic is that players find their other half

through VR games. Some are couples only in social VR games, and others meet in person and even get married.

> *"I have met some of the best people on here and my current boyfriend"; "VRChat is an amazing game! I've made a lovely friend group on here and have also met my boyfriend on here! We recently met in person and I had an amazing time"; "I met my current wife on this game, thanks VRChat!"*

The second hot topic is that social VR platform offers opportunities for remote interaction between LDRs and boost relationships between couples:

> *"Since my girlfriend doesn't live near me, I mainly use VRChat to still spend time with her"; "Being in a long-distance relationship, its also where I can get close to my boyfriend and emulate close-to-real dates and hangouts"*.

Older Adults

In our study, we extract 150 user reviews about older adults using keywords in Table 3.2. Many older adults have reviewed that they had more opportunities to communicate with their children through the social VR platform. For example, the Real VR Fishing game provides a good opportunity for parent-child activities: *"I'm older and got this to play with my son"; "Fishing was something my dad I did a lot growing up, now that he's older this VR experience is a great way for my dad & I to spend time together"*. And for some older adults, the VR technology might be a little different to learn: *"Big learning curve for me as an older adult"*. Social VR has also become a way for older adults to make friends: *"I'm in the older crowd, and this game still changed my life! For the past 2 years, I've met people who have become cornerstones in my social circle"*.

However, in the VR game PokerStars VR, some younger players complained that they did not want to play with older and vice versa: *"At very least, the game should have an all age area and an adult area and possibly a 30+ area to make it easier for older people to find each other"*. That means it's better to create different rooms to separate users of different age groups.

And harassment is a common topic in different age groups, and some reviews report harassment from older adults:

> *"I entered and the first room I walked into some older guy was trying to groom some children"; "I have entered lobby's/instances where older men/women actively try to invite children to engage in sexual or other actions with them"*.

LGBTQ

In the past five years, social VR is becoming increasingly popular with the LGBTQ community, and some researchers have took notice to study how social VR supports LGBTQ users. Freeman *et al.* [27] studied the self-presentation in social VR by conducting an in-depth interview of 30 participants, including four trans-women participants. In [1], the authors recruited eight LGBTQ participants to explore the LGBTQ users' engagement in social VR and how social VR supports them.

In our study, we extract 498 reviews using the related keywords shown in Table 3.2 from our collected review dataset.

First, social VR has become a popular communication platform for the LGBTQ community, breaking geographical barriers, especially during the COVID-19 pandemic. One user praised that *"If you are part of LGBTQIA++, you will feel super supported and hardly any racists"*. In a sense, LGBTQ users can use social VR to find other LGBTQ users or supportive people, especially if their gender, sexual identity, and lifestyle are less or unsupported in their natural social world:

> *"It has an extremely large presence of LGBTQ+ individuals (including myself) and lends itself to being a space for people to freely express themselves exactly as they see fit, or in whichever way they feel most comfortable."*

However, the social VR platforms flood of LGBTQ users has also caused disgust among other players. They also complained about this phenomenon in their reviews:

> *"90 percent of people in VRChat are either a guy or transgender and also gay (somehow, VRChat turns everyone gay)"; "It was fun back in 2017, but now it is overrun by gay furries"*.

On the other hand, LGBTQ users are more concerned about privacy and rarely identify themselves in the reviews, only 117 users indicated they were LGBTQ among the 105757 reviews. Some users are careful to reveal their identities in the reviews, fearing that others will know he is gay: *"I'm pretty sure nobody ever reads these things, so I just want to say that I'm gay", "Nobody reads the reviews for sure, so I'll say I'm gay"*. A valuable finding is that some players stated that they only became LGBTQ after playing a specific social VR game like VRChat: *"After 600h, I've now become bisexual", "This game made me a Transgender", "I was a straight male then this game turned me into a gay furry"*. Therefore, some players issued a warning in the reviews: *"Do not play it, my son is gay now", "This game will turn you gay", "It has a tendency to make people gay if you play for 5+ hours"*.

LGBTQ-related harassment is also a topic of concern, which can be divided into two categories, one is LGBTQ harassment of other users:

> *"I have never felt more uncomfortable while playing a video game, the constant harassment from gay males who make it their goal to make you as uncomfortable as possible is disgusting"; "Just after 5 minutes of playtime, I was sexually harassed by gay men with anime avatars".*

and the other is harassment of LGBTQ users:

> *"bullying gay people very nice"; "it's fun to make fun of gays and furries"; "this game is really fun but if you are LGTBQ+ you get bullied a lot, I'm bisexual and transgender and I get harassed a lot....."*

Introverts

As Baker and colleagues [7] indicated in their research, social VR platforms support a level of anonymity that allows users to blend into group communities. This feature has a huge positive impact on shy and introverted users. We apply keywords bag, including "shy, introvert, introverted, anonymity, social phobia, social anxiety disorder, SAD, nervous", to extract related reviews from the collected review dataset for studying the social VR influences on anti-social people. Among the 564 reviews, 80% of users said that they were shy, introverted, or anti-social and were nervous to talk to strangers face-to-face in real society. Fortunately, social VR platforms gave them a chance to become more social and make new friends. These players were timid at the beginning, then gradually overcame their social anxiety, participated in virtual bars, clubs, and lounges, talked to others, hung out, danced, roleplayed, and became more and more outgoing:

> *"It's also helpful for people who really have serious anxiety because of the level of anonymity it provides." "This is one of my favorite games, it is awesome and can make an introvert an extrovert." "I love this game, if you are shy or introverted like me then this game will bring you out of your comfort zone and help you make friends and just enjoy yourself."*

However, some users were still shy and nervous about communicating with others, even when they were anonymous. Moreover, some users complained that social VR platforms are full of introverted players and that it was easy to meet unsavory characters who take advantage of their anonymity:

"If I wasn't so f∗∗king shy, It might be more fun for me." "Game is filled with anti-social introverted kids." "Please be careful! There's a lot of manipulative people who enjoy the anonymity of the internet." "The anonymity that VRchat gives can allow users to be mean and bully others without repercussions."

3.4.4 RQ4: What are the physical Effects of social VR platforms?

Motion sickness will influence user experiences in the VR environment, and a large body of VR research has investigated the phenomenon [48, 55, 19]. In our study, we extracted 265 (0.25%) reviews related to motion sickness issue using the keywords "sick, sickness, cybersickness" from the collected review dataset. The first author read through these reviews and classified them into three categories: *sickness, no sickness, warning*. Among the 265 reviews, 166 users indicated that they suffered motion sickness. The reasons include (1) the influence of locomotion methods: *"If I move my head around, it's instant motion sickness"*; (2) poor performance: like the participant (P10) in [69], some users complained about that *"low FPS in VR is very worse for VR sickness"*, *"considering that poor performance can lead to motion sickness, headaches, and other discomfort"*; (3) new VR user or at the beginning of a game: *"Can get pretty motion sickness inducing if you are new to VR", "For beginners this can make them motion sickness"*; (4) specific game: *"This is the only game that gives me motion sickness"*.

And 50 users cleared that they did not get motion sickness like others: *"For me, I got used to the movement quick so I didn't get motion sickness, but there is a good possibility that you might", "Didn't get motion sick like I expected"*. Moreover, 49 users expressed a warning for other users who may have motion sickness problems and gave some advice: *"WARNING!! Not a good game for someone with motion sickness", "If you suffer from anything like motion sickness, epilepsy or headaches, stay well away from this game"*.

3.4.5 RQ5: What are the benefits of social VR during the COVID-19 pandemic?

In the past two years, the coronavirus has raged worldwide, people were obliged to stay home, and public spaces (parks, gyms, etc.) were closed to combat the COVID-19 pandemic. Therefore, social VR platforms are popular among people during the COVID-19 pandemic. People can do sports with families, communicate with distant friends, play games, attend online concerts, company meetings, church activities, and so forth. Take the VRChat game on the Steam platform as an example, As Figure 3.1 shows that before the COVID-19 pandemic,

the number of players of VRChat per day was around 7000, after the outbreak of COVID-19, the number of players has continued to grow.

Previous research has investigated the benefits of using social VR platforms during the COVID-19 pandemic. Kelley analyzed 259 user reviews of VRChat on Steam to explore the uses and satisfactions of Social VR [41]. Barreda-Ángeles *et al.* [10] surveyed 220 participants to study the psychological benefits of using social VR platforms. In [69], the authors focused on the dance experience in social VR, and some of their participants emphasized that the VR club provided them with a safe space for socializing and physical activity during the COVID-19 pandemic.

In our study, we extract 466 user reviews containing the keywords (e.g., covid, pandemic) from the collected review dataset. We find that 90% of the reviews emphasized that social VR platforms freed them from restrictions imposed by COVID-19. And users could talk to friends and play games or sports together with friends in the immersive environment.

> *"Love it! I and my friend live far from each other and especially in these crazy COVID-19 times, this is a perfect way for us to hang out, catch up and catch some fish at the same time."*

Social VR platforms are also crucial for psychological building during the COVID-19 epidemic. Some users also mentioned that social VR platforms help them overcome loneliness and stay sane.

> *"Good to pass the time during the pandemic and take social distancing seriously while also helping my mental health and possibly killing it at the same time."*
> *"This game has allowed me to stay sane through this pandemic and has allowed me to make some amazing friends from around the world."*

3.5 Discussion

User experience is a significant aspect of social VR application design. To better understand user experience in social VR platforms, we set out to analyze user reviews. Our work directly addresses the limitations of previous interview-based research on user experience in Social VR. We can now offer deeper insights into the user experience in commercial Social VR applications.

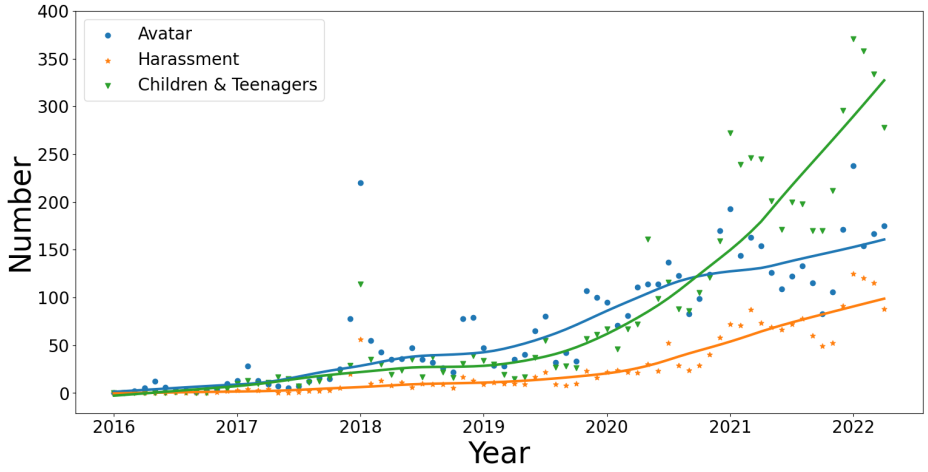


Fig. 3.4 Avatar, Harassment, Children & Teenagers

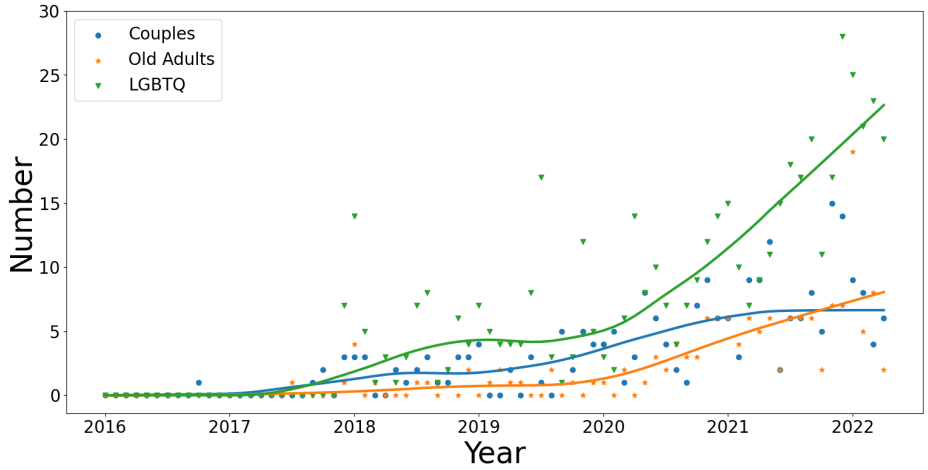


Fig. 3.5 Couples, Old Adults, LGBTQ

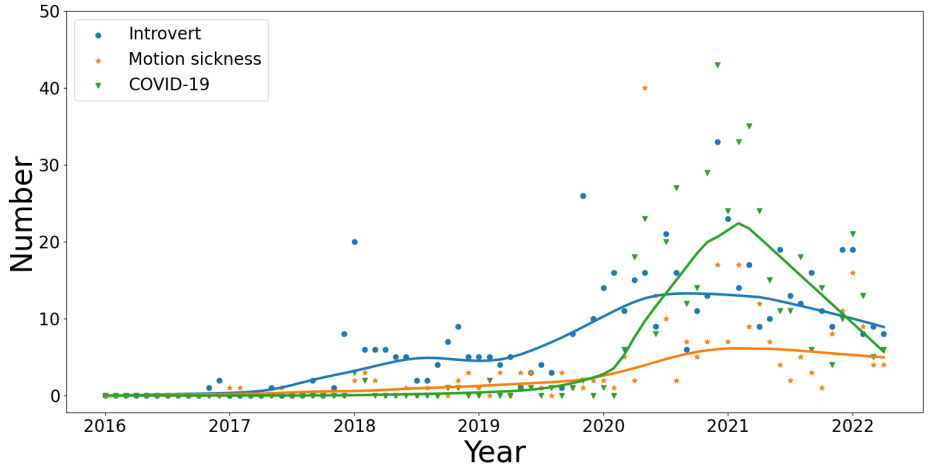


Fig. 3.6 Introvert, Motion Sickness, COVID-19

3.5.1 Key Insights

This paper aims to answer five research questions (RQ1 $\sim$ RQ5, see Section 3.1). For RQ1, we found that the users would like to create their avatars and want more avatar choices. Social VR platform developers should give players more choices of avatars or allow players to design their avatars. The compatibility of avatar models and NSFW avatars are two pain points that players complain about the most. NSFW avatars may have a negative impact on child players, social VR game developers should pay attention to this issue. Some social VR platforms support users to import an avatar model created by any other 3D software. but it sometimes brings compatibility issues. Moreover, the VR community should ban sexual suggestiveness avatars. In Figure 3.4, the solid blue line shows that the frequency of avatar-related reviews has increased from 2016 to 2022, which shows that users are very concerned about their avatar display in social VR applications. Social VR application developers should pay more attention to avatars.

For RQ2, sexual harassment and racism are two of the most widespread types of harassment behaviors on social VR platforms. Sexual harassment is a common form of harassment that exists in different groups. Although players can be shunted to different rooms, not all players abide by the game's rules. Players should have certain psychological expectations that others may harass them. And parents should guide their children well, virtual social networking is a double-edged sword for them. In Figure 3.4, the solid orange line shows that such reviews are increasing, especially after 2020, the rate of increase is faster. Social VR application developers should establish a complete user feedback mechanism and a harassment identification system and issue some punitive measures to prevent harassment among users, such as freezing accounts.

For RQ3, social VR platforms benefit these five different groups of people, but it is easy to influence and bullying between different groups of people. The best way is to divide different groups of people into different rooms or increase each room's number of moderators. In Figure 3.4, the solid green line shows the frequency of Children & Teenagers reviews increased slowly from 2016 to 2020. It increased sharply after 2020, indicating that more children and teenagers are pouring into social VR platforms. The reason may be that children are confined at home during covid-19 and flocking to social VR applications for entertainment. Figure 3.5 shows the trends in the number of reviews related to couples, old adults and LGBTQ. The monthly number of reviews related to these three groups is not very high. The number of reviews related to couples has stabilized since 2021, and that related to LGBTQ and old adults has increased significantly from 2020, indicating that 2020 is a watershed, possibly due to the impact of the COVID-19 epidemic, these two groups prefer online social VR activities. The solid blue line in Figure 3.6 shows that the number of

Introvert-related reviews increased from 2016 to mid-2020, after which began to decline. In RQ3, we found that although each group can find its circle in social VR applications, different groups often cannot live peacefully, such as bullying against children and discrimination against LGBTQ groups. How to avoid conflicts between different groups of users is also a problem that developers should consider.

For RQ4, we found that motion sickness is no longer a significant issue for VR players. The solid orange line in Figure 3.6 shows that the number of motion sickness-related reviews is less than ten between 2016 and 2022, and there is a downward trend from 2021. Motion sickness only exists in new VR players, and certain games can cause players to experience motion sickness. Although motion sickness is no longer a common phenomenon, developers should also pay attention to player feedback and solve problems timely.

For RQ5, social VR platforms provide the opportunity to interact with others in virtual worlds for lockdown people during the COVID-19 pandemic and help people overcome loneliness. In Figure 3.6, the solid green line shows the trends of players discussed COVID-19 in reviews. From 2020 to the beginning of 2021, there was an upward trend in COVID-19-related comments, and then, as the restrictions were lifted around the world and people did not have to isolate at home, the related comments trended downward.

3.5.2 Limitations and Future Work

We discuss some of our work's limitations in the paragraphs that follow. First, our study is based on user reviews. We cannot guarantee the authenticity of reviews. Fake reviews are a concerning problem. For example, in LGBTQ-related comments, many users claim to be gay or become gay because of playing social VR games. Some players may be following other players or joking, but we believe all reviews are genuine.

We have no way of knowing the gender of the player. In [77], the authors found that females reported more harassment than males. The gender information of the players was not included in the reviews we collected, which prevented us from delving into the gender differences in harassment.

This paper only focuses on English reviews, and in future research, we will focus on analyzing multilingual reviews to explore players' social VR experiences in different cultural backgrounds. Our collected dataset has 52.53% (105757 of 201326) English reviews. The languages that account for more of the remaining reviews are Simplified Chinese, French, Russian, and German. It's also meaningful to research user experience in these language regions.

3.6 Conclusion

Social VR has become an appealing online social space for people to interact, socialize, and connect in an immersive way. In this paper, we have engaged in a reviews-driven study of user experience on social VR platforms. Our findings show that players prefer avatar customization and would like to have more avatar choices. Social VR platforms provide a suitable place for some groups, such as LGBTQ, introverts, and the elderly, to communicate and interact. However, social VR platforms are also full of harassment. Sexual harassment and racial discrimination are the most common forms of harassment. In addition, developers also need to pay attention to bullying between children and adults. Furthermore, social VR also helps people overcome loneliness and remain connected with friends during the COVID-19 epidemic. We hope our findings contribute to a better understanding of the user experiences of different groups in social VR and guide developers to design more friendly and fulfilling experiences in social VR applications for users.

Chapter 4

CyberSickness in VR Games

4.1 Motivation

Consumer-grade VR Head-Mounted Displays (HMDs) are now broadly distributed on the public market (e.g., Oculus Quest 2, HTC VIVE Pro). Massive VR applications have been expanded to various fields, such as game, education, film, medicine, to name a few. VR applications can provide a 360-degree immersive experience using HMDs, smartphones or personal computers. Regarding the considerable potential of VR technology, academia and industry have a lot of exploration, accompanied by the popularity of the concept of Metaverse, VR applications will usher in explosive development in the future. Therefore, it is crucial to research human reactions within VR environments.

Duanmu *et al.* [20] researched the user navigation behaviors when viewing 360° videos on PCs, and Ban *et al.* [8] proposed a framework with cross-user behaviors to predict viewer's fixation. Some literature focused on researching the head movement when users watch 360-degree videos and released several head tracking datasets [47, 16, 29, 3, 14]. However, the user's head movement when playing VR games is completely different from watching VR videos, there are a variety of interaction contents in games. For instance, the user generally has some emergency reactions, such as being frightened or avoiding obstacles in the game scenes. These interactive contents will strongly affect the user's head movement and may lead to cybersickness. The aforementioned datasets are not suitable for exploring the relationship between head movement and VR games. In this paper, we present a novel head movement dataset collected while playing VR games, and in the meantime, we also collected the heart rate data while playing VR games. The comparison of the exiting datasets with ours is shown in Table 4.1, and the detail of the dataset will describe in Section "Experiment environment".

Table 4.1 The comparison of public head movement and eye tracking datasets with ours.

REF	Categories	Duration	No. of participants
[47]	10 VR videos	60 s	50
[16]	5 VR videos	70 s	59
[102]	18 VR videos	164 $\sim$ 655 s	48
[29]	20 VR videos	12 $\sim$ 377 s	48
[18]	19 VR videos	20 s	57
[3]	15 VR videos	38 $\sim$ 85 s	13
[14]	15 VR videos	10 $\sim$ 36 s	Not mentioned
Ours	5 VR games	180 $\sim$ 300 s	30

With the spreading of VR devices, there is still a significant issue: VR cybersickness. Cybersickness is a type of motion sickness caused by immersive Extended Reality (XR) environments, such as VR, augmented reality (AR), and Mixed Reality (MR) applications. The symptoms of cybersickness include: disorientation, headache, eye strain, sweating, vertigo, nausea, vomiting [44]. In recent years, many studies have focused on cybersickness caused by VR applications. Adhanom *et al.* [2] explored the effect of a foveated Field-of-View restrictor on VR sickness. Venkatakrishnan *et al.* [84] conducted a study based VR driving simulation to evaluate how the presence/absence of motion control influences the onset and severity of cybersickness. Wang *et al.* [90] developed two approaches based on fuzzy logic to integrate the knowledge of three individual differences (Age, Gaming experience, and Ethnicity). Then they explored the effect of individual factors on cybersickness.

Studying how players respond and navigate in VR games will benefit many applications, such as VR game design, VR devices development, medical studies. Martin *et al.* [54] proposed a Machine Learning algorithm to detect cybersickness in VR games using physiological signals. In [75, 76], the authors explored how to reduce cybersickness in VR first-person shooter (FPS) game and racing game, respectively. In this paper, we recruited 30 volunteers to play five different VR games with HMD and collected their head movement and heart rate data, then we made a comprehensive analysis of this dataset to explore the causes of cybersickness when playing VR games. Our contributions are concluded as follows:

- Firstly, unlike other head movement datasets mainly constructed by watching 360-degree videos, our dataset focuses on collecting head movement data and heart rate data while playing VR games. To our best knowledge, this is the first available head movement trajectory dataset based on playing different VR games.

- Secondly, every participant filled the Simulator Sickness Questionnaire after playing each VR game, we collected the SSQ data and then did a deep analysis about the head

movement trajectory to explore the influence of head movement on cybersickness. We also studied the relationship between players' heart rate and VR cybersickness.

- Thirdly, we compared and analyzed the head movement trajectory with those published prior datasets, in which participants watched 360° videos, to explore how the head movement trajectory differed between viewing VR videos and playing VR games.

4.2 Related Work

Recently, some researchers have released several public head movement datasets while viewing VR videos. Lo *et al.* [47] presented a 360° video watching dataset, they collected the head positions and orientation of 50 viewers watching 10 different VR videos, the viewing duration is 1 minute. In [16], the authors collected a head movement dataset including 59 users' data of watching five 70s-long 360° videos. Wu *et al.* [102] presented a dataset consisting of 48 users' head movement data of watching 18 sphere videos from five categories with a HTC Vive headset. Fremerey *et al.* [29] introduced an open dataset recording 48 users' head movement watching 20 different entertaining 360° videos using an HTC Vive HMD. Chakareski *et al.* [14] proposed a dataset of 121 head navigation viewing full HD 360° videos. In addition to head movement data, eye movement data is also crucial for analyzing user behavior. In [18], the authors collected a new head and eye tracking dataset of 57 observers watching 19 omnidirectional videos. Agtzidis *et al.* [3] collected an eye movement dataset of thirteen observers viewing 15 naturalistic VR videos, however, the duration of each video is less than 120 seconds, which is not a representative sample for analyzing VR sickness as cybersickness usually grows over time.

Cybersickness in VR games has attracted much attention in recent years. In [54], the authors collected physiological signals (electrodermal and cardiac activities) of 103 players playing VR games and proposed a Machine Learning approach to predict and classifier cybersickness. Seok *et al.* [75] introduced using the visual guide (e.g., crosshairs) in VR FPS games to reduce VR sickness. Shi *et al.* [76] compared different VR sickness mitigation methods, including Field of View (FoV) reduction, Depth of Field (DoF) blurring using VR racing games as a case study.

The traditional measurement of cybersickness is SSQ [42], and SSQ has 16 items to assess the physiological influences of cybersickness, each item can have a score between 0 and 3 (0: Not at all; 1: Slight; 2: Moderate; 3: Severe) and the 16 items are divided into three categories: Nausea (N), Oculomotor (O), Disorientation (D). Thus, we can get four SSQ scores: Nausea score (SSQ-N), Oculomotor score (SSQ-O), Disorientation score (SSQ-D),

Table 4.2 The items comparison of SSQ and VRSQ, and the score calculation formulas.

(a) The comparison between 16 items of SSQ and 9 items of VRSQ.

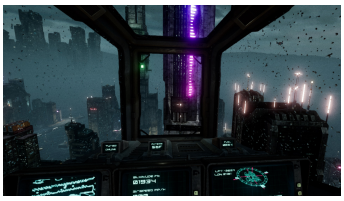
	SSQ			**VRSQ**	
Items	N	O	D	O	D
1. General discomfort	✔	✔		✔	
2. Fatigue		✔		✔	
3. Headache		✔			✔
4. Eyestrain		✔		✔	
5. Difficulty focusing		✔	✔	✔	
6. Increased salivation	✔				
7. Sweating	✔				
8. Nausea	✔				
9. Difficulty concentrating	✔	✔			
10. Fullness of head			✔		✔
11. Blurred vision		✔	✔		✔
12. Dizzy (eyes open)			✔		
13. Dizzy (eyes closed)			✔		✔
14. Vertigo			✔		✔
15. Stomach awareness	✔				
16. Burping	✔				
Total	[1]	[2]	[3]	[4]	[5]

(b) The calculation formulas of SSQ Nausea score, Oculomotor score, Disorientation score, and total score.

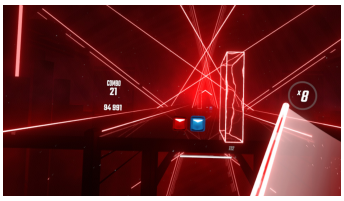
SSQ
SSQ-N = [1] * 9.54
SSQ-O = [2] * 7.58
SSQ-D = [3] * 13.92
SSQ-T = ([1] + [2] + [3]) * 3.74

(c) The calculation formulas of VRSQ Oculomotor score, Disorientation score, and total score.

VRSQ
VRSQ-O = [4] / 12 * 100
VRSQ-D = [5] / 15 * 100
VRSQ-T = (VRSQ-O + VRSQ-D) / 2



(a) Aircar



(b) Beat Saber

(c) Moss

(d) Arizona Sunshine

(e) SUPERHOT

Fig. 4.1 The screenshots of the five VR games.

and total score (SSQ-T). However, the VR system is significantly different from simulators, SSQ scores may not be suitable enough to judge VR sickness, some researches attempted to improve SSQ. Kim *et al.* [43] presented VRSQ, the authors deleted 7 items from SSQ 16 items, and divided the rest 9 items into two categories: Oculomotor (O), Disorientation (D). Therefore, there are three VRSQ scores: Oculomotor score (VRSQ-O), Disorientation score (VRSQ-D) and total score (VRSQ-T). The authors organized experiments to verify the VRSQ, and the results indicated a strong association between SSQ and VRSQ. Pérez *et al.* [67] proposed a single-question method named Vertigo Scale to measure simulator sickness using question "Are you feeling any sickness or discomfort now?" and using a five-grade scale (Unbearable, Unpleasant, Uncomfortable, Light effects, No problem). Table 4.2a presents the items of SSQ and VRSQ, Table 4.2b and Table 4.2c present the calculation formulas of SSQ score and VRSQ score, respectively. In our experiment, the participants were asked to complete an SSQ questionnaire after playing each VR game, and we calculated both SSQ and VRSQ scores to analyze the relationship between head movement and VR sickness.

4.3 Experiment Environment

4.3.1 VR games

In our experiment, we tested five different VR games in four categories, which are exploration game (Aircar), music rhythm game (Beat Saber), First-person shooter game (Arizona

Sunshine, SUPERHOT), and an adventure game (Moss). Figure 4.1 shows the screenshots of the five VR games. The details of these games are as follows:

Aircar[1]**:** is a simple immersive flying and exploration game built for VR, The player pilot an aircar through a futuristic cyberpunk cityscape, doing vertical nosedive, spinning, turning around.

Beat Saber[2]**:** is a VR rhythm game developed and released by Beat Games. The game simulates a surrealistic neon light environment. Players use two sabers of corresponding colors to cut two different blocks representing the music beat. The game includes multiple songs, and the difficulty is up to five levels, from easy to expert+. In our experiment, all participants played normal levels.

Moss[3]**:** is a VR adventure game with a primary focus on solving puzzles, the game is presented from a blend of first-person and third-person perspectives.

Arizona Sunshine[4]**:** is a zombie survival FPS VR game. The player uses the joystick on the handle to walk long distances in the game. The player can hold one gun or both guns to shoot the zombies. Players need to collect bullets from abandoned vehicles or houses.

SUPERHOT[5]**:** is an FPS VR game where players eliminate hostile attackers who try to kill them in a simple environment. The most significant innovation of this game is that the time will only proceed normally when the player moves or shoots, otherwise the time will slow down.

4.3.2 Apparatus

We used an Oculus Quest 2 HMD for participants to play VR games. The HMD could be connected to a laptop with a three meters Oculus Link cable or wireless connection method using Air Link technology. Because the head movement data can only be collected by the OpenTrack software if the Oculus Quest 2 HMD is connected to the computer with a cable, the same configuration (HMD and laptop were connected with a cable) was used for every participant in our whole experiment. The laptop used in our experiment is Alienware M15 R2 with an Intel i9 processor and NVIDIA GTX 2080 GPU.

The open source head tracking tool OpenTrack[6] was applied in our experiment for recording the participants' head orientations, including yaw, pitch, and roll in the range of [-180, 180]. The software collects data at 250Hz and saves data as CSV files. In addition, we

[1]https://store.steampowered.com/app/1073390/Aircar/
[2]https://store.steampowered.com/app/620980/Beat_Saber/
[3]https://store.steampowered.com/app/846470/Moss/
[4]https://store.steampowered.com/app/342180/Arizona_Sunshine/
[5]https://store.steampowered.com/app/617830/SUPERHOT_VR/
[6]https://github.com/opentrack/opentrack

also collected the participants' heart rate data using a smart watch Misfit Vapor X, which has a heart rate sensor. The participants wore the smart watch on the left wrist when playing the five VR games. We developed Android Wear program to read the participants' heart rate data every second and saved in CSV files.

4.3.3 Participants

In our experiment, there were 30 participants (12 females and 18 males) with an average age of 25 (sd = 1.8) years old, they were all from our lab. We prepared the Oculus Quest 2 myopia lens for whom is shortsighted so that they have no visual difficulties playing VR games. Among of all the participants, 35% have experience of playing VR games or watching VR videos, and the rest have no VR experience at all. The participants were asked to stand up throughout the test, and if they were very dizzy or nauseous, they could choose to sit on a rotating chair. During our experiment, no participant sat on the chair, all the data was collected while the participants playing the five VR games in a standing position.

4.3.4 Data collection

First, the participants filled in their personal information (gender, age) and whether they have VR game or video experience. The experiment is anonymous. Second, we organized a short training and told participants how to operate Oculus Quest 2 HMD and handles, and the regulations of playing the five VR games. Then, the participants watched some 360-degree scenes shown by the software DreamPark. Thirdly, after the VR training and adaptation session, the participants played the five VR games in turn. Our experiment is a randomized partial counterbalanced design. The VR game playing order for each participant is different. Every participant played each VR game for $3 \sim 5$ minutes. If the participants felt uncomfortable, they could quit the game at any time. Finally, the participant filled out the questionnaire immediately after playing one VR game and then rested ten minutes before playing the next VR game. We opened OpenTrack software to record the head movement while participants played VR games. The log file contains 4 fields: timestamp, raw yaw, raw pitch, and raw roll. The heart rate data was collected by smart watch and the heart rate log file contains one field: bpm (beats per minute).

4.4 Data Analysis and Discussion

In this section, we comprehensively analyze the collected head movement dataset and discuss the impact of VR games on the cybersickness.

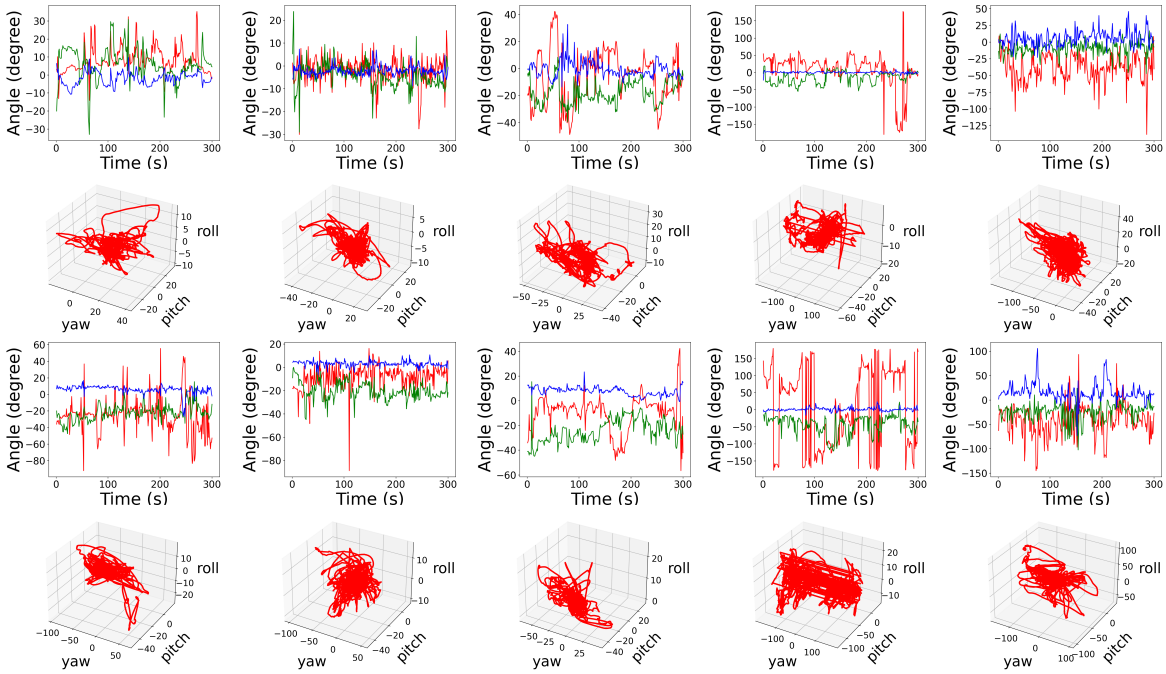


Fig. 4.2 Two typical players' view angle variation (Yaw: red; Pitch: green; Roll: blue) and head movement trajectory (unit: degree) in five different VR games (from left to right: Aircar, Beat Saber, Moss, Arizona Sunshine, SUPERHOT). The upper two rows: player No. 08, the lower two rows: player No. 19.

The players have three Degrees of Freedom (DoFs) for view orientation when playing VR games, namely, yaw, pitch, and roll. The roll angle represents the direction of rotation of the head, while the yaw and pitch angles describe its horizontal and vertical orientations. In general, the players can rotate 360° in the horizontal direction and 180° in the vertical direction. In Figure 4.2, we illustrate two typical players' view angle variation range in five different VR games. It is observed that the roll value is pretty stable $(-10° \sim 20°)$ in the four former games, which manifests that players do not make significant viewport changes in the roll orientation. This is because the first four games do not require the player to move their head vigorously but only need to look ahead. In the last game (SUPERHOT), the players need to have tremendous movement to avoid the attacks of enemies or pick up (guns, bottles, etc.) to counterattack enemies, so the roll rotation is more than the four former games. In the second game (Beat Saber), the players sometimes need to move slightly to left and right or squat down to avoid obstacles in the form of oncoming walls. The fourth column images (game: Arizona Sunshine) present the pitch fluctuation in $0° \sim -90°$. That's because the player needs to put the handle on his waist when changing the clip, the player habitually bows his head when changing the clip, and the player also habitually bows his head when searching for loot in the game. And in the horizontal direction, the curves of variation is between $-150°$

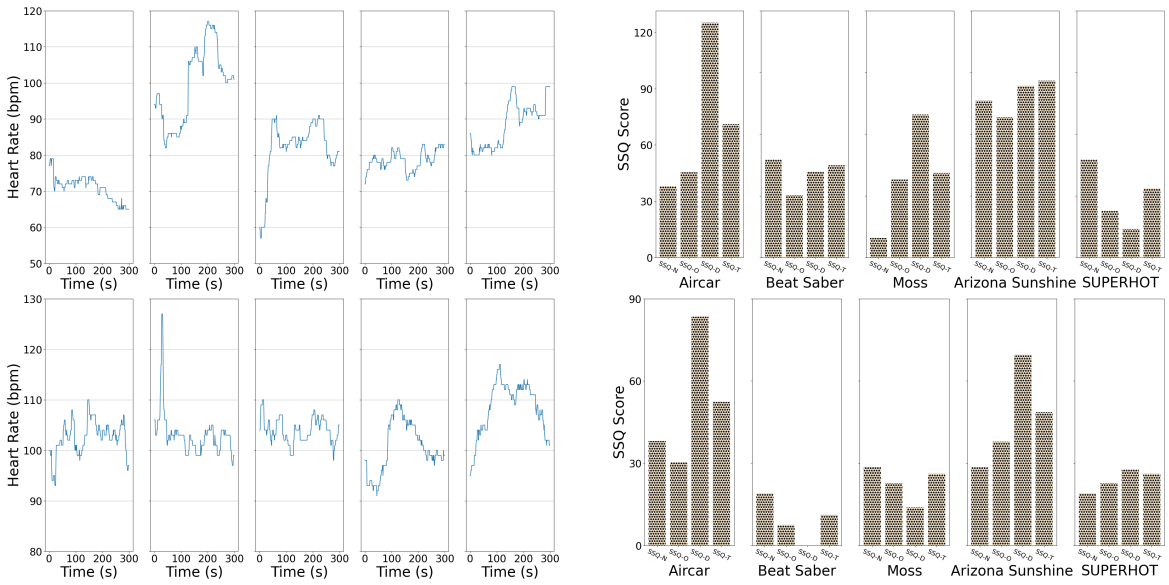


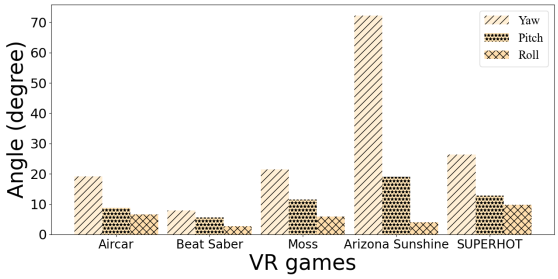
Fig. 4.3 Two typical players' heart rates and their SSQ scores of Nausea, Oculomotor and Disorientation domains in the five different VR games (from left to right: Aircar, Beat Saber, Moss, Arizona Sunshine, SUPERHOT). The upper row: player No. 08, the lower row: player No. 19.

and 150°, which means players constantly move back and forth in the horizontal direction. The high fluctuations in the view direction (especially in the horizontal orientation) are more likely to cause players nausea and disorientation.

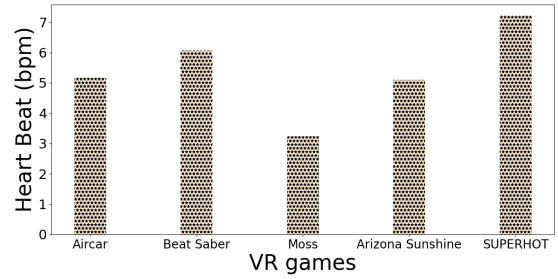
The second and fourth rows of Figure 4.2 show the head movement trajectories of the two typical subjects. We can observe that their head trajectories are primarily concentrated in a particular range. Taking the game Moss as an instance, the pitch direction is in range $(-30°, 20°)$ and the yaw direction is in range $(-60°, 40°)$, the roll direction is in range $(-10°, 30°)$. Moreover, the three movement directions of the game SUPERHOT are broader than those of the other four games due to the intensity of the game.

As Figure 4.3 shows, we also recorded the heart rate of players when they play VR games. In Aircar, Moss, and Arizona Sunshine games, the subjects have lower bpm because of little exercise during these games, and in Bear Saber and SUPERHOT games, the subjects have higher bpm because of intense movement. Judging from the SSQ reports reported by the players in the second and fourth rows, there is no obvious relationship between the SSQ scores and the heart rate, and the player's heart rate is mainly affected by exercise intensity. And compared the two typical players' SSQ scores, they all have the most significant symptoms in the Disorientation domain.

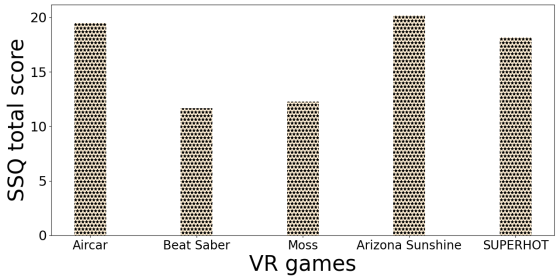
In Figure 4.4, we analyzed the standard deviation of users' yaw, pitch, roll angles, heart rate, and SSQ total score in each VR game. As the Figure 4.4a shows, on the one hand,



(a) The standard deviation of players' view angle in three directions: yaw, pitch and roll.

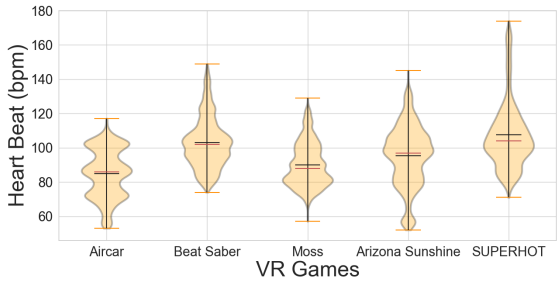


(b) The standard deviation of players' heart rate.

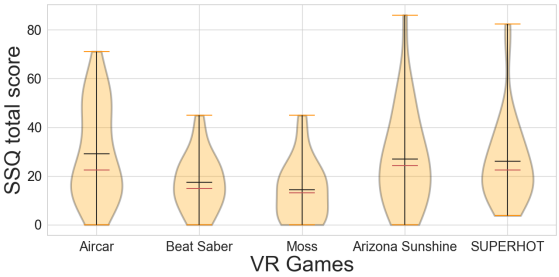


(c) The standard deviation of SSQ total score of five VR games.

Fig. 4.4 The standard deviation of players' view angle, heart rate, and the SSQ total score of five VR games.



(a) The full distribution of 30 participants' heart rate.



(b) The full distribution of 30 participants' SSQ total score of five VR games.

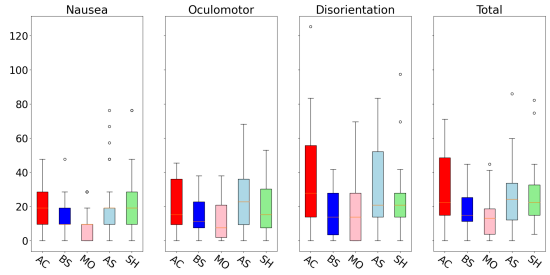
Fig. 4.5 The full distribution of 30 participants' heart rate and SSQ total score of five VR games.

the fluctuation in the yaw direction is the most severe in all tested VR games, followed by the pitch direction, and the roll direction is the smallest. It indicates the players have the most different movement in the horizontal, and they have nearly stable fluctuation in the roll direction. On the other hand, comparing the five games with each other, the three directions fluctuation of Arizona Sunshine are more severe than the other four games. Arizona Sunshine is a zombie survival FPS game, the player has the highest degree of freedom for when to start to move, the direction of movement, and other operations. On the contrary, in the Beat Saber game, the players stand in a position, swing the handles to chop the oncoming block, only sometimes squat down or move left and right to avoid obstacles, and the moving distance is not too far. Compared with Arizona Sunshine, the player's degree of freedom is very low. The order of appearance of the blocks and obstacles in each song is fixed, so the player's operations are roughly the same. The standard deviation of heart rate is shown in Figure 4.4b, among these five VR games, SUPERHOT is a very intense game, the player needs to do a lot of exercises. For people who do not exercise regularly or who are obese, the amount of exercise in this game is large. On the contrary, the exercise intensity is not bad for people who do regular physical exercise. From Figure 4.3, we can also notice that the player's heart rate is around 110 bpm when play SUPERHOT. This situation also exists in game Beat Saber.

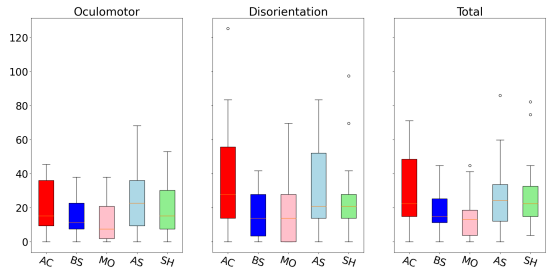
And game Aircar simulates driving a plane through a cyberpunk city. For players without VR experience, some people will feel weightless when aircraft diving steeply or dizziness will occur when the fuselage is overturned, which will cause players to become nervous and increase their heart rate. Nevertheless, this will not happen for experienced players, so the standard deviation of heart rate in this game is also high. Moss is a puzzle and exploration game, and players manipulate a tiny mouse to decrypt various levels, they are like watching a 3D movie. There is almost no exercise, so the standard deviation of heart rate in this game is the smallest. Figure 4.4c shows the standard deviation of SSQ total score of five VR games. This value of Arizona Sunshine and SUPERHOT is top two and the value of Beat Saber is the smallest. This result is similar to Figure 4.4a and that means the cybersickness is more related to head movement.

Figure 4.5 shows the full distribution of 30 participants' heart rate and SSQ total score of five VR games. As the Figure 4.5a shows, most participants' heart rate is in 80 bpm to 120 bpm, however some participants' heart rate exceeded 140 bpm When they play the Beat Saber, Arizona Sunshine, SUPERHOT games. When players play Aircar, the heart rate is the calmest, but according to Figure 4.5b, the SSQ total score of game Aircar is bigger than game Beat Saber, Moss. It seems that driving an aircraft in a VR game is more likely to cause cybersickness to the player. Participants also have relatively high SSQ total scores in the Arizona Sunshine and SUPERHOT games. In these two games, players turn their heads and exercise frequently, which leads to an increase in the player's heart rate and is more likely to cause cybersickness.

The SSQ and VRSQ scores of each VR game are illustrated in Figure 4.6. At first, we analyze each game. In game Aircar and Moss, the subjects have the greatest symptoms in the Disorientation domain and suffer less in the Oculomotor domain. In game Beat Saber and Arizona Sunshine, the situation is just the opposite, the players suffer most from symptoms in the Oculomotor domain and less in the Disorientation domain. In game SUPERHOT, the participates suffer most from symptoms in the Nausea domain and less in the Oculomotor domain. Then, the Total score subfigure indicates that the players suffer the most sickness symptoms in the game Aircar and Arizona Sunshine, and fewer sickness symptoms in the game Beat Saber and Moss. From the Figure 4.6a and Figure 4.6b, we could see that VRSQ scores have a high correlation with SSQ scores. We also calculate the Pearson correlation coefficients of Oculomotor, Disorientation, Total score between the SSQ and VRSQ. The correlation coefficients are 0.906, 0.869, 0.935, respectively. These results mean that VRSQ could replace SSQ in the research of VR motion sickness domain. And VRSQ has fewer questionnaire items which will improve the efficiency of VR sickness research.



(a) SSQ scores for each dimension of the five VR games.



(b) VRSQ scores for each dimension of the five VR games.

Fig. 4.6 The comparison of SSQ and VRSQ scores for each dimension among the five VR games (AC: Aircar; BS: Beat Saber; MO: Moss; AS: Arizona Sunshine; SH: SUPERHOT).

Then, we compared our dataset with one published prior dataset [47] , in which participants watch 360-degree videos. In their dataset, the subjects tended to move in the horizontal direction while watching VR videos, however, players tended to move in different directions in each game in our dataset. And in their dataset, the standard deviation of yaw and pitch direction are in range (30°, 85°) and (8°, 30°), respectively, which are (12°, 72°) and (7°, 20°) in our dataset.

4.5 Conclusion

In this paper, we collect a head movement and heart rate dataset of 30 participants while playing five different VR games (Aircar, Beat Saber, Moss, Arizona Sunshine, and SUPERHOT). And after playing VR games, the SSQ questionnaires were filled by the participants. We analyzed the relationship between head movement, heart rate and VR sickness. Vigorous head movements are more likely to cause VR sickness in players, and the degree of the player's head movement is more dependent on the game content. VR sickness is less affected by player's heart rate, and the player's heart rate is more affected by their own health status. Our dataset is public[7] and could be used in a variety of research fields: VR games design, medical research, VR hardware development. In the future, we will collect eye tracking data and physiological data to broaden our dataset and continue to research the VR player behaviors.

[7]https://doi.org/10.5281/zenodo.6371281

Chapter 5

Conclusions and Future Directions

This chapter summarizes the primary findings of this dissertation and outlines future research prospects. The goal is to offer valuable insights to researchers working in the field of UX in VR games. The dissertation is organized into four distinct sections.

In the first Chapter, I briefly introduce the history of VR games from 1980s and the three research problems about UX in VR games.

In Chapter 2, I conducted an empirical study to analyze VR game tendencies and players' concerns using 1362 VR games data from the Steam platform. I explored the VR game tendencies grounded in the analysis of release frequency, price, genre, support language, play areas, input devices, HMDs, and game developers. We also clustered the top five praise and complaint topics of each language from reviews in three different languages (English, Simplified Chinese, and French). The most important findings of this study are: 1) English is the first language supported by VR games, and developers should add support for other languages, especially Simplified Chinese. 2) The majority of recently released VR games have support for multiple categories of HMDs and play areas. However, for input devices, almost all VR games support tracked motion controllers, and the support rate for gamepad, keyboard & mouse is almost zero. 3) The music, game experience, and gameplay are the three aspects that players praise most. 4) In the meantime, the game bugs, not enough content, and overprice are the three areas that players complain about most.

In Chapter 3, I have engaged in a reviews-driven study of user experience of different groups on social VR platforms. Our findings show that players prefer avatar customization and would like to have more avatar choices. Social VR platforms provide a suitable place for some groups, such as LGBTQ, introverts, and the elderly, to communicate and interact. However, social VR platforms are also full of harassment. Sexual harassment and racial discrimination are the most common forms of harassment. In addition, developers also need to pay attention to bullying between children and adults. Furthermore, social VR also

helps people overcome loneliness and remain connected with friends during the COVID-19 epidemic. I hope these findings contribute to a better understanding of the user experiences of different groups in social VR and guide developers to design more friendly and fulfilling experiences in social VR applications for users.

In Chapter 4, I studied the cybersickness in VR games. I collected a head movement and heart rate dataset of 30 participants while playing five different VR games (Aircar, Beat Saber, Moss, Arizona Sunshine, and SUPERHOT). And after playing VR games, the SSQ questionnaires were filled by the participants. I analyzed the relationship between head movement, heart rate and VR sickness. Vigorous head movements are more likely to cause VR sickness in players, and the degree of the player's head movement is more dependent on the game content. VR sickness is less affected by player's heart rate, and the player's heart rate is more affected by their own health status. Our dataset is public and could be used in a variety of research fields: VR games design, medical research, VR hardware development.

In the future, I would like to extend my work vertically and horizontally. First, I will collect more VR game data from other VR game digital distribution platforms, such as Oculus and VIVEPORT. Second, apart from clustering complaints from negative reviews, I will also study the complaints in positive reviews and the positive factors about VR games in negative reviews. I will also collect eye tracking data and physiological data to broaden our dataset and continue to research the VR player behaviors.

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