

Dissecting User Experience of Social Virtual Reality: A Tale of Five Platforms

RUIZHI CHENG, George Mason University, USA

JIE LI, MIT Media Lab, USA

SONGQING CHEN, George Mason University, USA

BO HAN, George Mason University, USA

Social virtual reality (VR) has the potential to replace conventional online social media by offering quasi-real-world social experiences. As such, it has been extensively examined by the research community. However, existing studies fall short of providing a comprehensive understanding of how different aspects of social VR platforms interact to affect user experience. Motivated by this limitation, we conduct a user study with Oculus Quest 2 headsets and dissect the user experience on five social VR platforms. We evenly and randomly divide 42 participants into short-term (spending 10–30 minutes/platform) and long-term (spending at least 120 minutes/platform) groups. Besides employing surveys and interviews, we measure the frame rate and resolution of these platforms and explore how various factors interplay to influence the user experience of social VR. Our findings reveal that the frame rate, resolution, and interactive events of social VR platforms have a more significant impact on the experience of long-term users compared to short-term users. The scalability limitations of these platforms, as evidenced by decreased frame rates with the increasing number of concurrent users, result in an increased prevalence of motion sickness among long-term users, negatively impacting their overall experience. Moreover, the absence of highly interactive events also deteriorates their overall experience, and the low resolution combined with the lack of interactive events further decreases their sense of social presence. Additionally, our study demonstrates several common limitations negatively affecting the experience of both long-term and short-term users. For example, the harassment prevention mechanisms on all five platforms are inadequate, and being harassed has a detrimental effect on users' overall experience and sense of social presence. The avatar embodiment of investigated platforms has limited contribution to users' sense of social presence, mainly due to the lack of realism and full-body tracking. Our findings call for more research in scalability support, motion sickness relief, interactive event design, harassment prevention, and avatar development for improving social VR platforms in the future.

CCS Concepts: • **Human-centered computing** → **Virtual reality**; **Empirical studies in collaborative and social computing**.

Additional Key Words and Phrases: Social Virtual Reality, User Experience, Qualitative Analysis, Quantitative Comparison, Online Social Interaction

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Authors' Contact Information: [Ruizhi Cheng](mailto:rcheng4@gmu.edu), rcheng4@gmu.edu, George Mason University, Fairfax, Virginia, USA; [Jie Li](mailto:jieli@mit.edu), jieli@mit.edu, MIT Media Lab, Cambridge, Massachusetts, USA; [Songqing Chen](mailto:sqchen@gmu.edu), sqchen@gmu.edu, George Mason University, Fairfax, Virginia, USA; [Bo Han](mailto:bohan@gmu.edu), bohan@gmu.edu, George Mason University, Fairfax, Virginia, USA.



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1 Introduction

Social virtual reality (VR) is an emerging online social media that employs VR technologies to provide geo-distributed users with an immersive experience via their avatar embodiment in a shared virtual environment [45, 50]. In recent years, there has been an upsurge in user engagement with social VR applications for daily social needs due to their ability to simulate in-person experience [60, 62, 67, 76], especially during the COVID-19 pandemic [61]. Thus, social VR has been deemed an important building block of the burgeoning Metaverse [16, 80]. With its growing popularity, both VR and HCI (human-computer interaction) communities have extensively studied various aspects of social VR, including avatar embodiments [29, 30, 32, 38, 50, 53], interpersonal relationships [27, 62, 102, 108], harassment [8, 26, 31, 101], self-disclosure [58, 107], *etc.* However, existing work [11, 45, 50, 68, 109] has yet to provide a comprehensive comparison of commercial social VR platforms, especially in terms of how the system performance of these platforms, such as frame rate and resolution, affects user experience. A recent study [59] starts to explore this direction and focuses primarily on platform usability, lacking an investigation of how different features of social VR platforms interact to impact the experience of users.

Understanding and comparing user experiences across multiple platforms is crucial for identifying common strengths and weaknesses, thereby pinpointing the key factors that drive user satisfaction and retention. Each platform offers unique features, and the way these features interact with system performance can significantly impact the overall user experience. For instance, some platforms may deliver superior technical performance (*e.g.*, higher frame rates), but their social interaction features may be less developed. Conversely, platforms with strong social features may face technical limitations, such as lag or frame drops, which can hinder immersion and reduce user engagement. By comparing user experiences across platforms, we can determine which features are most effective at promoting positive user engagement and immersion. Additionally, this comparison allows us to evaluate whether certain technical or social factors are universally important or vary depending on the platform's design and intended use case.

In light of these motivations, we conduct an extensive user study with 42 participants using Oculus Quest 2 headsets to understand and compare their experience on five widely used social VR platforms at the time of our study: Horizon Worlds (Worlds for short) [72], AltspaceVR [74], VRChat [120], Rec Room [89], and Mozilla Hubs (Hubs for short) [77]. We randomly and evenly divide participants into two groups, long-term (at least 120 minutes of usage per platform) and short-term (10–30 minutes of usage per platform) to explore the impact of usage time on user experience. The rationale and method for this setup are detailed in §3.2. Instead of using a controlled lab environment, our study was conducted remotely with an open format. This design choice was driven by two considerations: 1) The free-interaction nature of social VR poses a challenge in defining consistent tasks for all participants. Thus, an open-form user study with reduced experimental control is more suitable than an in-lab study [97]; 2) The long experience time required for long-term users (exceeding 600 minutes for all five platforms) makes it difficult to schedule in-lab sessions for participants.

We design an exploratory study to examine how different aspects of these platforms, such as system performance (*e.g.*, frame rate and resolution), interactive events, avatar embodiment, and harassment, impact the user experience, including overall experience and presence (comprising personal presence and social presence, as defined in §3.3). We choose to separately evaluate the overall experience and presence due to the following considerations. The overall experience is a broad measure that encompasses user satisfaction, comfort, and enjoyment across different platforms. Presence, on the other hand, is a unique feature of social VR, offering users the feeling of being physically immersed in a virtual environment. Therefore, studying presence alongside

overall experience allows us to capture a more comprehensive view of how well these platforms deliver immersive and engaging social interactions.

Moreover, considering both technical (*e.g.*, frame rate and resolution) and social (*e.g.*, interactive events, avatar embodiment, and harassment) factors is critical to understanding the holistic user experience in social VR. Technical factors directly impact users' ability to interact smoothly within the virtual world, while social factors shape the quality of social interactions. For example, technical issues such as frame rate drops can degrade the user experience by disrupting communication and interactions. Conversely, poor social features (*e.g.*, insufficient harassment prevention) can also detract from the user experience, even if the platform performs well technically. By examining these factors together, we can better understand how they collectively contribute to both overall experience and presence, offering a more integrated and nuanced view of what makes a social VR platform successful.

Based on these considerations, our study aims to answer the following two research questions (RQ1 and RQ2).

- **RQ1:** What common and unique factors affect the overall experience of long-term and short-term users on social VR platforms?
- **RQ2:** What common and unique factors affect the sense of personal presence and social presence of long-term and short-term users on social VR platforms?

To thoroughly and accurately answer the above research questions, we present a novel method that integrates quantitative comparisons, qualitative analysis, and system performance measurements. During the experiments, we collect user ratings on various factors and experiences, along with conducting in-depth user interviews. We begin the data analysis by performing significance tests to identify key factors influencing overall experience and presence for both long-term and short-term users. We then use qualitative insights from the interviews to explain and contextualize the statistical results. To further support these findings, we apply factor analysis on the user ratings to identify the dominant factors affecting user experience, thereby corroborating the qualitative feedback. Finally, we validate and reinforce these insights through system performance measurements, particularly when users report technical issues as a major factor influencing their experience. This multi-faceted approach, detailed in §3, provides a robust and well-rounded understanding of user experience by integrating user feedback, statistical analysis, and system performance data.

Based on this comprehensive analysis, we have the following main findings.

- System performance is a crucial factor that affects both long-term and short-term users' overall experience. Our study reveals the increased likelihood of users experiencing motion sickness on VRChat, Hubs, and Rec Room owing to their low frame rate, which results in low ratings of overall experience (§4.1). Moreover, motion sickness exerts a detrimental effect on users' sense of personal and social presence (§5). Our measurement results further corroborate user perceptions of low frame rate (*e.g.*, <50 FPS on these platforms with >15 concurrent users, a potential scalability issue).
- Poor system performance, such as a low frame rate, leads to an increased incidence of motion sickness among long-term users and ultimately results in a poorer overall experience than that of short-term users, as observed on VRChat and Hubs (§4.1). Also, the absence of highly interactive events on AltspaceVR makes long-term users feel fatigued, negatively impacting their overall experience (§4.2). Moreover, the lack of highly interactive events combined with the low frame rate and resolution of Hubs further decreases the sense of social presence for long-term users (§5.2).
- Once users are subjected to motion-based harassment, their overall experience of social VR will degrade. Therefore, it is essential and urgent to solve harassment issues on social VR platforms.

However, existing harassment prevention mechanisms on all five platforms are inadequate to effectively protect users, as they are passive and require manual activation by users (§4.4).

- The avatar appearance of these platforms has limited contribution to users' sense of social presence, even though some platforms have full-body avatars (e.g., VRChat) and human-shaped avatars (e.g., Worlds). This is due to the fact that avatars on these platforms still lack realism (§5.2). Nevertheless, the full-body avatars of VRChat can enhance users' sense of personal presence (§5.1).

Our findings have profound implications for the future design of social VR and the Metaverse at large. First, in order to serve thousands of concurrent users, the Metaverse must address scalability issues to ensure a truly immersive experience and lower the risk of users experiencing motion sickness. Second, designing rich and engaging content, such as highly interactive events, is crucial for increasing user engagement and stickiness on social VR platforms. Third, to guarantee users' uninterrupted and enjoyable social experience, the prevention mechanism of emerging motion-based harassment on social VR deserves an in-depth study. Finally, the avatar embodiment of social VR needs to be highly realistic to provide a social environment comparable to the real world.

2 Related Work

2.1 Metaverse and Social VR

Since the term Metaverse was introduced in 1992, its notion has continuously evolved [25, 43, 55, 80, 96, 126]. In its current development phase, the Metaverse is widely considered a collection of virtual worlds connected by the Internet, whose enabling technologies include extended reality (XR), 5G networks, edge computing, and blockchain [55, 86]. Lee *et al.* [55] study eight cutting-edge technologies and six user-centric characteristics associated with the Metaverse. Park *et al.* [86] investigate three components and three approaches to realize the Metaverse. In this work, we aim to examine the user experience of social VR, a key element of the Metaverse [80]. Socialization and entertainment are users' primary needs for social VR [106]. As a result, social VR applications provide numerous interactive events, such as games [106] and immersive movies [56], to satisfy users' social demands. Moreover, social VR platforms offer users various tools to host their social events. Existing work demonstrates that social VR is suitable for a wide variety of social activities, such as dancing [88], organizing conferences [124], remote collaboration [97], meditation [60], and online education [14].

2.2 Comparison of Commercial Social VR Platforms

Recent years have witnessed the rapid development of social VR applications, with over 100 platforms currently available [95]. Given this surge, comparing different social VR platforms is crucial for shedding light on the design practices for social VR and the Metaverse. Consequently, there has been a wealth of studies comparing various aspects of social VR, such as avatar systems [50], non-verbal communication [109], design principles [45, 68], and server infrastructure [19]. However, no comprehensive user studies have examined how multiple factors interact to shape the overall experience across different social VR platforms. This comparison is essential because it allows us to determine which features are effective in fostering user engagement and immersion. Additionally, it enables us to assess whether certain technical and social factors are universally important across platforms or highly dependent on platform design and intended use cases. While Liu and Steed [59] employ a method called guided group walkthrough to compare six social VR platforms, this study primarily focuses on the evaluation of usability. Moreover, it does not compare long-term and short-term user experience on these platforms. However, long-term and short-term users may perceive the same platform differently due to differences in their exposure and engagement levels.

Motivated by these limitations, in this paper, we aim to examine what factors affect the overall experience of long-term and short-term users on social VR platforms (RQ1).

2.3 Avatar Embodiment and Presence in Social VR

Avatar embodiment is crucial in social VR, as it enables users to perceive their avatars as extensions of their physical selves. This is achieved through real-time motion tracking, which mirrors users' physical movements in the virtual space [29, 38, 50]. Full-body avatars significantly contribute to this sense of embodiment, offering a more natural and engaging way for users to interact with others in the virtual environment [29, 38, 53]. Additionally, user behavior can be influenced by the appearance of their avatars, a phenomenon known as the Proteus Effect, where users unconsciously modify their actions to align with their avatar's characteristics [29, 30, 85]. However, a key challenge in avatar design is achieving realism without falling into the "uncanny valley", where avatars that appear almost lifelike, but not quite, evoke discomfort [75, 128]. Moreover, increasing avatar realism often comes with higher system overhead, such as the rendering load. This requires careful design and a balanced trade-off between visual fidelity and performance to ensure both rich social interactions and efficient platform operation [53, 128].

Avatar embodiment is also a major factor affecting user presence in social VR since it can augment the social and experiential aspects of traditional online social media by producing a strong sensation of virtual body ownership [42, 46] and a sense of being physically present in the shared virtual environment [103]. Sense of presence is a significant aspect influencing the quality of VR users' experience [98, 116]. It can be described along two dimensions: 1) personal presence: "being in the virtual world", and 2) social presence: "being together with others in the virtual world" [98]. The key research goal in investigating how avatar embodiment affects presence is to understand how users perceive their avatar embodiment in virtual environments as their own bodies, which has been broadly studied in VR and HCI communities [29, 30, 32, 33, 38, 50, 53, 63, 64, 87]. Existing work diverges on the design principles of avatar models in social VR. For example, Heidicker *et al.* [38] suggest that cartoon-shaped and physically incomplete avatars (e.g., with only head and hands) are adequate for users. However, other work argues that more refined avatar models are needed for social VR, such as full-body [29] or realistic-looking [52, 53] avatars, to meet the expectations of users. In addition to avatar embodiment, other features in social VR, such as interactivity of the environment [93] and social events [122], can affect user presence. Although previous studies have investigated various aspects that affect presence in social VR, they lack a comparison of presence experience on different social VR platforms, which motivates us to answer RQ2.

2.4 Additional Factors Affecting User Experience in Social VR

In addition to avatar embodiment, various other factors in social VR platforms influence user experience and should be considered when designing experiments to compare experiences across platforms. These factors primarily relate to user interactions, which are fundamental to the social nature of these platforms.

Non-verbal Communication. VR headsets are equipped with the 6DoF (degrees of freedom) tracking capability, enabling the measurement of both the position and orientation of users' heads and hands in three-dimensional space. 6DoF tracking facilitates non-verbal communication among users, such as natural gestures and body language [27, 62, 66, 104, 108]. Moreover, the internal cameras of headsets can be utilized to capture facial expressions to further enhance avatar realism and social presence by providing real-time emotional feedback [24, 36, 48]. The ability to convey non-verbal cues in virtual environments has been shown to promote social comfort and a sense of social presence among users [62, 65, 107], as well as to enhance the sense of physical closeness and

intimacy in virtual relationships [60, 129]. In fact, a recent study [12] shows that some users rely solely on non-verbal communication to interact with others on social VR platforms.

Interpersonal Relationships. Social VR platforms enable users to build meaningful connections and foster emotional bonds through both verbal and non-verbal interactions in immersive environments that closely mimic real-world social dynamics [23, 27, 62, 108]. Thus, social VR attracts a diverse range of users, from teenagers to older adults, each bringing unique interaction styles [1, 4, 61]. For example, teenagers seek immersive experiences that allow them to form emotional connections and explore their sense of self-identity [61], while older adults benefit from avatar-mediated communication, which helps reduce social isolation and provides a comfortable medium for self-expression [4]. An important factor in these interactions is self-disclosure, where users selectively share personal information to deepen relationships. Recent studies show that users often approach self-disclosure cautiously, balancing the need for privacy with the desire for authentic connections [58, 107].

Harassment. Although social VR is gaining popularity due to its ability to simulate real-world interactions, the increasing number of reports on harassment [20, 21, 111, 112, 114] may impede its deployment. Social VR provides abundant mediums for verbal and non-verbal communication. Thus, it gives opportunities for not only text-based harassment, which has been studied in online social networks [7], but also emerging motion-based harassment, such as virtual grabbing and touching [8, 26, 31, 101]. Currently, most social VR platforms allow users to define their own personal space, bubbles, or boundaries, which are protected areas in the virtual environment that can prevent harassment [9, 50]. However, the latest reports of harassment on social VR platforms [20, 21, 28, 99, 100, 111, 112, 114] imply that such mechanisms may not be sufficient to protect users from harassment.

3 Methodology

In this section, we present the methodology of our IRB-approved user study, including an introduction of the social VR platforms that we have investigated, the participants, the design of our study, and the system performance we measure.

3.1 Social VR Platforms

We conducted the user study on five social VR platforms: Worlds [72], AltspaceVR [74], VRChat [120], Rec Room [89], and Hubs [77]. We chose these platforms mainly because they have been broadly studied by the VR and HCI communities, for example, from the design perspectives [45, 60, 62, 67, 68, 107]. We summarize the key features of these platforms as follows:

- *Horizon Worlds* is the newest among these five social VR platforms, which was released in December 2021 by Meta (previously known as Facebook). It supports a variety of social events, such as gaming and concerts.
- *AltspaceVR* was released in 2015 and acquired by Microsoft in 2017. It focuses on professional activities, allowing brands, creators, and businesses to host live events easily. However, it does not provide many highly interactive events.
- *VRChat* was launched in 2017. It is known for its “wild west” and freedom [67]. VRChat does not impose excessive limitations on how the platform can be utilized, providing users the freedom to define and build their virtual worlds.
- *Rec Room* was released in 2016. It is a gaming-based platform, which provides various highly interactive multi-user games, such as paintball and co-op adventures.
- *Mozilla Hubs* is an open-source and Web-based social VR platform (released in 2018). Most events on Mozilla Hubs are chat-based and not highly interactive.

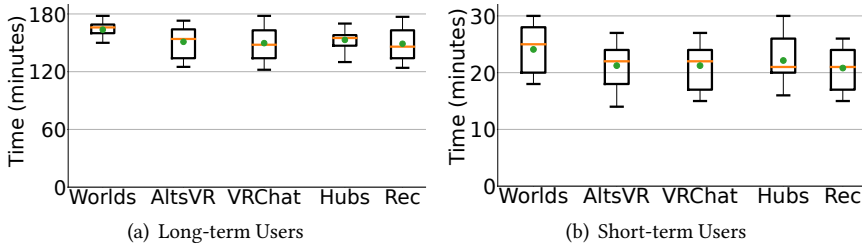


Fig. 1. Distribution of usage time across five platforms for long-term and short-term users.

The availability of these platforms changed after our experiments were conducted. For instance, AltspaceVR [113] and Mozilla Hubs [78] were discontinued. We discuss how our study provides insights into these market developments and their implications in §6.

3.2 Recruitment and Participants

We recruited 42 participants from a university. Among them, 27 are aged 18–24, and the rest are 25–34. The age distribution of our participants is consistent with that of common users on social VR platforms [106]. They did not have prior experience with these five platforms. The study follows a between-subject design. We evenly and randomly divided them into the short-term group (denoted as S_i ; Female: 7, Male: 14; 12 with prior VR experience) and long-term group (denoted as L_i ; Female: 10, Male: 11; 11 with prior VR experience). Participants conducted the experiments at their residences using their home networks. The network throughput for all participants was at least 100 Mbps, as measured by Speedtest [83] and Fast.com [81], which is sufficient to support the functionality of these platforms [3]. Distinguishing between short-term and long-term users is based on the hypothesis that short-term users have limited time with each platform, and thus their experience will be largely based on initial impressions; while long-term users have more time to explore different features, leading to high risks of experiencing motion sickness and harassment. For short-term users, we want to know whether they are willing to continue using the platforms; while for long-term users, we are interested in understanding whether the platforms retain their interest over time.

As there is no established definition of long-term users, we conducted a crowdsourced interview with individuals from the communities (e.g., Discord and Reddit) of these platforms who self-identified as “long-term users”. We specifically asked these users how long they have spent on these platforms. Over 95% of these participants reported using the platforms for at least 120 minutes. Based on this, we defined 120 minutes as a reasonable threshold for long-term usage in our study. Each long-term user was therefore required to spend at least 120 minutes per platform.

Social VR platforms provide a variety of social events, ranging from highly interactive experiences (e.g., time-limited gaming sessions) to open-ended environments primarily designed for socializing and meeting new people. To ensure that users experienced a comprehensive range of activities on each platform, we required long-term users to participate in 10–20 distinct social events. Long-term users were allowed to complete their sessions over an extended period to minimize fatigue and motion sickness. This design also helped simulate real-world conditions, where users engage with platforms periodically. On average, long-term users took 61 days to complete the study (Min: 51 days, Max: 71 days, SD: 4.82).

For short-term users, we required them to complete the experience within 10 days to ensure that their impressions of each platform were based on initial and fresh memories. Based on typical usage patterns in social VR platforms [5], each short-term user was asked to participate in 3–5 social events, spending a total of 10–30 minutes on each platform. Figure 1 presents the distribution

Question Categories	Demographic Questions	Overall Experience Ratings & Explanations	Visual Quality Ratings	Interactive Events Ratings	Personal & Social Presence Ratings	Motion Sickness Yes/No & Explanations	Harassment Yes/No & Explanations
Questions	Q1-Q3	Q4-Q5	Q6	Q7	Q8-Q9	Q10-Q11	Q12-Q14
Scales	Multiple choices	Rate on a 5-point scale about overall experience, visual quality, and interactive events (1= extremely bad to 5= extremely good).			Rate on a 5-point scale about personal & social presence (1= very weak to 5= very strong).	Give Yes/No and explanations about motion sickness experience.	Give Yes/No and explanations about harassment experience.

Fig. 2. Survey structure with information on question categories and scales. The detailed survey is provided in Appendix B.

of usage time spent on five platforms by long-term and short-term users, respectively. The results show the 95th, 75th, 25th, and 5th percentiles, median, and mean (green dots). Detailed per-user usage data is provided in Appendix A. All participants were instructed to interact with users outside of the study, ensuring that each individual had a unique and authentic experience. Additionally, we required them to refrain from using any other VR applications during the experiments. We emphasized this condition prior to the study and validated it during each user interview.

In contrast to previous work that does not restrict the type of devices for accessing social VR platforms [50, 57, 106, 124], we provided each user with an Oculus Quest 2 VR headset. This decision is motivated by several factors. Firstly, our study aims to compare user experience across five social VR platforms. Therefore, to avoid introducing new variables, we ensure that all participants experience the platforms with the same type of device. Secondly, Quest 2 is arguably the most popular VR headset [110]. Thirdly, it has become the major device on some social VR platforms, for example, Rec Room [94] and VRChat [121]. Lastly, Worlds supports only Quest 2 at the time of our experiment (between 2022 and 2023).

3.3 Study Design and Procedure

Experimental Procedure. We reset each headset before handing it to the participants, who then used the headset to experience five platforms. Since all platforms have a tutorial for new users, we did not design additional tutorials for them. When participants returned the headset, we checked the usage time of each platform to ensure that they used the platforms for the required amount of time. To gain a comprehensive understanding of user experiences on different platforms, we focus our analysis on four key factors that have been previously identified for social VR (§2.4): visual quality, interactive events, motion sickness, and harassment. We investigate how these factors interact to affect users' overall experience, as well as their sense of place presence and social presence, which helps us answer RQ1 and RQ2. Given the remote nature of our study and the prolonged duration for our long-term users (~60 days, as described in §3.2), we periodically interviewed them to track their overall experience, personal presence, and social presence on the five platforms. This approach allowed us to gain a more nuanced and accurate understanding of the users' experiences. Specifically, we interviewed long-term users every week after they had been using the platform for a month, and short-term users every three days. Furthermore, we asked participants to report the harassment and motion sickness experience immediately after they occurred.

Survey. After the participants experienced all five platforms, we asked them to fill out a lightweight survey. Figure 2 shows the structure of our survey. We also provide the full survey in Appendix B. After demographic questions, users self-reported how many events they participated in on each platform. We then asked participants to rate their overall experience on five platforms using a 5-point Likert scale and to provide an open-ended response if they rated 1 or 5, to better understand their reasoning. Next, we asked users to rate their experience of highly interactive events and the

visual quality of these platforms. To define the highly interactive social events more clearly, we gave two examples in the questionnaire: sports games and dancing events. Given that the definition of visual quality is subjective, we did not define it in the survey. Instead, we allowed users to define the visual quality by themselves and asked for their definitions during user interviews. Users were then asked to rate their sense of personal presence and social presence on these platforms. Finally, considering users may forget to report their motion sickness and harassment experiences while using the platforms, we designed two Y/N and open-ended questions to understand scenarios in which users felt motion sickness and harassed. We also designed an open-ended question to ask for their opinions on the harassment prevention mechanism of these platforms.

When measuring the personal presence, social presence, and motion-sickness experience of users, we chose not to rely on existing questionnaires since finishing all of them for different factors requires a significant amount of time, which is not practical for our study that requires participants to compare five platforms simultaneously. Prior to conducting our main user study with 42 participants, we conducted a pilot study with five other participants. These participants experienced five social VR platforms in accordance with the criteria established for short-term users. Following the experiences, they were asked to complete three existing questionnaires, including the *igroup presence questionnaire* (IPQ) [40], the *social presence module of the game experience questionnaire* (GEQ) [41], and the *virtual reality sickness questionnaire* (VRSQ) [47], for measuring their personal presence, social presence, and motion-sickness experience on five platforms, respectively. The average completion time for all questionnaires is 43.7 minutes ($SD : 11.2$), which is much higher than the suitable completion time for a survey (*i.e.*, 10–20 minutes) [34]. Thus, we adopted a more efficient approach by providing a clear and concise definition of these factors by selecting and summarizing the relevant items from the standardized questionnaires. Based on the items SP1 – SP5 from IPQ, which measure the spatial presence of users, we defined the personal presence as *users have the feeling that they are actually inside the virtual environment*. Based on the social presence module of GEQ, we defined the social presence as *users have the feeling that other users' beings co-exist with them in the virtual environment*. Based on the VRSQ, we summarized vertigo, nausea, headache, and fatigue as symptoms of motion sickness. We explained these definitions before our study and each user interview, as well as in the survey. By doing this, we optimized the survey completion time to an average of 16.4 minutes ($SD : 3.3$).

Exit Interview. After users finished the survey, we conducted another interview with the following questions to gain a deeper understanding of their experience on the five platforms: 1) *Which platform do you like the most, which one is the second best, and which do you dislike the most?*; 2) *Comparing the best and worst platforms, what do you think differentiates them? What factors influence your overall rating of these platforms?*; 3) *How do you define the visual quality of these platforms?*

Factor Analysis. We analyzed the statistical relationship between the factors and user experience based on the survey results. Besides applying the statistical significance test, we employed multivariate linear regression analysis to identify the dominant factor affecting the overall experience, personal presence, and social presence of long-term and short-term users. Our study design included the ratings of visual quality, interactive events, motion sickness, and harassment as independent variables. We examined the dominant factors affecting overall experience, personal presence, and social presence separately. To account for the binary nature of motion sickness and harassment, we created dummy variables (1 for “Yes” and 0 for “No”). In order to ensure a fair comparison, we normalized the ratings of the overall experience, personal presence, social presence, visual quality, and interactive events using max-min normalization [123], which scales the values to the range of [0, 1]. The adjusted R-squared values for all regression models are > 0.7 ($M : 0.81$; $SD : 0.06$),

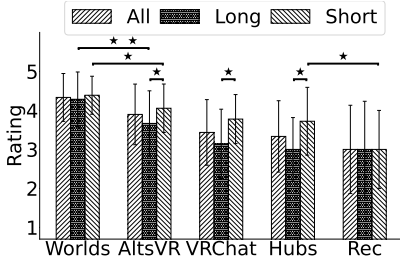


Fig. 3. Ratings of overall experience on five social VR platforms from all, long-term, and short-term users. ★: $p \leq 0.05$. ★★: $p \leq 0.01$.

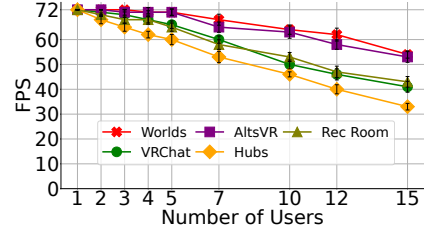


Fig. 4. Average FPS of five platforms with different numbers of users (results are from at least 20 experiments).

indicating a strong linear correlation between the independent and dependent variables [6]. The independent variable with the highest coefficient is considered the dominant factor [44].

3.4 Measurement Setup

To validate the findings from our user study of these social VR platforms, we used a Quest 2 to access them and measured their FPS and resolution with the OVR Metrics Tool [82], an official performance monitoring tool from Oculus.

- **Average FPS:** FPS on Quest 2 is 72 by default, the same as its fresh rate.
- **Resolution:** The content resolution rendered by applications. The greater the value, the higher the rendering overhead, and the better the user experience. Note that the display resolution of Quest 2 is 1832×1920 per eye. The content resolution could be larger than it to provide a satisfactory user experience [91].

4 Factors Influencing Overall Experience of Users

Figure 3 shows ratings of the overall experience from all, long-term, and short-term users on five platforms. We apply the Shapiro-Wilk test and find that none of these ratings is normally distributed. Thus, we apply the Friedman test to detect statistical differences of ratings on five platforms [127]. We summarize the major findings from this figure and explain their reasons as follows.

#1 Long-term and short-term users rated their overall experience on Worlds significantly higher than other platforms. For long-term users, the Friedman test indicates that ratings of five platforms are significantly different ($\chi^2(4) = 22.48$, $p < .001$, Kendall's $W = .38$). The Conover post-hoc test with the Benjamini-Hochberg correction shows that the rating of Worlds ($M = 4.29$, $SD = 0.70$) is significantly higher than the other four (AltspaceVR: $M = 3.67$, $SD = 0.84$, $p < .05$; VRChat: $M = 3.14$, $SD = 0.88$, $p < .01$; Hubs: $M = 3.00$, $SD = 0.81$, $p < .01$; Rec Room: $M = 3.00$, $SD = 1.23$, $p < .01$). For short-term users, the Friedman test shows that there are significant differences among ratings of five platforms ($\chi^2(4) = 23.42$, $p < .001$, Kendall's $W = .32$). The Conover post-hoc test with the Benjamini-Hochberg correction shows that the rating on Worlds ($M = 4.40$; $SD = 0.49$) is significantly higher than the other four (AltspaceVR: $M = 3.94$, $SD = 0.91$, $p < .05$; VRChat: $M = 3.61$, $SD = 1.06$, $p < .05$; Hubs: $M = 3.72$, $SD = 0.86$, $p < .05$; Rec Room: $M = 3.00$, $SD = 1.00$, $p < .01$). This is because Worlds has the smallest frame rate drop as the number of users increases, which causes the fewest users to experience motion sickness (§4.1), rich highly interactive events (§4.2), and clear user instructions of harassment prevention (§4.4).

#2 For the overall experience on AltspaceVR, the ratings from long-term users are significantly lower than short-term users (long-term users: $M = 3.56$, $SD = 0.83$; short-term users: $M = 4.17$,

Platforms	Resolution	Motion Sickness		Harassment		Dominant Factor	
		Long	Short	Long	Short	Long	Short
Worlds	1584×1440	6	5	1	1	V	V
AltspaceVR	2224×2016	7	6	3	2	I	V
VRChat	1584×1440	15	8	6	5	M	H
Hubs	1344×1216	15	7	2	1	M	V
Rec Room	1346×1224	16	14	2	2	M	M

Table 1. The content resolution of five platforms on Oculus Quest 2, the number of long-term and short-term users who felt motion sickness and harassed on them, and the dominant factor that affects the overall experience for long-term and short-term users. V: visual quality; I: interactive events; M: motion sickness; H: Harassment.

$SD = 0.60$; $p < .05$ from the Mann-Whitney U test; Rank-biserial correlation $r = .40$). The reason is that its lack of highly interactive events makes long-term users feel fatigued (§4.2).

#3 On VRChat and Hubs, long-term users rated their overall experience significantly lower than short-term users. (VRChat: long-term: $M = 3.14$, $SD = 0.88$; short-term: $M = 3.77$, $SD = 0.62$; $p < .05$ from the Mann-Whitney U test; Rank-biserial correlation $r = .43$; Hubs: long-term: $M = 3.00$, $SD = 0.81$, short-term: $M = 3.72$, $SD = 0.86$, $p < .05$ from the Mann-Whitney U test, Rank-biserial correlation $r = .44$). This is mainly due to their low resolution and FPS, which leads to more long-term users feeling motion sickness than short-term users (§4.1).

#4 On Rec Room, based on the Conover post-hoc test with the Benjamini-Hochberg correction, short-term users ($M = 3.00$, $SD = 1.00$) rated their overall experience significantly lower than VRChat ($M = 3.77$, $SD = 0.62$, $p < .05$) and Hubs ($M = 3.72$, $SD = 0.86$, $p < .05$). However, such an observation does not exist in the ratings from long-term users (Rec Room: $M = 3.00$, $SD = 1.23$; VRChat: $M = 3.14$, $SD = 0.88$; Hubs: $M = 3.00$, $SD = 0.81$). One possible explanation is that 66% of short-term users felt motion sickness on Rec Room because it has rich highly interactive social events but low frame rate and resolution (§4.1).

4.1 System Performance and Overall Experience

Through user interviews, we discovered that motion sickness is the primary reason why users gave a platform a low rating for overall experience. For example, S_{20} , who experienced motion sickness on all five platforms and rated 1 for overall experience on all of them, explained: “After using these platforms, I often felt dizzy and nauseous. I had to stop and rest a few times. This was not friendly. I did not want to continue the experience.” Table 1 shows the number of users who experienced motion sickness on the five platforms. We observe that 71.4% of long-term users felt motion sickness on VRChat and Hubs, which is >30% higher than short-term users who felt motion sickness (38.1% for VRChat and 33.3% for Hubs). Also, 66.6% of short-term users felt motion sickness on Rec Room, which is >25% higher than VRChat (38.1%) and Hubs (33.3%). Moreover, as shown in Table 1, motion sickness is the dominant factor affecting the overall experience of long-term users on VRChat and Hubs, as well as long-term and short-term users on Rec Room. These results confirm our explanations in Findings #3 and #4.

Given that previous work has demonstrated that frame rate is a potential contributor to motion sickness in VR [69, 130], we next measure the frame rate of these platforms to better understand overall experience of users. We used Quest 2 to attend at least 20 events on these platforms. Social VR platforms currently impose a maximum number of concurrent users per event. Among them, Worlds supports the least number of users, with a hard cap of 16. Thus, we accessed public events with 1 to 15 users on these platforms. Figure 4 illustrates the average FPS on the five platforms

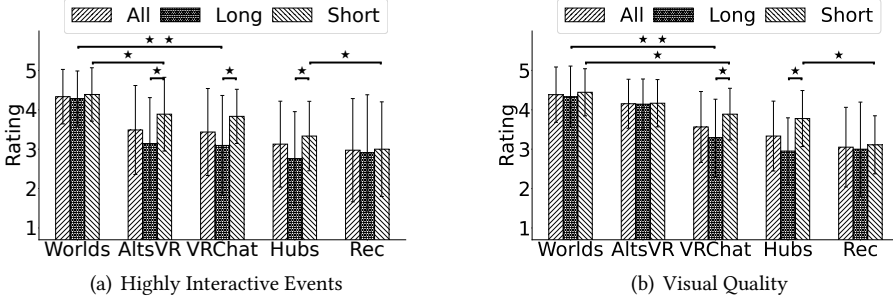


Fig. 5. Ratings on five social VR platforms from all, long-term, and short-term users. ★: $p \leq 0.05$. ★★: $p \leq 0.01$.

with different numbers of users. We observe that the FPS of all platforms decreases as the number of users increases, indicating that they face potential scalability issues. Moreover, when there are only 7 users, the FPS of VRChat, Rec Room, and Hubs drops to below 60, which is the minimal requirement for a high-quality VR system [10, 51]. When the number of users increases to 15, the FPS of these three platforms further drops to below 50. Note that these three platforms have a higher cap on the number of participants per event than 15 (e.g., 80 for VRChat [119], 40 for Rec Room [90], and 25 for Hubs [79]), which may result in even lower FPS for the untethered Oculus Quest 2 when more users attend the social events on them.

In addition, seven users who experienced motion sickness on Hubs or Rec Room attributed the low resolution as the main reason. For example, S_5 , who felt motion sickness on Rec Room, said: “Rec Room has a wide range of games, which makes it very popular and interactive. The main disadvantage is its low resolution, which induces motion sickness.” Thus, we measure the resolution of these platforms and show the results in Table 1. Rec Room and Hubs have the lowest resolution, echoing users’ opinions that low resolution may lead to motion sickness. Although the resolution and FPS of Hubs are lower than Rec Room, fewer users experienced motion sickness on Hubs due to its chat-based, low-interaction events that do not require users to frequently move in the virtual environment (§3.1). For instance, S_5 , who felt motion sickness on VRChat and Rec Room, reported: “On Hubs, I basically just chatted with other people. I didn’t move much and didn’t feel any discomfort.” Moreover, we find that long-term users could not get used to the low resolution and frame rate of these platforms even after a long time of usage. For example, L_8 stated: “VRChat provides a decent way to socialize with others. Even so, I still often feel dizzy after having been using it for two months.” L_{19} stated: “I feel motion sickness on all these platforms even after I have used them for a long time.”

Finally, we note that the FPS of Worlds and AltspaceVR drops to below 60 when there are 15 users, as shown in Figure 4. Moreover, even though they perform better than the others, there are still six long-term and five short-term users who experienced motion sickness on Worlds (Table 1). In summary, the above results indicate that enhancing the system performance on untethered VR headsets (e.g., Oculus Quest 2) is an urgent issue for all five social VR platforms.

4.2 Interactive Events and Overall Experience

We next investigate the impact of interactive events on the overall experience of users. As summarized in Finding #2, long-term users of AltspaceVR rated their overall experience significantly lower than short-term users. However, in contrast to VRChat and Hubs, AltspaceVR has a relatively good performance with the highest resolution among the five platforms (Table 1) and comparable FPS with Worlds (Figure 4). Based on user interviews, we find that the reason for Finding #2 is that AltspaceVR does not provide many interactive events (§3.1), causing long-term users to lose their interest after using it for a long time. For instance, L_2 said: “AltspaceVR has a very good resolution, but

it does not offer many games, so I am getting tired of it after about a month." L_{19} further mentioned: *"AltspaceVR has a genuine graphical view and provides a lot of flexibility to the users. I stay comfortable and do not have motion sickness even after using it for a long time, but it is really boring."*

The above findings reveal that the highly interactive event is another important factor influencing users' overall experience, particularly for long-term users. Thus, we next analyze the ratings of their experience in highly interactive events on five platforms, as shown in Figure 5(a). The Shapiro-Wilk test shows that none of these ratings is normally distributed. Hence, we apply Mann-Whitney U test and identify there exists a significant difference between ratings from the long-term and the short-term users on AltspaceVR (long-term users: $M = 3.14$ and $SD = 1.16$; short-term users: $M = 3.88$, $SD = 0.93$; $p < .05$; Rank-biserial correlation $r = .34$). Moreover, the Spearman correlation test shows that there exists a moderate correlation between ratings of experience in highly interactive events and overall experience on AltspaceVR from both short-term and long-term users ($k > 0.5$). Furthermore, as shown in Table 1, the rating of highly interactive events is the dominant factor affecting the overall experience for long-term users on AltspaceVR. These results corroborate that the reason for the lower overall experience ratings of long-term users than short-term users on AltspaceVR is due to its lack of highly interactive events.

However, highly interactive events may induce motion sickness that negatively impacts overall experience when the frame rate and resolution of these platforms are low, as demonstrated on VRChat, Rec Room, and Hubs. In Figure 5(a), we observe that long-term users' ratings of highly interactive events on VRChat and Hubs are significantly lower than those of short-term users (VRChat: long-term: $M = 3.09$ and $SD = 1.26$; short-term: $M = 3.83$ and $SD = 0.68$; $p < .05$ from the Mann-Whitney U test; Rank-biserial correlation $r = .35$. Hubs: long-term: $M = 2.66$ and $SD = 1.19$; short-term: $M = 3.38$ and $SD = 0.88$; $p < .05$ from the Mann-Whitney U test; $r = .38$). Moreover, the Friedman test shows that there are significant differences among ratings from short-term users on five platforms ($\chi^2(4) = 19.80$, $p < .001$, Kendall's $W = .37$). The Conover post-hoc test with the Benjamini-Hochberg correction shows that the rating on Rec Room ($M = 2.94$; $SD = 1.22$) is significantly lower than the other four platforms (Worlds: $M = 4.39$, $SD = 0.68$, $p < .005$; AltspaceVR: $M = 3.89$, $SD = 0.94$, $p < .05$; VRChat: $M = 3.83$, $SD = 0.69$, $p < .05$; Hubs: $M = 3.46$, $SD = 0.86$, $p < .05$). User interviews reveal that motion sickness severely affects the overall experience for interactive events on these three platforms. For example, L_{18} shared: *"It is really hard to appreciate the events on VRChat and Hubs since I suffer from severe motion sickness on these two platforms."* L_{10} commented: *"VRChat and Rec Room have a lot of fun games. But I feel severe vertigo when I move in those games, especially in the multi-user games."* S_{18} told us: *"I like Rec Room the least, because it makes me feel the dizziest. Although the fencing game there attracts me a lot, I cannot enjoy it because of the dizzy feeling."*

Furthermore, we observe from Figure 5(a) that the ratings of highly interactive events on Worlds from long-term users and short-term users are significantly higher than the others. The Friedman test shows that there are significant differences among ratings from long-term users on five platforms ($\chi^2(4) = 16.29$, $p < .01$, Kendall's $W = .19$). The Conover post-hoc test with the Benjamini-Hochberg correction shows that the rating on Worlds ($M = 4.40$ and $SD = 0.49$) is significantly higher than the others (AltspaceVR: $M = 3.94$, $SD = 0.91$, $p < .05$; VRChat: $M = 3.61$, $SD = 1.06$, $p < .05$; Hubs: $M = 3.72$, $SD = 0.86$, $p < .05$; Rec Room: $M = 3.00$, $SD = 1.00$, $p < .001$). For short-term users, the Friedman test shows that there are significant differences among their ratings on five platforms ($\chi^2(4) = 19.80$, $p < .001$, Kendall's $W = .37$). The Conover post-hoc test with the Benjamini-Hochberg correction shows that the rating on Worlds ($M = 4.39$, $SD = 0.68$) is significantly higher than the others (AltspaceVR: $M = 3.89$, $SD = 0.94$, $p < .05$; VRChat: $M = 3.83$, $SD = 0.69$, $p < .05$; Hubs: $M = 3.46$, $SD = 0.86$, $p < .005$; Rec Room: $M = 2.94$; $SD = 1.22$, $p < .001$). The reason is that Worlds has colorful highly interactive social activities and the least number of



Fig. 6. Avatars on five platforms. From left to right: Worlds, VRChat, Rec Room, AltspaceVR, and Hubs.

users who experienced motion sickness (Table 1). For instance, L_{10} explained, “*Horizon Worlds is highly engaging and provides a high-level graphical view, making it attractive. Compared to other platforms, it offers exceptional comfort and convenience. It provides a variety of games and rooms for people to interact. Personally, I did not feel any motion sickness even after engaging with it for a long period of time.*”

4.3 Visual Quality, Avatar Appearance, and Overall Experience

In our survey, we let users define the “visual quality” and rate it for all platforms. Then, we asked them to explain their definitions in interviews (§3.3). We find that 71% short-term and 67% long-term users defined “visual quality” of the platforms according to the frame rate and resolution. In §4.1, we have demonstrated that frame rate and resolution are important factors contributing to users’ overall experience. Therefore, we first apply the Shapiro-Wilk test and find that all visual-quality ratings, as shown in Figure 5(b), are not normally distributed. We then perform the Spearman correlation test and find that the ratings of visual quality from short-term and long-term users are moderately correlated ($k > 0.5$) with their ratings of overall experience on each platform. Nevertheless, there were eight users (four short-term and four long-term) who defined the “visual quality” as the avatar embodiment. Among them, four users (two short-term and two long-term) mentioned they preferred the full-body avatar of VRChat, as shown in Figure 6, and thus rated its visual quality high. For example, L_6 said: “*I define the visual quality as the appearance of the avatar and I love VRChat most since it is the only platform having full-body avatars.*” Moreover, four users (two short-term and two long-term) who defined the “visual quality” as the avatar embodiment rated the visual quality of Worlds high since it is the only platform that provides human-shaped avatars, as shown in Figure 6. However, L_{16} and S_{19} have different views on this. L_{16} stated: “*I do not like cartoon-shaped avatars like these platforms. I prefer the full-scale realistic avatar model like the one in the alyx [115].*” S_{19} shared: “*I like simple but cute or quirky avatars. I would say Rec Room and Mozilla Hubs were the most enjoyable.*” For the other participants, three of them (one short-term and two long-term) defined visual quality as the brightness and hierarchy of colors, and two of them (one short-term and one long-term) defined it as the instant animation feedback. All of them felt no significant difference between the five platforms in terms of the visual quality.

4.4 Harassment, Prevention Mechanism, and Overall Experience

We next investigate how harassment and its prevention mechanism affect users’ overall experience. Table 1 shows the number of users who were harassed on five platforms. Through analyzing the overall-experience ratings of users who were harassed on a platform, we notice that they all rated ≤ 3 to the overall experience. Moreover, as shown in Table 1, harassment is the dominant factor affecting the overall experience of short-term users on VRChat. User interviews support our findings. For example, L_{21} said in the interview: “*In Rec Room, I once dressed my avatar in a new*

outfit and entered a virtual room. While I was talking to other people, one user teleported to me and started touching my avatar. That experience made me feel very uncomfortable. I've never worn that outfit again since then." S_7 mentioned: "Once I built a scene in VRChat. I was satisfied and made it public for everyone to access. But some users commented unfriendly what I made was ugly. I felt very sad. I haven't opened that scene or even the tool for creating scenes since then because it reminded me of this unpleasant experience". Moreover, users may dislike the platform after feeling harassed. For instance, L_6 stated: "I had two totally different attitudes before and after this situation [harassment]. I started to disgust this platform after I experienced this situation [harassment]."

In order to prevent users from harassment, except for Hubs, all other four platforms currently employ personal space-based harassment prevention mechanisms, which are user-definable regions [9, 67, 73]. However, these mechanisms are insufficient because they are passive means of defense. For example, L_6 mentioned: "I immediately opened my personal space after the harassment. That worked, but the experience still made me feel very uncomfortable." Some users also felt helpless because the platforms lacked an effective mechanism to support them in assisting and safeguarding people who were being harassed. For instance, S_5 said: "I was in VRChat walking around and saw two people talking off in the corner. I could tell from their voices that it was an adult man sexually insulting a younger girl. I felt uncomfortable and helpless. The only thing I could do to assist the girl was to report the man." Furthermore, users who have been harassed on Rec Room and VRChat gave feedback that they did not receive sufficient guidance or tutorials on how to use the harassment prevention mechanisms such as personal space and reporting features. For example, S_{21} mentioned: "Most of them, except AltspaceVR and Horizon Worlds, have a lot of harassment from other VR users and not enough guidance or tutorials on preventing the harassment." L_{17} summarized the harassment prevention mechanisms of these platforms: "Horizon [Worlds] has a clear user guide to teach you how to avoid unwanted touching. The protecting and reporting functions are easy to find and use. AltspaceVR also has some kind of 'bubble' function to avoid touching, but the 'bubble' cannot protect users from oral or gestural harassment. Rec Room has reporting function in its menu, but it doesn't explicitly educate new users. Mozilla Hubs has no feature to prevent unwanted touching. The reporting button is not found in it. For VRChat, it is difficult to find protection mechanisms in it. Its community is full of harassment." This shows that Worlds performs well in terms of guiding users on protecting themselves, which may explain why Worlds has a small number of users who felt harassed (a total of two, as shown in Table 1).

Key Findings: We summarize our key findings on factors that influence users' overall experience on social VR platforms as follows.

- System performance (e.g., frame rate and resolution) is a crucial factor impacting users' overall experience. Low frame rate and resolution increase the probability of motion sickness, significantly degrading their overall experience.
- Having only relatively good system performance without a rich set of highly interactive events can cause user fatigue, deteriorating the overall experience, especially for long-term users.
- Harassment is another important factor that affects the overall experience. However, harassment prevention mechanisms on all five platforms are insufficient or nonexistent. Additionally, a comprehensive user guide for harassment prevention may lower the number of harassed users.

5 Factors Affecting Personal Presence and Social Presence of Users

5.1 System Performance, Avatar Appearance, and Personal Presence

Figure 7(a) shows the ratings of personal presence on five platforms from all, long-term, and short-term users. We perform the Shapiro-Wilk test and observe that all ratings are not normally

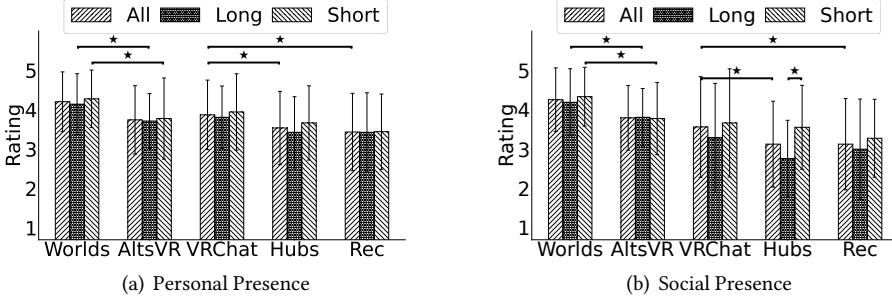


Fig. 7. Ratings of presence on five platforms from all, long-term, and short-term users. *: $p \leq 0.05$.

Platform	Dominant Factor			
	Personal Presence		Social Presence	
	Long	Short	Long	Short
Worlds	V	V	V	V
AltspaceVR	V	V	V	V
VRChat	V	V	M	H
Hubs	M	M	M	M
Rec Room	M	M	M	M

Table 2. The dominant factor that affects the personal presence and social presence for long-term and short-term users on five platforms. V: visual quality; I: interactive events; M: motion sickness; H: Harassment.

distributed. The Friedman test shows that ratings from all users on five platforms are significantly different ($\chi^2(4) = 19.65, p < .001$, Kendall's $W = .42$). The Conover post-hoc test with the Benjamini-Hochberg correction shows that the rating on Worlds ($M = 4.20, SD = 0.75$) is significantly higher than AltspaceVR ($M = 3.74, SD = 0.86, p < .05$), Hubs ($M = 3.50, SD = 0.92, p < .005$) and Rec Room ($M = 3.43, SD = 0.98, p < .005$), but not significantly higher than VRChat ($M = 3.88, SD = 0.88$).

In the interviews, users explained that motion sickness caused by poor system performance is one of the reasons for their low ratings of personal presence on Rec Room and Hubs. For example, L_8 said: “Hubs and Rec Room lag badly. I felt dizzy and nauseous while moving around inside them. It made me feel like I was not in the scene.” L_{19} also commented: “I think if a platform wants to make me feel like I am actually in a virtual environment, it should at least provide me with a comfortable, non-dizzy experience. How could motion sickness on a platform give me a sense of personal presence? After all, I do not get dizzy in the real world.” Another reason is that the cartoon-shaped avatars leave users with no sense of personal presence. For instance, L_6 said: “I feel the personal presence on Hubs is weak due to its pixel avatar”. S_{18} mentioned: “Avatar customization played a role in my sense of personal presence. I felt that Rec Room’s avatars were too cartoony, which I do not like.” The multivariate linear regression analysis also shows motion sickness is the dominant factor affecting the sense of the personal presence of both long-term and short-term users on Hubs and Rec Room, as shown in Table 2.

However, although the number of users experiencing motion sickness in VRChat is comparable to Hubs (Table 1), the Conover post-hoc test with the Benjamini-Hochberg correction shows that the ratings of personal presence on VRChat from all users are significantly higher than those on Hubs ($p < .05$) and Rec Room ($p < .05$). Users reflected in the interviews that this is due to VRChat’s full-body avatars (Figure 6). As L_6 said: “I think the personal presence of VRChat is good because it uses full-body avatars. Half-body avatar is not consistent with our real world, so whenever I see



Fig. 8. User's viewport when looking down on VRChat (left) and Worlds (right).

those half-body avatars, somehow, I am reminded that this is just a virtual place.” L_7 also commented: “VRChat’s full-body avatar allows me to see my body, especially when I am looking down. However, I cannot see my lower body on other platforms, leaving me with no sense of personal presence” (Figure 8). In addition, Worlds’ human-shaped avatars (Figure 6) have been considered by users to enhance their sense of personal presence. For example, L_1 said: “My avatar in Horizon Worlds looks really like me, and my friend [L_2] thinks so too. It is really fun that I can drive myself in a virtual world, which makes me feel I am really in that world.”

5.2 System Performance, Interactive Events, Avatar Interaction, Harassment, and Social Presence

Figure 7(b) shows the ratings of social presence on the five platforms from all, long-term, and short-term users. All ratings are not normally distributed based on the Shapiro-Wilk test. From this figure, we have the following observations.

- First, the Friedman test indicates that the ratings from all users have significant differences on five platforms ($\chi^2(4) = 40.44$, $p < .001$, Kendall’s $W = .48$). The Conover post-hoc test with the Benjamini-Hochberg correction shows that the ratings on Hubs ($M = 3.12$; $SD = 1.09$) and Rec Room ($M = 3.12$; $SD = 1.16$) are significantly lower than the other three platforms (Worlds: $M = 4.26$, $SD = 0.80$, AltspaceVR: $M = 3.79$, $SD = 0.82$, VRChat: $M = 3.60$, $SD = 1.27$; $p < .001$). Moreover, based on the multivariate linear regression analysis, motion sickness is the dominant factor affecting the sense of the social presence of both long-term and short-term users on Hubs and Rec Room, as shown in Table 2. User interviews support our findings. For example, L_9 commented: “My social experience on Hubs and Rec Room is zero since I am so dizzy due to their poor graphical quality.” S_9 also said: “I couldn’t talk with others since I had a bad headache on Hubs and Rec Room.” L_{14} mentioned: “In Rec Room, I once played a game similar to hide-and-seek. That game required people to turn their heads a lot to find other people. The VR game is awesome. But my social presence is very bad because if I turn my head fast, I get dizzy and have a headache.”
- Second, in contrast to the ratings of personal presence in Figure 7(a), the Conover post-hoc test with the Benjamini-Hochberg correction shows that the ratings of social presence from all users on VRChat ($M = 3.60$, $SD = 1.27$) are significantly lower than Worlds ($M = 4.26$, $SD = 0.80$, $p < .001$). Also, we apply the Wilcoxon signed-rank test and observe that the ratings of social presence on VRChat from all users ($M = 3.55$, $SD = 1.27$) are significantly lower than their ratings of personal presence ($M = 3.94$, $SD = 0.88$, $p < .05$ and $r = .41$). Although VRChat could offer users a better sense of personal presence thanks to its full-body avatar (§5.1), it does not provide users with a greater sense of social presence, mainly because it does not offer full-body tracking to control



Fig. 9. Facial expressions of the avatar on Worlds when the user performs thumbs-up and thumbs-down.

its avatars. For example, L_6 , who considered the full-body avatars of VRChat could improve the sense of personal presence (§5.1), told us: *“The movement of the [avatar’s] lower body is faked by the software, not controlled by my real movement. I do not think this helps enhance social presence.”* In addition, we find in interviews that harassment is another factor affecting users’ sense of social presence. For instance, L_{13} , who felt harassed on VRChat and Hubs, commented: *“The only thing I want to do after being harassed is to exit that room or even that platform.”* Moreover, we observe that users who were harassed on a platform rated it low for social presence ($M = 2.05$ and $SD = 0.86$). Since VRChat has the highest number of harassed users (Table 1), this affects the rating of its social presence. The multivariate linear regression analysis supports this by demonstrating that harassment becomes the dominant factor influencing the sense of social presence on VRChat of short-term users (Table 2). For long-term users on VRChat, motion sickness is the dominant factor affecting their sense of social presence (Table 2). The reason is that 15 out of 21 experienced motion sickness on VRChat (as shown in Table 1).

- Third, the Mann-Whitney U test shows that the ratings of social presence on Hubs from long-term users ($M = 2.76$ and $SD = 0.97$) are significantly lower than short-term users ($M = 3.55$, $SD = 1.06$, Rank-biserial correlation $r = .41$). This is due to its lack of highly interactive events (§3.1) that further decreases long-term users’ sense of social presence. As L_{18} said: *“I cannot feel I have any social interaction on Hubs since it is very boring and lags badly.”* L_{17} commented: *“I think Hubs has the weakest social presence because it only has a few simple chat events, which are boring. And I still feel dizzy in the chat events, which makes me feel worse.”* While AltspaceVR also lacks highly interactive events (§4.2), its highest resolution (Table 1) made long-term users have a comparable sense of social presence as short-term users, as shown in Figure 7(b). For example, L_2 , who got tired of AltspaceVR after using it for a while, told us: *“AltspaceVR is boring, but at least I can still talk with others. Hubs is also boring, and I cannot even talk with other guys because I feel really dizzy there. Boredom and dizziness felt like double punishments for me on Hubs.”*

- Finally, both long-term and short-term users rated their sense of social presence on Worlds significantly higher than others. The Friedman test indicates that there are significant differences in ratings on the five platforms from long-term ($\chi^2(4) = 25.42$, $p < .001$, Kendall’s $W = .30$) and short-term users ($\chi^2(4) = 18.51$, $p < .001$, Kendall’s $W = .35$). The Conover post-hoc test with the Benjamini-Hochberg correction shows that Worlds’ social-presence ratings from long-term users ($M = 4.22$ and $SD = 0.85$) are significantly higher than the others (AltspaceVR: $M = 3.78$, $SD = 0.73$, $p < .05$; VRChat: $M = 3.28$, $SD = 1.38$, $p < .05$; Hubs: $M = 2.76$, $SD = 0.97$, $p < .001$;

Rec Room: $M = 3.00$, $SD = 1.27$, $p < .005$). Such observation is also found in short-term users on Worlds ($M = 4.33$, $SD = 0.74$), compared to others (AltspaceVR: $M = 3.77$, $SD = 0.91$, $p < .05$; VRChat: $M = 3.88$, $SD = 1.04$, $p < .05$; Hubs: $M = 3.55$, $SD = 1.06$, $p < .01$; Rec Room: $M = 3.27$, $SD = 0.98$, $p < .001$).

Worlds performs best in all the factors affecting users' sense of social presence that we have investigated. For example, it has the lowest number of users who were harassed (Table 1), the highest frame rate among five platforms (Figure 4), and the richest social activities (§4.2). In addition, we also find that the avatars of Worlds have rich facial expressions based on users' gestures (Figure 9), which can enhance their sense of social presence. This is confirmed by user interviews. For instance, L_{17} commented: *"I think the social presence of Worlds is the best since I can get feedback when I interact with others. For example, the avatar of Worlds will have different facial expressions when others and I perform different gestures, making me feel like we are connected. The facial feedback encourages people to interact and chat with each other, and enforces a sense of social presence. I don't feel the same sense of connection on other platforms. I think their avatars' interaction is not natural."*

Key Findings: We summarize our key findings on factors influencing users' sense of personal presence and social presence on social VR platforms as follows.

- System performance and avatar appearance influence users' sense of personal presence. Good system performance, as well as human-shaped and full-body avatars, can enhance their sense of personal presence.
- Human-shaped and full-body avatars that can improve users' sense of personal presence have limited contributions to their sense of social presence, due to the lack of realism.
- Users' sense of social presence is negatively impacted by poor system performance and harassment. In addition, the lack of interactive social events, combined with poor system performance, can further degrade the sense of the social presence of long-term users.

6 Discussion and Future Work

6.1 Discussion

Our findings have broad implications for the design practice and improvement of social VR platforms and the Metaverse, as discussed below.

System Performance. Our user study and measurement results reveal that all five social VR platforms suffer from poor system performance on Quest 2 (an untethered VR headset) when supporting a large number of users, which increases the likelihood of users experiencing motion sickness and degrades their experience. Thus, improving system performance on untethered VR headsets is a pressing issue for social VR platforms. The root cause of this issue is that untethered VR headsets have to rely on their own CPUs and GPUs, which are not powerful, primarily due to their compact form. Consequently, they can render VR content with only fair quality. Moreover, as the number of users in the virtual environment increases, the rendering stress on the headset increases, leading to scalability issues (e.g., FPS declines, as shown in Figure 4). However, the full-fledged Metaverse should support tens of thousands of users [55, 86], which will exacerbate this issue. We point out that leveraging remote rendering [10, 51, 70] that offloads the rendering process to the cloud/edge, is a promising solution. The reason is two-fold. First, cloud and edge servers are equipped with more powerful CPUs and GPUs, enabling high-quality VR rendering. Second, in the remote rendering scheme, even though there are many users in the virtual scene, the servers will render the entire scene into a video frame whose size is independent of the number of users, alleviating the scalability issues.

We next discuss the potential impact of network bandwidth and latency on user experience. We did not evaluate these factors in our study for the following reasons. Currently, the bandwidth consumption of social VR platforms is relatively low (e.g., less than 5 Mbps [3]), and we verified that the available bandwidth of our participants' networks was sufficient to support the operation of these platforms (§3.2). Regarding latency, no user reported experiencing significant delay during the study. However, we anticipate that both bandwidth and latency could become more critical factors affecting user experience in the future. First, the avatars in current social VR platforms are not yet highly realistic or equipped with full-body tracking. High-quality, full-body avatars may require significantly higher bandwidth than what we observed. For example, existing prototypes such as Holoportation [84] demonstrate that creating a photo-realistic 3D model of the human body and capturing real-time movement can demand more than 1 Gbps for a single person. A potential solution is to leverage viewport-aware optimizations [37] and semantic communication [13] to reduce bandwidth consumption. Second, due to the highly interactive nature of social VR, reducing end-to-end latency between users is crucial for maintaining a satisfactory user experience (e.g., <100 ms [17]). Given that latency is largely influenced by the physical distance between users, with longer distances leading to higher round-trip times (RTT) [22], one potential reason that our participants did not report latency issues is that the majority of social VR users are currently located within the US [106]. However, as social VR platforms become more globally popular, latency issues are likely to become more pronounced. For instance, the RTT between Europe and Asia can already exceed 100 ms [125]. A viable solution would be to deploy geo-distributed servers, ensuring that users connect to a nearby server, while high-speed private networks interconnect these servers to reduce RTT [19].

Interactive Events. We find that highly interactive event, such as gaming, is an important factor that affects long-term users' experience. Some previous study also demonstrates that the primary purpose of using social VR platforms is socializing and enjoyment [106]. This prompts platforms to design more interactive events in order to increase user stickiness. Moreover, our study reveals that designing highly interactive events to engage users is contingent on having satisfactory system performance. For example, we find that many users encountered performance issues and felt motion sickness on Rec Room and VRChat (Table 1). As shown in Figure 3, this results in even lower overall experience ratings for them than AltspaceVR, which has relatively better system performance but lacks highly interactive events. This finding contradicts previous user surveys that indicate VRChat and Rec Room are the most popular social VR platforms since they have intriguing events [106, 107]. This is due to the fact that users in those studies accessed social VR platforms via different types of devices (e.g., PCs, tethered, or untethered VR headsets). In our study, we let users access these platforms using only Oculus Quest 2, an untethered headset, which contributes new insights into the relationship between highly interactive events and user experience on social VR platforms.

Avatar Appearance and Interaction. Our findings reveal that these platforms' avatars have limited contribution to users' social presence and overall experience, even though some of them have full-body (e.g., VRChat) and human-shaped (e.g., Worlds) avatars. This contrasts with prior research, which suggests that full-body and human-shaped avatars can provide users with a satisfactory level of user experience [29, 38, 53]. Our experiments indicate that this is because these avatars still lack full-body tracking and are not realistic, reflecting two avatar-design limitations on current social VR platforms. These findings align with previous research, which emphasizes that full-body tracking [105] and high visual fidelity are critical for enhancing user experience [85]. However, enabling these features is non-trivial. First, despite the fact that VRChat does support full-body tracking, it requires additional sensors bound to users' bodies and a tethered VR headset connected to a high-end PC for rendering [118], which is inconvenient and increases the risk of the user

tripping over cables while moving [51]. One potential solution is to add downward-facing cameras to the headset [18] and/or controllers [2] for full-body tracking. Second, as discussed above, realistic avatar embodiment necessitates capturing and updating more user movements, increasing network bandwidth demand and rendering overhead [52]. While various optimization approaches, such as viewport-aware optimizations [37] and semantic communication [13], have been proposed, as discussed above, they may in turn negatively impact visual quality. For instance, viewport-aware optimizations rely on predicting users' future viewports and transmitting/rendering content only within that field of view. If the prediction is inaccurate, it can result in content drift, which negatively impacts perceived visual quality and user experience. Therefore, these trade-offs warrant further investigation to determine the optimal balance between avatar realism and system performance.

Platform Availability. After our experiments (conducted between 2022 and 2023), the availability of some of the platforms we tested changed. Both AltspaceVR [113] and Hubs [78] were shut down, while Worlds continues to expand, supporting access in more countries [92]. Our study's findings offer insights into these market developments. For instance, although AltspaceVR exhibited relatively strong system performance, it lacked engaging and dynamic events, leading to lower overall experience ratings among long-term users compared to short-term users. Similarly, Hubs faced challenges with both technical performance (e.g., low frame rates and resolution) and a lack of interactive events, which resulted in a poor user experience for both long-term and short-term users. In contrast, Worlds consistently performed well across multiple factors, contributing to its continued growth and global expansion. The differences in platform sustainability observed in the real world align with our findings, reinforcing the validity of our study. While these findings suggest potential factors influencing user retention, we acknowledge that platform discontinuation is also driven by business factors, such as company priorities, beyond user experience.

Harassment Prevention. We find that harassment in social VR can severely impact users' social presence and overall experience. Also, harassment prevention mechanisms provided by these platforms are inadequate to protect users. An effective mechanism should be able to recognize and respond to incidents of harassment when (or even before) they occur. Such mechanisms have been investigated for both text-based and image-based harassment in traditional online social media [35, 117], which can provide some clues for the design of motion-based harassment prevention mechanism for social VR.

6.2 Future Work

While this is the first comprehensive study to dissect user experience on social VR platforms, there are some limitations in our work that we plan to address in the future.

Different Types of Devices. In this work, we provide users with a Quest 2 VR headset to understand their experience of social VR platforms. However, most of the social VR platforms allow other types of devices, such as tethered VR headsets and PCs, to access them [15]. In our future work, we plan to conduct a large-scale user study to understand and compare user experience on social VR platforms with different types of devices.

Prior VR Experience. When recruiting participants, we ensured they had no prior experience with the five selected social VR platforms to guarantee that the comparison of long-term and short-term user experiences is valid. However, we did not consider users' prior VR experience (e.g., what VR devices they have used and how long they have used them), which may provide us with more insight into the factors that influence the user experience on social VR platforms. This is part of our future work.

Measuring System Performance during User Study. In this work, we measure the system performance of these platforms in our controlled lab environment rather than during the user

study to minimize the interference of measurements with user experience. Moreover, we measure mainly two performance metrics (*i.e.*, resolution and FPS). There are other metrics that may affect user experience, for example, motion-to-photon latency. We are currently building lightweight, comprehensive, and open-source tools on VR headsets to facilitate large-scale measurements for a better understanding of user experience on social VR platforms.

Other Aspects of User Experience. In this study, in addition to overall experience, we focus on evaluating presence, one of the most critical and unique components of user experience in social VR. We make this decision because the study allows users the freedom to explore the platforms without being constrained by specific tasks. As a result, we chose to focus on generic user experiences, such as presence and overall experience, which are applicable across different social VR platforms, minimizing potential biases that could arise from users engaging with various types of social events. In future work, we plan to design structured tasks on these platforms to evaluate more specific aspects of user experience. For example, we could create online education sessions within social VR platforms [39]. In this way, we can explore user experiences closely tied to learning processes, such as interest and motivation [39], effectiveness [71], and outcomes [54], by using widely adopted online education surveys such as the Online Learning Enrollment Intentions (OLEI) scale [49].

7 Conclusion

In this paper, we presented a comprehensive study to understand short-term and long-term users' experience on five social VR platforms, one of the fundamental elements of the emerging Metaverse. We found that motion sickness, attributed to poor system performance (*i.e.*, low frame rate), plays a pivotal role in influencing users' overall experience and sense of social presence on social VR platforms. Moreover, lacking highly interactive events led to a poorer overall experience for long-term users compared to short-term users. In addition, our analysis shows that avatar appearance has a limited contribution to users' sense of social presence across all five platforms. We hope these findings can shed light on future efforts to design social VR platforms and the emerging Metaverse.

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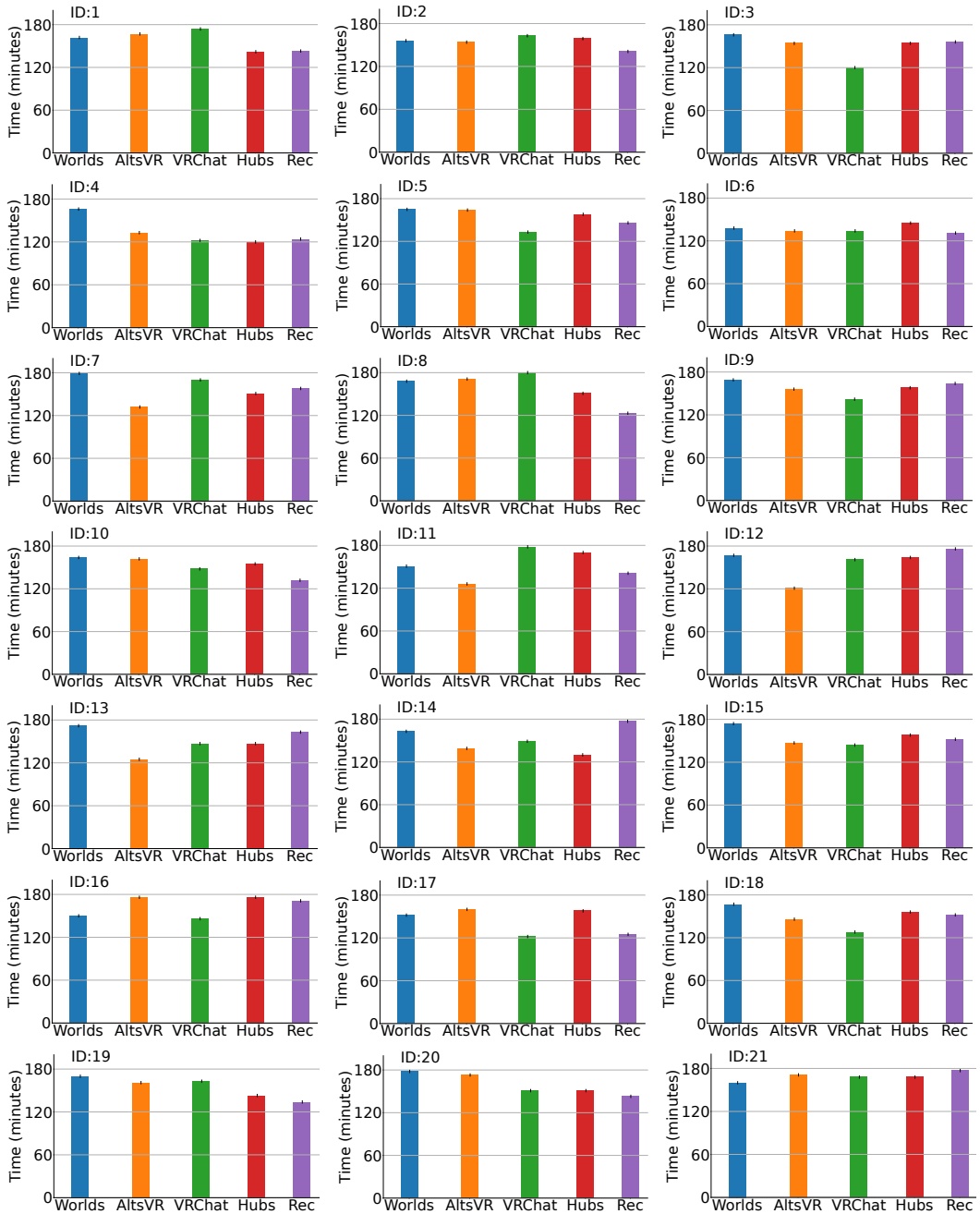


Fig. 10. Usage time spent on five platforms by each long-term user.



Fig. 11. Usage time spent on five platforms by each short-term user.

Appendices

A Usage Time for Each User

Figures 10 and 11 present the time spent on five platforms by each long-term and short-term user, respectively.

Q1: What is your name?

Q2: What is your gender?

☐ Male
☐ Female
☐ Prefer not to say

Q3: How old are you?

☐ < 18
☐ 18 to 24
☐ 25 to 34
☐ > 34

Q4: What is your rating of the overall experience on these platforms?

	Extremely bad	Somewhat bad	Medium	Somewhat good	Extremely good
Horizon Worlds	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
AltspaceVR	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Rec Room	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Mozzlio Hubs	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
VRChat	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Q5: Please describe why you rated 1 (Extremely bad) or 5 (Extremely good) for the overall experience on these platforms. Skip this question if you didn't rate 1 or 5 for these platforms.

Q6: What is your rating of the visual quality on these platforms?

	Extremely bad	Somewhat bad	Medium	Somewhat good	Extremely good
Horizon Worlds	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
AltspaceVR	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Q7: What is your rating of highly interactive events (e.g. sports games, dancing activities, etc.) provided by these platforms?

	Extremely bad	Somewhat bad	Medium	Somewhat good	Extremely good
Rec Room	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Mozzlio Hubs	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
VRChat	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Q8: Do you feel a sense of personal presence when you use these platforms? (Personal presence: Users have the feeling that they are actually inside the virtual environment)

	Very weak	Weak	Medium	Strong	Very strong
Horizon Worlds	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
AltspaceVR	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Rec Room	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Mozzlio Hubs	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
VRChat	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Q9: Do you feel a sense of social presence with other users when you use these platforms? (Social presence: Users have the feeling that other living or synthetic beings co-exist with them in the virtual environment.)

	Very weak	Weak	Medium	Strong	Very strong
Horizon Worlds	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
AltspaceVR	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Rec Room	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Mozzlio Hubs	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
VRChat	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Q10: When you use these platforms, have you experienced motion sickness?

	No	Yes
Horizon Worlds	<input type="radio"/>	<input type="radio"/>

Q11: If you have ever felt motion sickness on these platforms, please describe the scenario.

Q12: Do you ever feel harassed by other users when you use these platforms?

	No	Yes
Horizon Worlds	<input type="radio"/>	<input type="radio"/>
AltspaceVR	<input type="radio"/>	<input type="radio"/>
Rec Room	<input type="radio"/>	<input type="radio"/>
Mozzlio Hubs	<input type="radio"/>	<input type="radio"/>
VRChat	<input type="radio"/>	<input type="radio"/>

Q13: If you have ever felt harassed on these platforms, please describe the scenario (You can omit the privacy information.)

Q14: What is your opinion on the harassment prevention mechanism of these platforms?

Fig. 12. Full survey used in our study.

B Full Questionnaire

Figure 12 shows the full survey used in our study.

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