

International Journal of Human–Computer Interaction

ISSN: 1044-7318 (Print) 1532-7590 (Online) Journal homepage: www.tandfonline.com/journals/hihc20

Safety Paradox: How Uncertainty Shapes Immersive Engagement and Social Bonding in Location-Based Virtual Reality

Zhiyun Lei & Shuyue Li

To cite this article: Zhiyun Lei & Shuyue Li (04 Sep 2026): Safety Paradox: How Uncertainty Shapes Immersive Engagement and Social Bonding in Location-Based Virtual Reality, International Journal of Human–Computer Interaction, DOI: 10.1080/10447318.2026.2722788

To link to this article: https://doi.org/10.1080/10447318.2026.2722788

Published online: 04 Sep 2026.

Submit your article to this journal

View related articles

View Crossmark data

Full Terms & Conditions of access and use can be found at
https://www.tandfonline.com/action/journalInformation?journalCode=hihc20

INTERNATIONAL JOURNAL OF HUMAN–COMPUTER INTERACTION
https://doi.org/10.1080/10447318.2026.2722788

Taylor & Francis
by informa

Check for updates

Safety Paradox: How Uncertainty Shapes Immersive Engagement and Social Bonding in Location-Based Virtual Reality

Zhiyun Lei[a] and Shuyue Li[b]

[a]Faculty of Humanities and Arts, Macau University of Science and Technology, Macao, China; [b]Computational Media and Arts, The Hong Kong University of Science and Technology (Guangzhou), Guangzhou, China

ABSTRACT

Location-based virtual reality (VR) enables large-area movement and co-located interaction in immersive shared environments. However, little is known about how users experience and regulate safety in hybrid physical–virtual spaces, particularly under uncertainty and social coordination. To address this gap, we conducted a qualitative study involving semi-structured interviews, focus groups, and participant observation with 49 participants who had experienced location-based VR. Thematic analysis identified recurring experiential states, organized into a three-zone framework—Comfort Zone, Optimal Experience, and Panic Zone—describing how perceived controllability shapes fear and engagement. We further propose a qualitative conceptual model synthesizing how participants described drawing on both system-based cues and interpersonal support to maintain embodied safety. Together, these findings reveal a safety paradox: immersive engagement often depends not on eliminating uncertainty but on sustaining a regulated form of insecurity that remains perceptible yet manageable.

KEYWORDS

Location-based virtual reality (VR); safety perception; social presence; immersive experience; qualitative research

1. Introduction

Location-based virtual reality (VR) extends the immersive experience beyond seated or stationary interaction by allowing users to move through large physical environments while engaging with virtual content alongside co-located participants (Lopes et al., 2017; Sayyad et al., 2020) (see Figure 1). By combining bodily movement, shared spatial navigation, and face-to-face coordination, such systems are widely assumed to enhance immersion through stronger embodiment, spatial realism, and social presence (Fan et al., 2022; Jicol et al., 2023; Turkay et al., 2021). Yet this hybrid arrangement also introduces a distinctive experiential condition of uncertainty. Users must act within environments where virtual scenarios unfold while real physical consequences remain possible.

Under these conditions, participants operate under persistent uncertainty. Because head-mounted displays visually occlude the physical world, users must infer spatial boundaries, track the movements of nearby participants through mediated cues, and continuously evaluate whether their actions remain physically safe. Moments of hesitation, disorientation, and bodily tension are therefore common in location-based VR experiences (Xu & Ge, 2025). At the same time, these moments are not simply disruptions. The very uncertainty that generates hesitation may also contribute to the intensity and excitement of the immersive experience. This creates a fundamental tension: immersive engagement appears to depend on uncertainty, yet excessive uncertainty can threaten users' sense of safety and control.

This tension can be understood as a safety paradox. On the one hand, immersive environments rely on credible uncertainty and perceived threats to sustain curiosity, exploration, and emotional intensity. If uncertainty is removed entirely, the experience risks becoming predictable and emotionally flat. On the other hand, users must simultaneously maintain a sufficient sense of bodily security to remain capable of acting within the environment. When uncertainty exceeds users' ability to orient themselves or

CONTACT Shuyue Li sli688@connect.hkust-gz.edu.cn Computational Media and Arts, The Hong Kong University of Science and Technology (Guangzhou), Guangzhou, China

© 2026 Taylor & Francis Group, LLC



Figure 1. Location-based VR experience venue.

coordinate with others, it can trigger panic, withdrawal, or loss of agency. Immersion, therefore, appears to arise not from eliminating uncertainty but from regulating it.

Safety in VR research has often been conceptualized primarily as a technical problem. Within human-computer interaction (HCI) and VR engineering, safety is typically addressed through system reliability, collision avoidance, and risk reduction mechanisms (Azmandian et al., 2014; Meehan et al., 2002; Sun et al., 2018). Design solutions such as boundary visualization, redirected walking, and multimodal warning systems aim to minimize uncertainty so that users can move fluently while remaining physically protected. These approaches have produced important technological advances, yet they also rely on an implicit assumption: that reducing uncertainty necessarily improves the immersive experience.

However, psychological and experiential research suggests that engagement often emerges not from the absence of uncertainty but from its careful regulation. Theories such as flow (Csikszentmihalyi, 1990), optimal arousal (Carrol et al., 1982; Yerkes & Dodson, 1908), and voluntary risk-taking (Lyng, 1990) indicate that challenge, tension, and perceived risk can intensify engagement when they remain within a manageable range. From this perspective, safety cannot be understood solely as the successful elimination of danger. Instead, it emerges through an ongoing appraisal process in which individuals evaluate perceived threat, controllability, and their capacity to act within a situation (Li et al., 2024; Riva et al., 2007).

This regulatory process becomes particularly complex in location-based VR because safety is not managed by the system alone. Users share physical space with companions and strangers, rely on mediated representations to infer proximity, and often adjust their behavior through mutual monitoring, reassurance, and coordination. Safety in these environments is therefore both embodied and relational. It is embodied because users must feel capable of moving without imminent harm (Penaud et al., 2023; Pritchard et al., 2016), and relational because this capacity often depends on the legibility of others' actions and the availability of social support (Almeida et al., 2022; Strojny et al., 2020). Yet existing research has not sufficiently explained how these socio-technical resources are combined in users' moment-to-moment regulation of safety, nor how such regulation shapes immersive engagement and social bonding.

To address this gap, the present study examines how safety is experienced and regulated in location-based VR under conditions of uncertainty and co-located interaction. Drawing on qualitative data from semi-structured interviews, focus groups, and participant observation with 49 individuals who have experienced location-based VR, we analyze safety not as a binary outcome, but as an ongoing experiential process. Specifically, this study asks:

RQ1: How do users perceive and interpret safety under conditions of uncertainty in location-based VR?

RQ2: How do participants regulate uncertainty to sustain immersion and social interaction in shared immersive environments?

Our findings show that users do not simply seek maximum safety. Instead, they attempt to remain within a workable experiential range in which uncertainty remains perceptible, but action remains possible.

This paper makes three contributions. First, it extends existing understandings of safety in immersive environments by examining how safety is dynamically regulated in location-based VR. Rather than treating safety solely as objective protection, our findings highlight users' ongoing appraisal of whether uncertainty remains manageable during action. Second, it identifies a socio-technical regulatory mechanism through which this balance is maintained, showing how users adjust their reliance between system-based cues and interpersonal coordination to stabilize their sense of embodied safety. Third, the paper introduces the concept of controlled insecurity, describing the experiential condition in which uncertainty remains credible enough to sustain immersion and social bonding while still preserving users' capacity to act.

By theorizing safety as an embodied and socially negotiated condition of immersive engagement, this study contributes to research on VR experience, social presence, and HCI. More broadly, it suggests that immersive systems may benefit not from eliminating uncertainty, but from supporting users in maintaining uncertainty within a range that remains experientially manageable. The remainder of the paper reviews related work, presents the empirical findings, discusses theoretical and design implications, and outlines directions for future research.

2. Literature review

We situate this work at the intersection of location-based VR, embodied experience, and co-located social interaction, focusing on how users experience and regulate safety within shared immersive environments. We begin by reviewing safety challenges in location-based VR, specifically how the combination of physical freedom and multi-user environments introduces collision risks that are typically managed through defensive design mechanisms. Next, we draw on theories of embodiment and risk engagement to distinguish between objective protection and the subjective sensation of safety, arguing that the latter is constructed through self-representation and perceived controllability. Finally, we synthesize research on social presence to frame safety as a relational negotiation, mediated not only by system boundaries but by the presence of others, setting the stage for our empirical study.

2.1. Safety in location-based VR

Despite these immersive affordances, navigating location-based VR environments raises important safety challenges. Because users move through shared physical spaces while visually immersed in virtual content, they must continuously manage physical boundaries and the movements of nearby participants (Michaelides et al., 2025). Prior work has primarily addressed these challenges through technical optimizations, such as redirected walking, which maximizes navigable space while keeping system constraints perceptually invisible (Razzaque et al., 2002; Steinicke et al., 2010). However, this engineering-focused perspective often overlooks how users experience and interpret safety during interaction, particularly how they assess system reliability, boundary legibility, and the manageability of potential physical consequences.

Beyond spatial scale, location-based VR is also distinguished by co-located physical presence (Slater, 2009). Unlike remote platforms such as VRChat, users share the same physical venue, enabling collaboration through embodied cues such as pointing, yielding, and coordinated movement. These interactions can significantly enhance social presence and cooperative behavior (Lacoche et al., 2017; Wienrich et al., 2018). High-fidelity tracking technologies further amplify embodied expressivity, making body coordination a central component of the shared experience (Sykownik et al., 2023). At the same time, however, the physical presence of others introduces new forms of spatial uncertainty (Witmer & Singer, 1998). Because users primarily rely on avatars and system-generated cues to infer the location and intention of others, the relationship between virtual representations and real bodies is not always fully transparent. As a result, co-located interaction often contains latent spatial tension, requiring participants to continuously interpret system signals while anticipating the movements of nearby users.

Consequently, managing spatial safety, particularly the risk of physical collision, has become an important challenge in HCI. Previous work has typically addressed this issue through defensive system design strategies, including multimodal warning signals, virtual guardrails, and automated redirection techniques that prevent users from approaching hazardous boundaries (Fan et al., 2022; Lei et al., 2023; Peck et al., 2013). While these approaches are effective from an engineering perspective, they tend to conceptualize collision risk primarily as a technical failure to be minimized (Podkosova & Kaufmann, 2018). Such a perspective provides limited insight into how users actually navigate location-based VR environments (Scavarelli & Teather, 2017). In practice, users do not rely solely on automated safeguards; instead, they actively interpret system cues, monitor the proximity of others, and dynamically coordinate their movements to maintain a workable sense of bodily safety (Langbehn et al., 2018).

2.2. Embodiment and risk engagement in VR experiences

Embodiment describes the experiential state in which users perceive a virtual body as their own (body ownership) and under their control (agency) (DeVeaux et al., 2025). This state arises from the integration of consistent multisensory cues—visual, proprioceptive, and haptic—which align virtual consequences with real-world actions (Barbot & Kaufman, 2020). While related to immersion (the sensation of being in a place), embodiment specifically concerns the user's relationship with their virtual body and their capacity to act (Kilteni et al., 2012). Crucially, embodiment influences not only whether users feel present but also how they interpret risk and evaluate their capacity for action (Burychka et al., 2021; Xu et al., 2025). When bodily signals align with virtual feedback, users are more likely to perceive threats as manageable challenges rather than uncontrollable hazards.

Sociological and HCI theories suggest that controlled exposure to risk can enhance engagement. Lyng's (1990) concept of edgework describes the voluntary navigation of boundaries between order and chaos to achieve mastery and focus. Shay (2017) adapts this to mediated environments as "edgework without the edge," where users experience the thrill of extreme activities with reduced physical consequences. Similarly, Benford et al. (2012) argues for "uncomfortable interactions," suggesting that carefully designed discomfort—whether physical, psychological, or visceral—can deepen entertainment and social bonding. These perspectives imply that felt risk is not necessarily a system failure. Under conditions of intelligibility and recoverability, risk becomes an experiential resource (Obeada et al., 2026). However, this requires users to perceive "control" not just as an objective safety measure, but as a subjective appraisal of rules, boundaries, and trust in the system (Raggiotto & Scarpi, 2023).

As a high-immersion medium, VR can elicit physiological responses comparable to real-world stressors, often exceeding the emotional impact of traditional media (El Basbasse et al., 2023). This capability is utilized in both therapeutic and entertainment contexts. In exposure therapy, patients confront fears (e.g., heights or social anxiety) within a controlled environment; the efficacy of the treatment relies on the user maintaining a ongoing regulation of perceived safety despite high arousal (Emmelkamp et al., 2020; North et al., 1998). Similarly, horror experiences leverage the tension between fear and curiosity to drive immersion (Perron, 2012). Collectively, this work demonstrates that VR's power lies in structuring a productive tension: users remain engaged and action-capable not because negative affect is eliminated, but because the environment remains legible and controllable.

While existing research demonstrates that fictional danger and affective arousal can enhance engagement in VR, it often overlooks the distinctive risk structure of location-based VR. In co-located settings, risk arises not only from narrative or perceptual illusions but also from the physical presence and movement of other users (Slater & Sanchez-Vives, 2016). Because avatars and system cues provide only partial information about others' positions and intentions, participants must continuously infer how virtual representations correspond to real bodies in shared space. As a result, maintaining safety becomes an ongoing process of interpretation and coordination rather than a purely technical guarantee. Users actively regulate their sense of safety by combining system feedback with interpersonal adjustments, such as yielding space, signaling intentions, or adapting movement trajectories.

2.3. Social presence and shared vulnerability

Short et al. (1976) originally defined *social presence* as the "salience of the other." Since then, the concept has evolved in HCI discourse from a static property of the medium to a dynamic, intersubjective experience (Biocca et al., 2003; Cummings & Wertz, 2022). In the specific context of location-based VR, however, social presence transcends the traditional "non-mediated illusion" of being there. Because users share a physical tracking space, social presence becomes embodied and consequential (Wienrich et al., 2018). It is not merely a psychological sense of "being with" a virtual avatar, but a heightened state of mutual awareness driven by the tangible reality of the other person's physical body (Tietenberg et al., 2025). Thus, in location-based VR, social presence serves as a key foundation for social bonding, weaving together the virtual narrative with the physical necessity of navigating a shared space.

Building on this embodied view, we introduce *shared vulnerability* as a key mechanism shaping social presence in location-based VR. Social psychology literature posits that co-experiencing challenges, threats, or even pain can rapidly accelerate trust and group cohesion (Bastian et al., 2014). Just as Bastian observed that shared adversity fosters "psychological distinctiveness" and solidarity in strangers, HCI research suggests that "uncomfortable interactions" or managed risks can function as powerful social glue (Benford et al., 2012). In VR, this may manifest as active "mutual care" among co-present users when they perceive a credible threat, whether arising from the demands of collaborative gameplay or the risk of physical collision (Tietenberg et al., 2025). This heightened state of alertness, where users must negotiate safety together, paradoxically amplifies social presence. The uncertainty of the environment transforms the partner from a mere bystander into a crucial ally, validating the theory that a calibrated level of unsafety can deepen the social bond. Shared vulnerability, therefore, functions as the experiential mechanism through which controlled uncertainty transforms potential risk into opportunities for social bonding.

2.4. Cross-cultural interaction in virtual environments

Emerging research suggests that social interaction in virtual environments remains shaped by culturally grounded norms of interpersonal behavior. Studies on avatar-mediated communication have shown that users from different cultural backgrounds maintain distinct patterns of interpersonal distance and spatial coordination even in virtual settings. For example, cross-cultural analyses of virtual proxemics indicate that users of Asian cultural contexts tend to maintain larger interpersonal distances than their European counterparts, reflecting culturally embedded norms of personal space and social interaction (Hasler & Friedman, 2012). Similarly, previous work has demonstrated that users continue to follow proxemic conventions from the real-world in immersive environments, maintaining socially appropriate distances and adjusting their behavior based on contextual cues (Bailenson et al., 2003). More recent studies further investigate interpersonal distance regulation in VR, extending proxemics theory to group interactions and dynamic social contexts (Nolte et al., 2025).

These differences are often interpreted through broader cultural frameworks, where collectivistic contexts tend to emphasize interpersonal awareness, coordination, and sensitivity to others in shared environments (Markus & Kitayama, 1991; Triandis, 2018). Together, these findings indicate that immersive environments do not neutralize cultural differences but instead reproduce and sometimes amplify culturally specific interaction patterns. This has important implications for shared immersive

experiences, where coordination, safety perception, and social awareness may be shaped not only by system design but also by culturally informed expectations of interpersonal behavior.

Prior research points to three complementary insights. First, while location-based VR enhances agency through natural movement and co-location, these features introduce embodied and interpersonal risks that transcend simple collision avoidance (Mangalam et al., 2024). Second, theories of embodiment and controlled risk suggest that engaging experiences rely on a calibrated tension between arousal and control, meaning that a user's sense of safety is an active, ongoing accomplishment rather than a static guarantee (Makani et al., 2024). Third, social presence in shared physical spaces is critical; mutual awareness and coordination are central to both the quality of the experience and the maintenance of safety (Deng et al., 2024).

A critical gap remains in understanding how users dynamically regulate safety in shared location-based VR environments, where physical movement, system boundaries, and co-located interaction intersect. Specifically, it remains unclear how users interpret boundary cues, how they shift reliance between system feedback and interpersonal coordination, and under what conditions managed uncertainty enhances rather than undermines immersive experience. Existing theories such as *Flow* (Csikszentmihalyi, 1990) and *Edgework* (Lyng, 1990) offer important accounts of how challenge, uncertainty, and perceived control contribute to engagement. However, these frameworks primarily conceptualize regulation as an individual process. In location-based VR, by contrast, maintaining engagement requires users to negotiate uncertainty not only through individual appraisal but also through coordination with technological systems, spatial boundaries, and co-located others. Addressing this gap, the present study examines safety as an experiential and socio-technical accomplishment that users continuously negotiate in situated immersive interaction. From this analysis, we develop a dynamic account of safety regulation in location-based VR and derive design implications for balancing experiential intensity with actionable safety.

3. Methods

3.1. Study design

This study draws on a qualitative investigation and employs thematic analysis to explore how users experience and negotiate safety within shared immersive environments. Given the exploratory nature of the research questions (see Table 1), qualitative methods were chosen to capture participants' subjective interpretations of bodily perception, uncertainty, and social interaction during location-based VR experiences.

This study was conducted in accordance with the principles of the Declaration of Helsinki. Ethical approval was obtained from the Research Construction and Development Department at The Hong Kong University of Science and Technology (Guangzhou) (Protocol No. HKUST(GZ)-HSP-2025-0320). All procedures complied with institutional and national guidelines for research involving human participants.

3.2. Participants

Participants were recruited using purposive sampling to capture a range of relevant experiences (Patton, 1990). Eligibility criteria required participants to be aged 18 or above and to have experienced location-based VR at least once. Recruitment was conducted through social media platforms (e.g., Xiaohongshu/Rednote) as well as university communities in mainland China, Macao, and Hong Kong.

A total of 49 participants took part in the study (27 female, 22 male), representing diverse professional and cultural backgrounds, including designers, researchers, engineers, lawyers, animators, and journalists. Among them, 35 were general users, and 14 were domain experts (see Table 2).

Participants referred to a range of location-based VR experiences, including cultural heritage reconstructions such as *Horizon of Khufu*, *Luoyang VR*, *Eternal: Notre-Dame*, *Titanic: Echoes from the Past*, *Wow! Sanxingdui*, and *Chinese Journey: Beijing Central Axis*; science-oriented experiences such as *Space Explorers: The Infinite*; and interactive narrative experiences such as *The Castle of Lost Times* and *Love*

Table 1. Broad interview questions.

Physical Insecurity
• During the experience, was there a specific moment where you suddenly hesitated to move forward? How did your body feel at that moment?
• How did you judge whether you were going to hit a real wall or a person? Did that worry stop you from fully enjoying the game?
Psychological Anxiety
• Did you feel like you were in total control the whole time? Was there any moment where you felt panicked or uncertain?
• How did it feel emotionally to be completely cut off from the real world while wearing the headset?
• Did looking at your virtual "self" feel weird or awkward? Were there any movements that just didn't feel right?
Social Anxiety
• Were you conscious of the staff or other people watching you from the outside? Was that feeling strong?
• Did you worry that you might look silly making movements in the real world? Did that hold you back?
Safety Needs
• When you felt scared or unsure, what did you instinctively do to make yourself feel safer?
• If you could add one feature to make people feel safe enough to run freely in this space, what kind of alert or warning would you add?

Table 2. Participant details.

		Formats		Gender		Age			Medium	
No.	Categories	Indiv.	Groups	M	F	18–30	31–40	41+	In-p.	Online
1	Users	30	5	13	22	17	15	3	11	24
2	Experts	7	7	9	5	7	5	2	14	0
Total number of interviews		49								

Between Fairy and Devil. Although these experiences differed in narrative content, historical setting, and interaction design, they shared several characteristics central to the present analysis: embodied movement through physical space, spatial navigation, environmental exploration, and real-time engagement within a location-based setting. These common features provided a comparable basis for examining safety regulation across experiences, while genre-specific differences were treated as contextual variations rather than primary analytical categories.

While this recruitment strategy ensured access to participants with direct experience of location-based VR, the sample may be somewhat skewed toward individuals who are relatively familiar with immersive technologies. As the study adopts a qualitative design, the findings are intended to provide analytically transferable insights into users' experiences rather than statistically generalizable results.

Although participants included both domain experts and general users, we examined whether expert and general-user accounts differed thematically by comparing coded excerpts across participant categories during the later stages of analysis. We reviewed category-specific coding matrices and analytic memos for differences in safety regulation, uncertainty management, and interpersonal coordination. Experts sometimes used more technical terminology, but no theme or subtheme appeared consistently in one group and not the other. Consequently, participants were treated as a single analytical sample, and the expert/general-user distinction was retained only to ensure experiential diversity rather than for comparative analysis.

Informed consent was obtained from all participants before their involvement in the study. Given the conversational nature of the semi-structured interviews and focus groups, consent was obtained either orally or in writing. Participants were informed of the purpose of the study, the voluntary nature of their participation, their right to withdraw at any time without penalty, and the use of audio recording. All data were anonymized before analysis.

3.3. Data collection

Data were collected through 37 semi-structured interviews and three focus groups ($n = 12$; four participants per group). Semi-structured interviews were used to capture participants' detailed personal experiences, emotions, and reflections on location-based VR. Focus groups complemented the interviews by encouraging participants to collectively discuss, compare, and negotiate their interpretations of safety, uncertainty, and social interaction, allowing shared experiential patterns to emerge through group discussion. Participant observation and field notes further provided contextual evidence for interpreting participants' accounts and enabled methodological triangulation across multiple qualitative data sources.

Interviews and focus groups were conducted both online and offline using video conferencing platforms (e.g., WeChat and Tencent Meeting) or in-person meetings. Interviews lasted between 28 and 185 min ($M = 66$ min) and were conducted in Chinese.

Participants were recruited based on their prior experience with location-based VR. Interviews therefore involved retrospective accounts of immersive experiences that had occurred at varying time intervals before the interview. While the exact time elapsed since participation varied across individuals, the study focused on memorable moments of uncertainty, safety regulation, and social coordination that participants could recall and reflect upon in detail.

To enrich the dataset, interviews were complemented by participant observation, field notes, session recordings, and publicly available materials such as promotional content and user-generated posts. In addition, the researcher engaged in first-hand experience of several location-based VR environments to develop contextual understanding of embodied sensations, uncertainty, and social interaction. These experiences were used to support interpretation rather than as primary data sources.

3.4. Data analysis

The interview transcripts, focus group discussions, and observational notes were transcribed verbatim and analyzed using thematic analysis, supported by NVivo 15. The analysis aimed to identify recurring patterns related to safety perception, uncertainty regulation, and social coordination in immersive environments.

The analytic process followed an iterative, multi-stage approach. First, the researchers familiarized themselves with the data through repeated readings of the transcripts. Initial open coding was then conducted to identify segments related to bodily awareness, spatial orientation, environmental cues, system reliability, interpersonal coordination, fear, and perceived control. Second, codes were iteratively grouped into broader thematic categories capturing shared experiential patterns. During this stage, particular attention was paid to how participants described the tension between uncertainty and immersion, as well as how they maintained a workable sense of safety during action. Third, emerging themes were refined through constant comparison with the original transcripts to ensure that the thematic structure remained grounded in participants' accounts.

During thematic analysis, participants were not assigned to discrete experiential zones. Rather, the three-zone framework emerged inductively from recurring patterns across participants' narratives of different moments of immersive experience. Through iterative coding and comparison, experiences characterized by low perceived threat, high environmental predictability, and minimal attentional demand were grouped into the Comfort Zone; experiences involving manageable uncertainty, moderate attentional mobilization, and sustained engagement were grouped into the Optimal Experience Zone; and experiences marked by loss of control, disorientation, or perceived inability to act effectively were grouped into the Panic Zone. The three zones were therefore treated as analytical abstractions derived from recurring experiential patterns across multiple participants and different location-based VR experiences, rather than as classifications of participants or as stages within a single participant trajectory.

Figures 2 and 3 summarize the analytical pathway from raw qualitative data to the final theoretical framework. Figure 2 illustrates how initial open codes were iteratively grouped into subthemes and abstracted into higher-order themes. Figure 3 shows how these themes informed the development of the Three-Zone Framework and subsequently the Conceptual Model of Safety Regulation.

To enhance the credibility of the analysis, methodological triangulation was employed by integrating evidence from interviews, focus groups, observational notes, experience diaries, and field recordings. Two researchers independently coded a subset of transcripts and resolved coding differences through discussion until consensus was reached. Representative quotations are presented throughout the Findings section to demonstrate how the reported themes were grounded in participants' accounts. The analysis continued until additional data no longer generated substantively new themes.

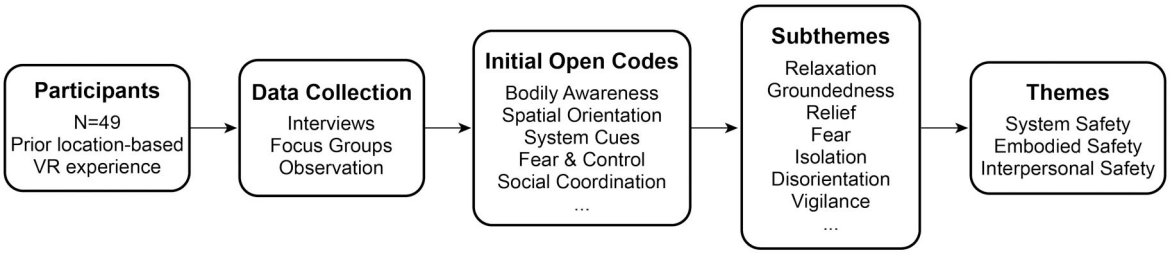


Figure 2. Analytical procedure used to derive higher-order themes from qualitative data. *Note:* Representative examples of initial open codes and subthemes are shown for illustrative purposes. Through iterative coding and constant comparison, subthemes were abstracted into three overarching themes that informed the subsequent theoretical framework.

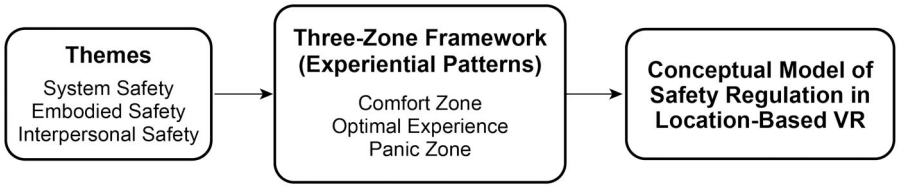


Figure 3. Development of the theoretical framework. *Note:* The three-Zone framework emerged inductively from recurring experiential patterns identified across the three themes. These experiential patterns subsequently informed the development of the Conceptual Model of Safety regulation in location-based VR.

4. Findings

The findings are organized around two related analytical outcomes. First, participants' accounts revealed three recurring experiential patterns, conceptualized as the Comfort Zone, Optimal Experience Zone, and Panic Zone. These zones describe how perceived threat, environmental clarity, attentional demand, and controllability shaped participants' sense of embodied safety in location-based VR (see Figure 4). Second, the findings show that participants regulated safety dynamically by shifting reliance between system-based cues and interpersonal coordination, forming the basis of the Conceptual Model of Safety Regulation (see Figure 5). Together, these findings suggest that safety in location-based VR is not simply a precondition for immersion, but an ongoing experiential accomplishment negotiated through perception, action, and social coordination.

4.1. Three-zone experiential framework

Participants' accounts revealed recurring patterns in how fear and uncertainty were experienced in location-based VR. Rather than simply reflecting emotional intensity, these experiences depended on how participants evaluated the manageability of potential real-world consequences during interaction. When spatial orientation was clear and physical boundaries could be verified, participants tended to feel reassured and in control. In contrast, when orientation cues became limited or bodily coordination with others was disrupted, uncertainty became more difficult to manage and began to reshape participants' sense of agency, attention, and willingness to act.

Table 3 summarizes the relationship between the three experiential zones, their defining characteristics, and representative participant accounts. These experiential patterns suggest that the dynamic interplay between perceived threat and perceived controllability shapes immersive experiences. The Comfort Zone describes moments when participants felt environmentally grounded, physically stable, and able to act without significant safety-related monitoring. The Optimal Experience Zone describes moments in which uncertainty remained present but manageable, allowing participants to sustain action, engagement, and immersion without losing a sense of control. The Panic Zone describes moments in which uncertainty exceeded participants' perceived capacity to understand or respond effectively to the environment, resulting in disorientation, hesitation, or withdrawal. Figure 4 summarizes the resulting

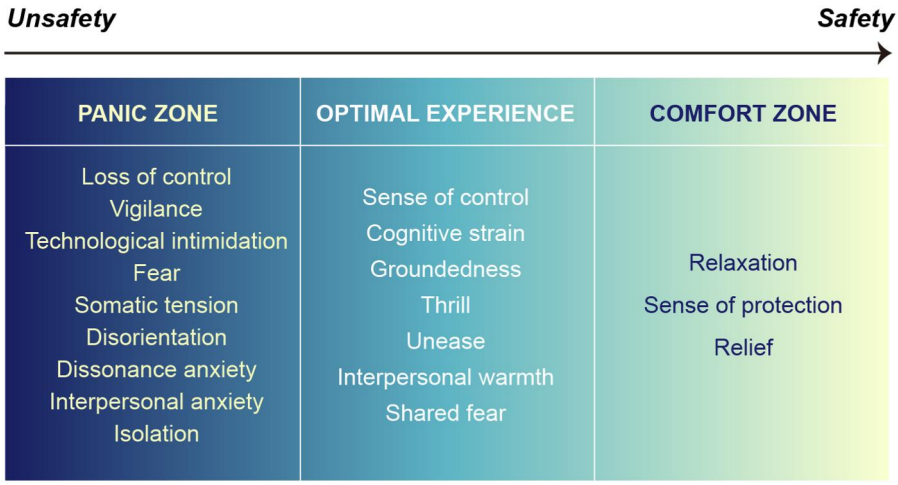


Figure 4. Three-zone framework of safety.

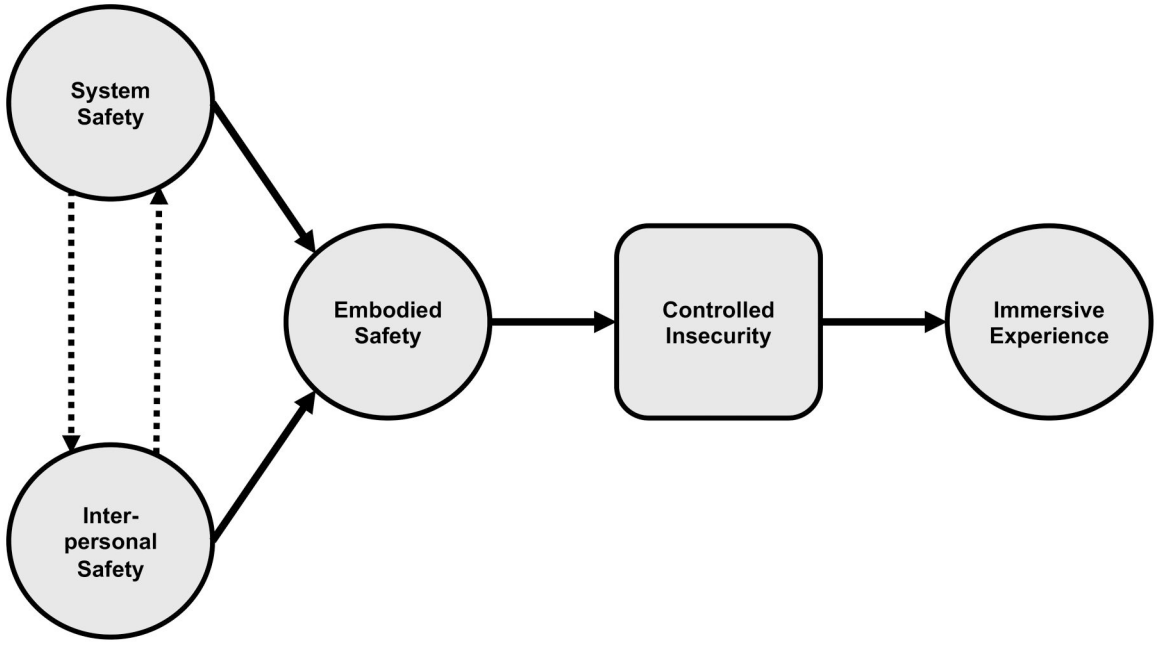


Figure 5. This figure presents a conceptual model derived from thematic analysis. The arrows represent conceptual relationships rather than statistically validated causal pathways or directly observed temporal transitions. Dashed arrows indicate the proposed compensatory interplay between System safety and Interpersonal safety.

three-zone framework and illustrates how participants' ongoing assessment of the manageability of real-world consequences shaped their experiences.

The three zones should not be interpreted as a fixed sequence through which participants necessarily progress. Rather, they represent analytically distinct experiential patterns that emerged across participants' accounts through thematic analysis. Immersion emerges not from either comfort or panic, but from the workable range between them. Although some participants' accounts reflected features associated with more than one zone, the present study did not treat the zones as a temporal sequence or as a model of movement between them. The framework is therefore intended primarily as a thematic abstraction derived from recurring experiential patterns rather than a direct representation of observed experiential trajectories or a classification of participants themselves.

4.1.1. Comfort Zone

In the Comfort Zone, participants relied on cues from the physical environment to regulate their responses to virtual threats. When the experience took place in a visible and socially shared setting,

Table 3. Key experiential states of (un)safety in location-based VR.

Themes	Subthemes	Illustrative quote	Explanation	Zone
System Safety	Relaxation	*"There is a setup later on where you have to cross a suspension bridge. Actually, because I knew my real space was a safe environment, even though the bridge in the plot was dilapidated … I just strode right across it without hesitation." (#58)*	Participants described relaxing both mentally and physically once the system was perceived as reliable	Comfort Zone
	Sense of protection	*"You have to tell me that this is enclosed, and that there are staff members guarding every intersection; then I would feel much more at ease." (#20)*	Participants described a sense of stability derived from the perception that supportive safeguards were in place	Comfort Zone
	Sense of control	*"You clearly know this is something you would absolutely never do in your real life … but in VR you can actually go try it, to challenge yourself. This feeling is very special." (#108)*	Participants reported a sense of agency arising from their ability to master the system and anticipate outcomes	Optimal Experience
	Loss of control	*"After putting on the glasses [headset], it's like being blindfolded with a black cloth; you don't know anything." (#45)*	Participants described panic when the system appeared unresponsive or when situations felt irretrievable	Panic Zone
	Vigilance	*"At the beginning, I was more uneasy. The level of trust in this equipment might have been relatively low, and the trust in the entire experience was a bit lower." (#92)*	Participants described maintaining constant vigilance when they were unable to fully trust the system	Panic Zone
	Cognitive strain	*"When putting on the VR glasses, there is a sense of nervousness, like you've lost the sense of control." (#50)*	Participants reported mental fatigue resulting from processing excessive system information	Optimal Experience
	Technological intimidation	*"She hadn't encountered this kind of novel thing before, so there was some fear and apprehension." (#58)*	First-time users reported a temporary sense of insecurity due to unfamiliarity with the system	Panic Zone
Embodied Safety	Groundedness	*"The visual impact was quite intense … although rationally I knew it was safe, and that there was a wall right next to me, I would still touch it with my hand first to confirm safety … knowing the wall was there actually made me feel much more grounded." (#18)*	Participants described feeling assured and grounded when they established a stable physical connection with the environment and perceived reliable control over their actions	Optimal Experience
	Thrill	*"You clearly know it's dangerous [in the scenario], but in VR, you can actually go ahead and try it, to challenge yourself." (#134)*	Participants acknowledged the pleasurable stimulation brought about by an adrenaline rush	Optimal Experience
	Fear	*"At the start, there was indeed a bit of fear, a bit of shock … I was walking rather gingerly." (#158)*	Participants described an instinctive fear of physical harm, such as falling or experiencing pain	Panic Zone
	Somatic tension	*"At first, we were really quite nervous, just because of the uncertainty. We would hold onto each other a bit. Especially my little one [child] would say, 'Mom, you have to hold onto me.' He was scared; he didn't know how many people were in there, or if we would get separated by the crowd, just so many unknowns. So he would say, 'You have to hold me, let's not let go of each other.'" (#20)*	Participants reported physiological stress reactions such as muscle stiffness or sweaty palms	Panic Zone
	Unease	*"Unease, a little bit of unease, because I wasn't sure exactly how big the space was, or how large the explorable area actually was." (#41)*	Participants reported feeling an indescribable physical discomfort or foreboding	Optimal Experience
	Disorientation	*"Because you can only see the image right in front of your eyes, you actually don't know what the current physical reality you are in looks like … you don't know the distance, whether you are five meters away or one meter away." (#79)*	Participants described a loss of direction, dizziness, or confusion in spatial perception	Panic Zone
	Dissonance anxiety	*"I would worry that my eyes and my feet weren't achieving a level of coordination." (#22)*	Participants reported anxiety caused by inconsistencies between visual and bodily sensations	Panic Zone

(*continued*)

Table 3. Continued.

Themes	Subthemes	Illustrative quote	Explanation	Zone
Interpersonal Safety	Relief	*"I feel that having company makes me feel much more at ease … having a trustworthy person … definitely provides a sense of safety." (#11)*	Participants acknowledged a sense of tranquility derived from trusting others or having companionship	Comfort Zone
	Interpersonal warmth	*"The communication was all about mutual protection; it was very united and felt very warm … whenever there was something thrilling, there was that sense of mutual support." (#100)*	Participants described feeling the warmth brought about by goodwill and solidarity during the experience	Optimal Experience
	Interpersonal anxiety	*"She [my mother] had a tense mood and would keep holding me." (#121)*	Participants described panic in unfamiliar situations when they feared losing physical or emotional connection with companions	Panic Zone
	Shared fear	*"At the beginning, when everyone was quite scared, we would all talk about it [share the fear]." (#58)*	Participants reported fear generated by the contagion of group panic or anxiety	Optimal Experience
	Isolation	*"If I were alone, I feel it would be quite lonely, and a bit scary." (#61)*	Participants reported the helplessness and desolation of facing the experience alone	Panic Zone

participants tended to interpret the situation as controlled and low-risk. Fear was therefore reduced and replaced by reassurance. However, this perceived safety often weakened immersion, as attention remained partly anchored to the real-world environment rather than the virtual scenario. As P12 explained:

> Overall, at a conscious level and even subconsciously, I knew I was in a public environment, and I could also see other players … I knew other people were there to play too, so overall, I wasn't that scared, the fear wasn't that strong.

Participants framed the experience through cues of situational safety. The visibility of other players and the shared physical space signaled that potential risks were limited and socially monitored.

At the same time, these same cues could disrupt immersion. When companions appeared as visible markers within the environment, participants became more aware of the surrounding physical space and reported a break in engagement. As P23 noted:

> I felt reassured and bold, and I forgot … forgot what was happening in the space you're actually in. But if there are people around you, your companions show up as a blue shadow, and I think that reduces the experience … it kind of snaps you out of it. If that person wasn't there, you'd forget reality.

These accounts illustrate a central tension within the Comfort Zone: cues that reassure participants about physical safety can simultaneously remind them of the real-world environment, shifting the experience from uncertain exploration toward a more controlled simulation.

4.1.2. Panic Zone

The Panic Zone emerged when participants experienced a loss of agency. When perceptual cues became limited or ambiguous, participants found it difficult to interpret their surroundings and act confidently. In these situations, fear was not primarily driven by the virtual narrative but by the disruption of basic action capacities, particularly maintaining spatial orientation and locating companions. As a result, uncertainty shifted from suspense to a condition participants felt unable to manage.

This loss of control was often first expressed as concern about physical collisions within the shared venue. When several groups occupied the same space, participants depended on system-mediated cues to track the proximity of others. Without these cues, the situation was interpreted less as part of the game and more as a risk to bodily safety. As P17 noted, the absence of virtual representations of strangers made the possibility of *"bumping into people"* more salient than the intended excitement of the experience.

Panic also took on a relational dimension. Anxiety intensified when restricted perception intersected with responsibility for a companion, particularly a child. As P2 explained:

> I need to ensure the environment inside is safe, right? With my child inside, even if I'm not holding his hand, there shouldn't be any risk. Because I'm in there, as a mother, if I'm blindfolded [in total darkness] and my son goes missing, where would I even look?

These situations illustrate that the Panic Zone was not defined by the intensity of virtual horror but by the erosion of participants' ability to interpret their surroundings and act with confidence. When uncertainty undermined their capacity to anticipate hazards or coordinate with others, controllable fear gave way to panic, often leading participants to disengage from the immersive experience.

4.1.3. Optimal experience

The Optimal Experience describes moments in which participants experienced heightened arousal while maintaining a sense of control over their actions. In this state, the challenges and tension of the virtual scenario were clearly perceived, yet the situation remained manageable. So uncertainty functioned not as an overwhelming threat but as a form of suspense that encouraged exploration, engagement, and a willingness to test personal limits.

One factor supporting this state was VR's capacity to make otherwise impossible actions feel safe enough to attempt. Participants recognized that behaviors such as crossing unstable structures or approaching virtual hazards would rarely be attempted in everyday life. Within VR, however, these

actions became experimentally accessible because the potential consequences were perceived as limited. As P10 explained, "*You clearly know this is something you would absolutely never do in your real life… but in VR you can actually go try it, to challenge yourself. This feeling is very special!*". The perception that risks were bounded enabled participants to engage with threatening scenarios while maintaining confidence in their ability to act.

Sustaining this state often required participants to stabilize their sense of safety while confronting intense sensory stimuli. Even when they understood cognitively that the environment was safe, many sought physical confirmation through contact with nearby boundaries. These grounding behaviors helped regulate embodied reassurance without interrupting the experience. As P18 noted:

> The visual impact was quite intense… although rationally I knew it was safe, and that there was a wall right next to me, I would still touch it with my hand first to confirm safety… knowing the wall was there actually made me feel much more grounded!

Optimal Experience was also supported through social interaction. Communication among companions functioned as a form of coordination and reassurance, helping participants remain in a tense but manageable state rather than slipping into panic. As P10 described, "*The communication was all about mutual protection; it was very united and felt very warm… whenever something was thrilling, there was that sense of mutual support.*"

In this zone, fear was not removed but regulated. Optimal Experience emerged when virtual threats remained credible enough to sustain emotional engagement while participants retained the ability to interpret the environment and act effectively. Under these conditions, uncertainty became a motivating element of the experience rather than a destabilizing force.

Taken together, the three experiential zones reveal a fundamental tension in location-based VR experiences. When the environment is perceived as fully safe and predictable, participants often remain aware of the physical setting, which reduces emotional engagement. Conversely, when uncertainty escalates beyond users' ability to orient themselves or coordinate with others, the experience shifts from suspense to panic, and participants tend to withdraw. These patterns suggest that immersive engagement does not arise from the elimination of uncertainty, but from maintaining it within a workable range. In other words, the conditions that sustain immersion simultaneously require the presence of a credible threat and the preservation of users' ability to act. This tension constitutes a safety paradox: immersive experiences depend on uncertainty and perceived risk, yet they can only be sustained when users continue to feel sufficiently safe to act within the environment.

4.2. Conceptual Model of Safety regulation

The safety paradox identified above suggests that participants described maintaining immersive engagement by balancing credible threats with a workable sense of safety. To summarize these recurring experiential patterns, we propose a qualitative conceptual model of safety regulation in location-based VR. Our analysis indicates that participants relied on two recurring resources during this regulatory process: cues provided by the VR system and coordination with companions. Rather than representing a fixed condition, safety emerged as an ongoing process of adjustment. Participants continuously calibrated their engagement to maintain a workable level of Embodied Safety—high enough to prevent panic or withdrawal, yet sufficiently constrained to preserve the tension that sustains immersion.

As illustrated in Figure 5, the conceptual model organizes recurring qualitative themes around two primary safety resources: System Safety and Interpersonal Safety. The arrows indicate conceptual relationships among System Safety, Interpersonal Safety, Embodied Safety, Controlled Insecurity, and Immersive Experience; they do not represent statistically validated causal pathways or an empirically observed temporal sequence. Our findings indicate that participants continuously adjusted reliance between technological cues and interpersonal support to maintain Embodied Safety under changing experiential conditions, suggesting that safety regulation can be understood as involving the ongoing

redistribution of reliance across these complementary resources rather than through a single source of reassurance. We define the model's three core constructs as follows:

- **System Safety**: The perceived reliability and legibility of the VR system, including the clarity of physical–virtual boundaries, the responsiveness of sensory feedback, and the predictability of action–consequence relationships.
- **Interpersonal Safety**: Safety resources derived from companions, such as informational guidance, emotional reassurance, and physical coordination (e.g., tactile contact or synchronized movement).
- **Embodied Safety**: The immediate bodily sense that one can act without imminent physical harm. This experiential state differs from cognitive certainty; participants may intellectually understand that a situation is safe while still lacking a bodily sense of security.

These constructs were derived from recurring experiential patterns identified across the themes and subthemes summarized in Table 3. Representative examples include relaxation, vigilance, and sense of control for System Safety; relief, interpersonal warmth, and isolation for Interpersonal Safety; and groundedness, disorientation, and somatic tension for Embodied Safety.

Within this regulatory process, Embodied Safety functions as the experiential condition that enables what we term *controlled insecurity*. Controlled insecurity refers to a state in which uncertainty and potential threat remain perceptible yet manageable. Rather than eliminating risk, participants maintained engagement by keeping perceived danger within a range that remained actionable and reversible. When this balance was achieved, the experience was often described as thrilling, engaging, and immersive. In this sense, controlled insecurity represents the regulatory condition through which location-based VR experiences sustain immersive engagement.

4.2.1. Compensatory relationship between system and interpersonal safety

The compensatory relationship between System Safety and Interpersonal Safety became visible in how participants adjusted their reliance on different resources under changing experiential conditions. Rather than depending consistently on either technological cues or interpersonal support, participants moved between these resources to maintain a workable sense of Embodied Safety. We observed this mechanism across four distinct patterns:

- **Interpersonal coordination compensates for sensory deficits**. When the system provided insufficient sensory information (e.g., complete darkness), participants relied on companions to navigate the environment. As P12 described: "*When we first went in… it was pitch black… so several of us held hands and went in like that.*" In this situation, physical contact substituted for missing system cues and enabled coordinated movement.
- **System constraints strengthen interpersonal coordination**. Limited sensory input often increased attention to companions. Participants relied more strongly on one another to maintain orientation and reassurance. As P2 explained: "*Because we couldn't see anything… It's like a blind person's perspective… so at this time, we relied on each other more.*"
- **Interpersonal observation validates system affordances**. Companions also served as reference points for interpreting environmental risks. Observing others interact with potential hazards provided indirect confirmation of the system's safety limits. As P6 noted: "*You can clearly see some people… walking towards the cliff… After letting others pass, those behind [adjusted their behavior].*"
- **Technological acclimation reduces reliance on companions**. As participants became more familiar with system cues, their reliance on interpersonal coordination often decreased. This pattern reflects the reversible nature of the compensatory relationship between system and interpersonal safety. As P21 remarked: "*But later he didn't pull me anymore, feeling that the environment inside was safe.*"

Taken together, these four patterns provide empirical grounding for the compensatory relationship between system and interpersonal safety proposed in the Conceptual Model of Safety Regulation. They show that Embodied Safety was maintained not through either technological reliability or interpersonal

support alone, but through participants' shifting reliance on both resources under changing experiential conditions. However, this compensatory mechanism had limits. When system cues remained unclear and social support was simultaneously absent, participants reported heightened bodily tension and a tendency to withdraw from the experience.

4.2.2. Controlled insecurity

The regulatory process described above produces a characteristic experiential condition that we term *controlled insecurity*. We conceptualize controlled insecurity as a state in which perceived threats remain credible while users retain sufficient Embodied Safety to act within the environment, thereby sustaining immersive engagement. In relation to the three-zone framework, controlled insecurity corresponds most closely to the Optimal Experience zone, where perceived threat remains present but manageable. By contrast, the Comfort Zone reflects situations in which uncertainty is largely contained, whereas the Panic Zone emerges when uncertainty exceeds participants' perceived capacity to act effectively.

System Safety plays an important role in enabling this condition. Participants reported relying on predictable system boundaries to maintain a sense of control when confronting physically demanding or risky virtual situations. These cues allowed them to attempt actions that would normally be avoided in everyday life. As P34 explained, *"You clearly know that this is something you would absolutely not do in real life… but in VR you can try it… This feeling is very special."* At the same time, cognitive awareness of safety was often not sufficient on its own. Participants frequently used grounding behaviors, such as touching nearby physical surfaces, to stabilize their sense of embodied security during intense moments.

A central experiential condition underlying this process was the balance between credible threat and perceived containment. When the experience lacked convincing consequences, participants reported reduced tension and engagement. As P2 noted, *"I found that I still didn't feel like falling… and my feet were actually safe."* Conversely, when threats remained believable but were clearly bounded by system and social cues, participants remained willing to act despite fear. As P4 described, *"I knew that was a fake suspension bridge… so I strode directly over it."*

Immersion in location-based VR emerges when uncertainty is maintained within a workable range rather than eliminated. In this state, threats remain credible enough to sustain attention, emotional arousal, and exploratory behavior, while still allowing participants to act with confidence. By keeping uncertainty within this workable range, users remain alert, socially responsive, and engaged with the environment. In this sense, controlled insecurity represents the experiential condition through which the safety paradox of immersive engagement is stabilized.

5. Discussion

This study examined how users experience and regulate perceived safety in location-based VR environments. The findings revealed that participants' experiences tended to organize into three recurrent experiential states—comfort, panic, and optimal engagement—depending on how manageable the situation felt in relation to real-world consequences. Beyond describing these states, the analysis also identified a dynamic regulatory process in which users maintained a workable sense of embodied safety by drawing on both system cues and interpersonal coordination. Together, these findings suggest that immersive engagement in location-based VR does not arise simply from the absence of risk but from the regulation of uncertainty within a manageable range. In the following sections, we discuss how these insights extend existing theories of immersion, risk perception, and embodied interaction in immersive environments.

5.1. Reconsidering safety in immersive environments

Research on immersive media has shown that moderate levels of uncertainty or risk can enhance engagement (Breves & Schramm, 2021; Leder et al., 2019; Xu et al., 2025). However, existing frameworks primarily conceptualize engagement in psychological terms and provide limited insight into how

users remain capable of acting under uncertainty in hybrid physical–virtual environments where real bodily consequences are possible. Our findings extend this perspective by showing that engagement depends not only on perceived challenge but also on users' ability to maintain actionable control through embodied and social regulation.

In location-based VR, users must not only experience excitement or challenge but also continuously regulate their sense of physical safety while navigating an environment that blends virtual threat with awareness of the physical world. This pattern points to a *safety paradox*: although VR design traditionally prioritizes seamless and absolute safety to preserve usability (Giaretta, 2024; Kim & Rhiu, 2024), eliminating uncertainty may also remove the very conditions that enable immersive engagement and social bonding. Rather than treating safety and risk as binary opposites, we conceptualize them as a dynamic tension within hybrid physical–virtual environments. In this framing, a calibrated degree of "unsafety" functions not as a defect but as a design resource that sustains immersion through the shared negotiation of risk.

The safety paradox shares affinities with theories of optimal arousal and flow, insofar as all three perspectives recognize that engagement may depend on a calibrated relation between challenge, uncertainty, and perceived control (Chapman et al., 2025; Zhang et al., 2024). However, the mechanism identified in this study differs from these primarily psychological accounts. Whereas optimal arousal and flow emphasize the regulation of stimulation, challenge, skill, or competence at the level of individual experience, the safety paradox concerns how users maintain actionable control under conditions where virtual uncertainty has possible real-world bodily consequences. In location-based VR, maintaining engagement requires users to regulate embodied safety while coordinating between system-based cues, spatial boundaries, and interpersonal resources. Safety regulation, therefore, becomes a socio-technical process rather than a purely individual one.

In traditional digital media, perceived risk is largely symbolic (Kruzan & Won, 2019; Pimentel & Kalyanaraman, 2024). In contrast, location-based VR introduces a distinctive risk structure in which virtual scenarios unfold within shared physical space. Participants must navigate real walls, avoid physical collisions, and coordinate movement with other bodies whose locations are only partially inferred through mediated cues. Under these conditions, uncertainty cannot be treated merely as a narrative or emotional stimulus. Instead, it becomes intertwined with the user's bodily capacity to move safely within the environment.

Hence, our findings suggest that safety in immersive environments should not be understood primarily as the elimination of risk. Rather, safety functions as an ongoing regulatory process through which users continuously evaluate whether uncertainty remains manageable. This evaluation is not purely cognitive but deeply embodied. Participants monitor spatial orientation, physical stability, and the proximity of others while navigating the environment, adjusting their behavior in response to changes in perceived controllability. Immersion emerges when uncertainty remains credible enough to sustain emotional arousal while still allowing users to maintain confidence in their ability to act.

This perspective reframes safety as a condition that enables rather than constrains immersive engagement. When uncertainty is reduced too extensively, the experience may become overly predictable or overly protective, weakening emotional intensity and diminishing the sense of exploration. Conversely, when uncertainty exceeds users' capacity to interpret the environment or coordinate with others, fear becomes destabilizing and engagement collapses. Thus, immersive experience depends on maintaining uncertainty within a workable experiential range rather than eliminating it.

The three-zone framework identified in this study illustrates how this dynamic becomes visible in users' experiences. Within this framework, engagement emerges between two forms of experiential failure: excessive safety that weakens immersion and excessive uncertainty that undermines users' sense of agency. Rather than representing a simple typology of emotional states, the framework reflects the experiential manifestation of the safety paradox: the ongoing tension between perceived threat and perceived safety that structures immersive interaction in hybrid environments.

5.2. Controlled insecurity as a mechanism of immersive engagement

While the safety paradox describes the structural tension between perceived danger and perceived safety in immersive environments, *controlled insecurity* offers one interpretation of how this tension may be

regulated during user interaction. Building on theories of embodied interaction, risk-based engagement, and social presence (Bastian et al., 2014; Benford et al., 2012; Kilteni et al., 2012), we conceptualize controlled insecurity as an experiential condition in which perceived threats remain credible enough to sustain attention and emotional arousal, while users retain sufficient embodied security to act within the environment.

This regulatory process is grounded in the embodied and relational management of safety. Rather than focusing on the balance between skill and challenge, users must maintain a bodily sense that their actions remain physically manageable within the environment. Even when participants cognitively recognize that the situation is safe, they frequently seek tactile confirmation, such as touching nearby walls, adjusting posture, or coordinating movement with companions, to stabilize this sense of security. These behaviors indicate that engagement is sustained not only through psychological appraisal but through ongoing embodied and social regulation of safety in hybrid environments.

Second, controlled insecurity highlights the socio-technical mechanisms through which this state is maintained. In location-based VR, safety is not regulated by the system alone. Instead, users dynamically combine two complementary resources: system cues and interpersonal cues. Environmental signals such as spatial boundaries, physical props, and sensory feedback provide the infrastructural basis for spatial orientation, enabling users to infer where it is safe to move. At the same time, companions function as an additional layer of safety regulation by offering reassurance, guidance, and behavioral cues that help participants interpret ambiguous situations. These practices resonate with prior accounts of socially negotiated safety and mutual awareness in shared immersive environments (Tietenberg et al., 2025; Wienrich et al., 2018).

The Conceptual Model of Safety Regulation proposed in this study describes how these resources interact to stabilize immersive engagement. When system cues become unclear or unreliable, participants often compensate by increasing their reliance on interpersonal coordination, for example, through verbal communication, synchronized movement, or physical contact. Conversely, when social coordination is limited, clear system cues allow individuals to maintain confidence in their actions. Through this shifting balance, users preserve a sense of embodied safety that enables them to remain engaged even in the presence of perceived threats.

From this perspective, immersion in location-based VR emerges not simply from exposure to danger but from the successful stabilization of uncertainty. Controlled insecurity describes the experiential state in which uncertainty remains perceptible and emotionally engaging while the environment continues to support the user's ability to act. Under these conditions, fear functions as a motivating rather than destabilizing element, echoing earlier observations that managed discomfort and risk can deepen engagement and strengthen social connection in interactive experiences (Benford et al., 2012).

Taken together, these findings suggest that immersive engagement in hybrid environments depends on the active stabilization of the tension between perceived threat and perceived safety. Controlled insecurity, therefore, explains how users regulate this tension in practice, sustaining immersion by maintaining uncertainty within a range that remains experientially manageable.

5.3. Socio-technical regulation of safety in location-based VR

The findings indicate that safety in shared immersive environments is not simply a background condition of the experience. Instead, safety emerges through the interaction between technological infrastructure and social relations within the environment. Previous research on VR has often conceptualized safety and comfort as individual perceptual states, focusing on factors such as simulator sickness (Van Gemert et al., 2024) or individual risk tolerance (Singh et al., 2025). While these perspectives provide important insights into user experience, the empirical observations in this study suggest that embodied safety in location-based VR cannot be adequately understood at the level of the individual alone. Rather, safety is jointly produced through the coordinated interaction of participants within the mediated space.

Beyond the practical coordination described in the Conceptual Model of Safety Regulation, these interactions also reveal a broader dynamic of shared vulnerability. When users enter hybrid environments in which direct visibility of the physical world is partially restricted, they become mutually

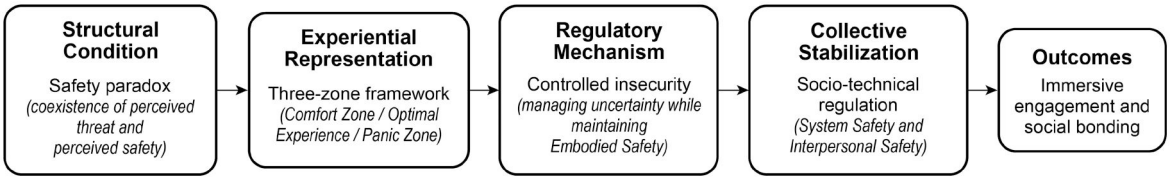


Figure 6. Conceptual framework.

dependent on others to maintain spatial orientation and avoid potential hazards. Prior research indicates that shared vulnerability can promote trust, empathy, and cooperative behavior among participants (Brown & Levinson, 1987; Smith & Mackie, 2015). In the context of this study, moments of uncertainty or perceived risk not only challenge participants' sense of control. They also encourage participants to communicate, coordinate their movements, and assist one another. Through these practices, participants manage uncertainty collectively and strengthen their interpersonal connections during the experience.

This interpretation also contributes to existing research on social presence. Social presence is commonly defined as the extent to which other individuals in mediated environments are experienced as socially real and emotionally accessible (Biocca et al., 2003; Short et al., 1976). Previous research has mainly emphasized representational factors such as avatar realism or communication channels (Nowak & Biocca, 2003; Oh et al., 2018). The present findings suggest an additional mechanism through which social presence may develop. When participants jointly regulate safety in uncertain environments, their awareness of others shifts from simple spatial awareness to relational dependence. Participants not only perceive where others are located in the environment but also rely on them for guidance, reassurance, and coordinated action. Under these conditions, social presence is strengthened through practical cooperation in managing environmental uncertainty (Gonzalez-Franco & Lanier, 2017).

Taken together, these perspectives form a coherent conceptual framework for understanding how safety operates in shared immersive environments (see Figure 6). The framework integrates four analytical levels. The safety paradox identifies the structural condition of immersive experiences in which perceived threat and perceived safety must coexist. The three-zone framework provides an experiential representation of this paradox by illustrating how immersive engagement emerges between excessive safety and excessive uncertainty. Building on this structure, the concept of controlled insecurity explains the mechanism through which users regulate this tension during interaction, maintaining uncertainty at a level that remains experientially manageable while preserving the capacity for action. Finally, the socio-technical regulation perspective highlights the collective processes through which this balance is stabilized in practice, emphasizing the joint role of technological infrastructures and interpersonal coordination in sustaining embodied safety within shared immersive environments and enabling immersive engagement and social bonding to emerge.

5.4. Cultural context and transferability of safety regulation

An additional consideration concerns the cultural context in which the present observations were made. All empirical data were collected in location-based VR venues in mainland China, Macao, and Hong Kong—regions where the location-based VR industry has expanded rapidly, and immersive entertainment venues have become widely accessible. Social norms regarding interpersonal proximity, coordinated movement, and collective responsibility in these contexts may shape how users interpret and regulate safety while navigating shared immersive environments.

Cross-cultural research suggests that people in more collectivistic cultural contexts often place greater emphasis on interpersonal coordination and mutual monitoring when responding to uncertain situations (Markus & Kitayama, 2014; Triandis, 2018). In such settings, individuals tend to remain attentive to the actions and well-being of others when navigating potentially risky environments. Research on virtual interaction similarly indicates that users frequently carry real-world social norms into immersive environments, including expectations regarding interpersonal distance, bodily coordination, and group-oriented movement (Bailenson et al., 2003; Iachini et al., 2014; Yee et al., 2007, 2009). Within shared

immersive spaces, these cultural orientations may encourage participants to rely more readily on companions for reassurance, guidance, and coordinated action when confronting uncertain scenarios.

These tendencies are consistent with broader research suggesting that collectivistic cultural environments often foster cooperative forms of risk management, in which individuals actively monitor the positions and safety of others while moving through uncertain environments (Markus & Kitayama, 2014; Triandis, 2018). In the context of location-based VR, such interactional norms may strengthen Interpersonal Safety mechanisms by encouraging patterns of coordinated navigation, mutual awareness, and collective orientation within immersive spaces.

These findings should be interpreted with attention to cultural context. While collectivistic norms may amplify interpersonal coordination and mutual monitoring in shared immersive environments (Norenzayan & Heine, 2005), they are unlikely to determine the existence of safety regulation itself. Rather, cultural norms shape how safety is enacted during interaction, particularly in terms of interpersonal proximity, coordination, and social responsibility. As a result, users may vary in the extent to which they rely on interpersonal versus system-based resources to maintain a sense of safety (Gong et al., 2024). The socio-technical co-regulation of safety identified in this study may therefore extend across diverse cultural settings, while manifesting through different interactional patterns.

Beyond cultural transferability, it is also important to clarify the intended scope of the proposed framework. The concepts of Safety Paradox, Controlled Insecurity, and the Conceptual Model of Safety Regulation are primarily intended for location-based VR experiences involving free movement, shared physical space, and co-located interaction. Under these conditions, users must continuously negotiate uncertainty arising not only from virtual content but also from the physical presence and movement of others. The framework is therefore most relevant to immersive experiences in which bodily action, spatial navigation, and interpersonal coordination jointly shape engagement.

By contrast, the framework may be less applicable to VR experiences that involve limited physical movement or minimal interpersonal coordination, such as seated VR, 360-degree video experiences, or single-user applications. In these contexts, uncertainty is more likely to arise from narrative, perceptual, or task-related factors rather than from the management of shared physical space. Future research may examine whether similar regulatory processes emerge in other forms of immersive media and investigate how the relative importance of technological and interpersonal resources varies across different VR contexts.

5.5. Design implications

The findings also offer several implications for the design of shared immersive environments, particularly in location-based VR settings where users navigate hybrid physical–virtual spaces together. Rather than treating safety solely as a technical constraint, designers may benefit from considering how safety resources shape the experiential balance between uncertainty and control.

First, immersive systems may benefit from carefully calibrating the visibility of safety cues. While boundary systems, physical props, and environmental feedback are essential for maintaining users' embodied safety, overly explicit reminders of the physical environment can disrupt immersion. The findings suggest that safety cues are most effective when they remain perceptible yet unobtrusive, allowing users to verify their safety without continuously foregrounding the physical infrastructure of the experience.

Second, immersive systems should support socio-spatial awareness among participants. In shared environments, users frequently rely on companions for reassurance and coordinated movement when navigating uncertain situations. Design features that facilitate awareness of others should prioritize unobtrusiveness; for instance, subtle avatar proximity indicators or directional audio cues may allow users to remain aware of companions' locations without introducing overly explicit safety signals that disrupt immersion. Such features help users maintain situational awareness while preserving the sense of collective exploration.

Third, designers may consider structuring experiences in ways that sustain controlled insecurity rather than eliminating perceived risk. The results indicate that immersion is often strengthened when virtual threats remain credible while still allowing users to verify their safety through system cues or

social coordination. Designing for this balance may enable experiences that remain intense and engaging without overwhelming users' sense of embodied manageability.

5.6. Implications for future empirical research

The mechanisms identified in this study suggest theoretical propositions that may guide future empirical research on immersive environments. Although the present study adopts a qualitative approach, the relationships revealed in our analysis can be translated into testable propositions using experimental, survey-based, or behavioral methods.

- **Proposition 1**: Moderate levels of perceived uncertainty in immersive environments are positively associated with immersive engagement, whereas both very low and very high levels of uncertainty reduce immersion. This proposition reflects the safety paradox identified in this study. When uncertainty is eliminated, the experience may become overly predictable and fail to sustain emotional intensity. Conversely, when uncertainty exceeds users' ability to interpret their surroundings or coordinate with others, fear may become destabilizing and disrupt engagement. Immersion, therefore, emerges when uncertainty remains within a manageable experiential range.
- **Proposition 2**: Embodied safety mediates the relationship between perceived uncertainty and immersive engagement. Our findings indicate that uncertainty alone does not determine engagement. Instead, users continuously evaluate whether they remain capable of acting safely within the environment. When embodied safety is maintained, uncertainty can function as a source of excitement and exploration. When embodied safety collapses, uncertainty is experienced as panic or loss of control.
- **Proposition 3:** System Safety and Interpersonal Safety jointly contribute to the maintenance of embodied safety in shared immersive environments. Participants relied on both technological cues (e.g., spatial boundaries, environmental feedback) and interpersonal coordination (e.g., verbal reassurance, synchronized movement) to regulate their sense of safety. These resources provide complementary mechanisms that support users' ability to act within uncertain environments.
- **Proposition 4**: System Safety and Interpersonal Safety function as compensatory mechanisms in the regulation of embodied safety. When system cues become ambiguous or unreliable, users tend to rely more heavily on interpersonal coordination. Conversely, when social coordination is limited, clear technological cues allow individuals to maintain confidence in their actions. This compensatory pattern may help users remain engaged even when one regulatory resource weakens.

Together, these propositions provide a theoretical foundation for future research examining how uncertainty, safety perception, and social interaction jointly shape immersive experiences. Testing these relationships through experimental manipulation, physiological measurement, or behavioral tracking would help further refine the model proposed in this study.

6. Limitations and future work

Several limitations should be considered when interpreting the findings of this study. First, the analysis primarily draws on semi-structured interviews, focus groups, and participant observation. These methods provided detailed insights into participants' interpretations of their experiences but rely in part on retrospective accounts. Because participants were interviewed at varying intervals following their location-based VR experiences, perceptions of fear, uncertainty, and safety may have been influenced by selective recall or post-hoc interpretation. Future research could complement these qualitative approaches with behavioral tracking, physiological measures, or system log data to capture the moment-to-moment dynamics of safety regulation during immersive interaction.

Second, the study was conducted in location-based VR venues in China. Although the immersive works examined were produced in several countries, the social and cultural context of these venues may shape how participants interpret interpersonal distance, group coordination, and responsibility in

shared immersive environments. Cross-cultural studies in other geographical contexts would therefore help to examine how the regulatory mechanisms identified here operate under different social norms.

Third, the findings are based on a qualitative sample of 49 participants across several immersive experiences. While this approach enabled an in-depth examination of experiential processes, future research could test and extend the proposed framework through larger-scale surveys, experimental studies, or comparative analyses across different types of immersive systems. Such work would help refine our understanding of how embodied safety, social coordination, and technological cues interact to support immersive engagement in diverse environments.

Finally, the study includes several genres of location-based VR, including cultural heritage, science-oriented, and interactive narrative experiences. Although these experiences shared embodied movement, spatial navigation, and co-located interaction, genre-specific design features may influence the intensity of fear, uncertainty, and immersion. For example, horror, adventure, or high-stakes narrative scenarios may amplify perceived threat, whereas cultural heritage or educational experiences may produce milder forms of uncertainty. Future research could compare genres more systematically to examine how content, pacing, and interaction design moderate safety regulation.

7. Conclusion

This paper has examined safety in location-based VR not as a static system requirement, but as a dynamically regulated dimension of user experience. Our qualitative analysis demonstrates that participants do not seek absolute security. Instead, they calibrate their engagement to remain within a tolerable range where uncertainty and fear are present yet manageable. Within this range, safety operates as a core experiential mechanism that enables agency, sustains immersion, and strengthens social bonds rather than undermining them.

By reframing safety as an embodied and socially negotiated process, this work contributes to broader HCI discourse on embodiment and social presence. We highlight the limitations of treating safety purely as a technical property, emphasizing the critical distinction between objective security and the felt sense of being safe. For designers, this suggests a shift in focus: away from the total elimination of uncertainty and toward supporting system legibility, interpersonal coordination, and user agency. More broadly, this perspective invites researchers to reconsider the role of risk and hesitation in immersive systems. When carefully regulated, uncertainty and vulnerability can function as resources that support meaningful, engaging, and socially grounded experiences in shared virtual environments.

Acknowledgments

The authors would like to thank all participants who generously shared their experiences and insights during the interviews and co-creation workshops. We also acknowledge the use of ChatGPT (OpenAI, GPT-5.3) as a generative AI tool to assist with minor language editing, including grammar and phrasing adjustments. The tool was used solely to improve readability and did not contribute to the conceptualization, methodology, data collection, analysis, interpretation, or scientific conclusions of this study. All final content was written, reviewed, and approved by the authors.

Author contributions

CRediT: **Zhiyun Lei**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing; **Shuyue Li**: Conceptualization, Data curation, Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work received partial financial support from the Red Bird Research Fund of The Hong Kong University of Science and Technology (Guangzhou) for a portion of the user study. The funder had no role in the design of the study, data collection and analysis, interpretation of the results, decision to publish, or preparation of the manuscript.

ORCID

Zhiyun Lei http://orcid.org/0000-0003-0448-2433
Shuyue Li http://orcid.org/0009-0003-5516-9372

Data availability statement

The data supporting the findings of this study are not publicly available due to ethical restrictions and participant privacy concerns. The dataset includes qualitative interview and focus-group transcripts, observational notes, experience diaries, and related field materials. These materials contain participants' personal experiences, professional backgrounds, descriptions of specific location-based VR venues, and context-specific narratives that may allow participants or sites to be indirectly identified even after anonymization.

This study was conducted in accordance with the principles of the Declaration of Helsinki. Ethical approval was obtained from the Research Construction and Development Department at The Hong Kong University of Science and Technology (Guangzhou) (Protocol No. HKUST(GZ)-HSP-2025-0320). Participants provided informed consent for the use of their anonymized data for academic research purposes. However, unrestricted public deposition of the full qualitative dataset was not included in the consent obtained from participants and would therefore not be consistent with the ethical conditions under which the data were collected.

De-identified excerpts or selected supporting materials may be made available from the corresponding author upon reasonable request. Requests should include a brief description of the intended research purpose, the specific materials requested, and confirmation that the data will be used only for scholarly, noncommercial purposes. Access will be considered on a case-by-case basis and may require an appropriate data use agreement, institutional approval, or evidence of ethics approval or exemption from the requester's institution. Any shared materials must not be redistributed or used to identify participants, venues, or organizations.

References

Almeida, L., Menezes, P., & Dias, J. (2022). Telepresence social robotics towards co-presence: A review. *Applied Sciences*, *12*(11), 5557. https://doi.org/10.3390/app12115557

Azmandian, M., Yahata, R., Bolas, M., & Suma, E. (2014). *An enhanced steering algorithm for redirected walking in virtual environments* [Paper presentation]. 2014 IEEE Virtual Reality (vr) (pp. 65–66). IEEE. https://doi.org/10.1109/VR.2014.6802053

Bailenson, J. N., Blascovich, J., Beall, A. C., & Loomis, J. M. (2003). Interpersonal distance in immersive virtual environments. *Personality & Social Psychology Bulletin*, *29*(7), 819–833. https://doi.org/10.1177/0146167203029007002

Barbot, B., & Kaufman, J. C. (2020). What makes immersive virtual reality the ultimate empathy machine? discerning the underlying mechanisms of change. *Computers in Human Behavior*, *111*, Article 106431. https://doi.org/10.1016/j.chb.2020.106431

Bastian, B., Jetten, J., & Ferris, L. J. (2014). Pain as social glue: Shared pain increases cooperation. *Psychological Science*, *25*(11), 2079–2085. https://doi.org/10.1177/0956797614545886

Benford, S., Greenhalgh, C., Giannachi, G., Walker, B., Marshall, J., & Rodden, T. (2012). Uncomfortable interactions. In *Proceedings of the Sigchi Conference on Human Factors in Computing Systems* (pp. 2005–2014).

Biocca, F., Harms, C., & Burgoon, J. K. (2003). Toward a more robust theory and measure of social presence: Review and suggested criteria. *Presence: Teleoperators and Virtual Environments*, *12*(5), 456–480. https://doi.org/10.1162/105474603322761270

Breves, P., & Schramm, H. (2021). Bridging psychological distance: The impact of immersive media on distant and proximal environmental issues. *Computers in Human Behavior*, *115*, Article 106606. https://doi.org/10.1016/j.chb.2020.106606

Brown, P., & Levinson, S. C. (1987). *Politeness: Some universals in language usage* (Vol. 4). Cambridge university press. https://doi.org/10.1017/CBO9780511813085

Burychka, D., Miragall, M., & Baños, R. M. (2021). Towards a comprehensive understanding of body image: Integrating positive body image, embodiment and self-compassion. *Psychologica Belgica*, *61*(1), 248–261. https://doi.org/10.5334/pb.1057

Carrol, E. N., Zuckerman, M., & Vogel, W. H. (1982). A test of the optimal level of arousal theory of sensation seeking. *Journal of Personality and Social Psychology*, *42*(3), 572–575. https://doi.org/10.1037/0022-3514.42.3.572

Chapman, J. R., Kohler, T. B., Rich, P. J., & Trego, A. (2025). Maybe we've got it wrong. an experimental evaluation of self-determination and flow theory in gamification. *Journal of Research on Technology in Education*, *57*(2), 417–436. https://doi.org/10.1080/15391523.2023.2242981

Csikszentmihalyi, M. (1990). *Flow: The Psychology of Optimal Experience*. Harper & Row.

Cummings, J. J., & Wertz, E. E. (2022). Capturing social presence: Concept explication through an empirical analysis of social presence measures. *Journal of Computer-Mediated Communication*, *28*(1), zmac027. https://doi.org/10.1093/jcmc/zmac027

Deng, D. S., Seo, S., Harrington, R. J., & Martin, D. (2024). When virtual others are with me: Exploring the influence of social presence in virtual reality wine tourism experiences. *International Journal of Wine Business Research*, *36*(4), 548–571. https://doi.org/10.1108/IJWBR-04-2024-0019

DeVeaux, C., Han, E., Hudson, Z., Egelman, J., Landay, J. A., & Bailenson, J. N. (2025). Black immersive virtuality: Racialized experiences of avatar embodiment and customization among black users in social vr. *Computers in Human Behavior*, *168*, Article 108639. https://doi.org/10.1016/j.chb.2025.108639

El Basbasse, Y., Packheiser, J., Peterburs, J., Maymon, C., Güntürkün, O., Grimshaw, G., & Ocklenburg, S. (2023). Walk the plank! using mobile electroencephalography to investigate emotional lateralization of immersive fear in virtual reality. *Royal Society Open Science*, *10*(5), 221239. https://doi.org/10.1098/rsos.221239

Emmelkamp, P. M., Meyerbröker, K., & Morina, N. (2020). Virtual reality therapy in social anxiety disorder. *Current Psychiatry Reports*, *22*(7), 32. https://doi.org/10.1007/s11920-020-01156-1

Fan, X., Jiang, X., & Deng, N. (2022). Immersive technology: A meta-analysis of augmented/virtual reality applications and their impact on tourism experience. *Tourism Management*, *91*, Article 104534. https://doi.org/10.1016/j.tourman.2022.104534

Giaretta, A. (2024). Security and privacy in virtual reality: A literature survey. *Virtual Reality*, *29*(1), 10. https://doi.org/10.1007/s10055-024-01079-9

Gong, Z., Gonçalves, M., Nanjappan, V., & Georgiev, G. V. (2024). Priming uncertainty avoidance values: Influence of virtual reality stimuli on design creativity in ideation. *Computers in Human Behavior*, *158*, Article 108257. https://doi.org/10.1016/j.chb.2024.108257

Gonzalez-Franco, M., & Lanier, J. (2017). Model of illusions and virtual reality. *Frontiers in Psychology*, *8*, Article 1125. https://doi.org/10.3389/fpsyg.2017.01125

Hasler, B. S., & Friedman, D. A. (2012). Sociocultural conventions in avatar-mediated nonverbal communication: A cross-cultural analysis of virtual proxemics. *Journal of Intercultural Communication Research*, *41*(3), 238–259. https://doi.org/10.1080/17475759.2012.728764

Iachini, T., Coello, Y., Frassinetti, F., & Ruggiero, G. (2014). Body space in social interactions: A comparison of reaching and comfort distance in immersive virtual reality. *PloS One*, *9*(11), e111511. https://doi.org/10.1371/journal.pone.0111511

Jicol, C., Clarke, C., Tor, E., Dakin, R. M., Lancaster, T. C., Chang, S. T., Petrini, K., O'Neill, E., Proulx, M. J., & Lutteroth, C. (2023). Realism and field of view affect presence in vr but not the way you think. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (pp. 1–17). Association for Computing Machinery. https://doi.org/10.1145/3544548.3581448

Kilteni, K., Normand, J.-M., Sanchez-Vives, M. V., & Slater, M. (2012). Extending body space in immersive virtual reality: A very long arm illusion. *PloS One*, *7*(7), e40867. https://doi.org/10.1371/journal.pone.0040867

Kim, Y. M., & Rhiu, I. (2024). Development of a virtual reality system usability questionnaire (vrsuq). *Applied Ergonomics*, *119*, Article 104319. https://doi.org/10.1016/j.apergo.2024.104319

Kruzan, K. P., & Won, A. S. (2019). Embodied well-being through two media technologies: Virtual reality and social media. *New Media & Society*, *21*(8), 1734–1749. https://doi.org/10.1177/1461444819829873

Lacoche, J., Pallamin, N., Boggini, T., & Royan, J. (2017). Collaborators awareness for user cohabitation in co-located collaborative virtual environments. In *Proceedings of the 23rd ACM Symposium on Virtual Reality Software and Technology* (pp. 1–9).

Langbehn, E., Harting, E., & Steinicke, F. (2018). *Shadow-avatars: A visualization method to avoid collisions of physically co-located users in room-scale vr*. In IEEE Workshop on Everyday Virtual Reality (Vol. 2). IEEE. http://hdl.handle.net/20.500.12738/11504

Leder, J., Horlitz, T., Puschmann, P., Wittstock, V., & Schütz, A. (2019). Comparing immersive virtual reality and powerpoint as methods for delivering safety training: Impacts on risk perception, learning, and decision making. *Safety Science*, *111*, 271–286. https://doi.org/10.1016/j.ssci.2018.07.021

Lei, Z., Zhou, W., Yang, X., & Zhou, J. (2023). Enhancing the chinese identity of young people in hong kong and macao based on the creation of cinematic virtual reality art, taking the cinematic virtual reality work i love being me: In my place, my home as an example. *International Communication of Chinese Culture*, *10*(2-4), 181–201. https://doi.org/10.1007/s40636-023-00276-6

Li, Y., Wu, B., Huang, Y., & Luan, S. (2024). Developing trustworthy artificial intelligence: Insights from research on interpersonal, human-automation, and human-ai trust. *Frontiers in Psychology*, *15*, Article 1382693. https://doi.org/10.3389/fpsyg.2024.1382693

Lopes, P., You, S., Cheng, L.-P., Marwecki, S., & Baudisch, P. (2017). Providing haptics to walls & heavy objects in virtual reality by means of electrical muscle stimulation. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (pp. 1471–1482). https://doi.org/10.1145/3025453.3025600

Lyng, S. (1990). Edgework: A social psychological analysis of voluntary risk taking. *American Journal of Sociology*, *95*(4), 851–886. https://doi.org/10.1086/229379

Makani, A., Saryazdi, R., Givetash, S., & Keshavarz, B. (2024). The presence of an avatar can reduce cybersickness in virtual reality. *Virtual Reality*, *28*(4), 163. https://doi.org/10.1007/s10055-024-01057-1

Mangalam, M., Oruganti, S., Buckingham, G., & Borst, C. W. (2024). Enhancing hand-object interactions in virtual reality for precision manual tasks. *Virtual Reality*, *28*(4), 166. https://doi.org/10.1007/s10055-024-01055-3

Markus, H. R., & Kitayama, S. (1991). Culture and the self: Implications for cognition, emotion, and motivation. *Psychological Review*, *98*(2), 224–253. https://doi.org/10.1037/0033-295X.98.2.224

Markus, H. R., & Kitayama, S. (2014). Culture and the self: Implications for cognition, emotion, and motivation. In *College student development and academic life* (pp. 264–293). Routledge. https://doi.org/10.4324/9781315051888

Meehan, M., Whitton, M., Razzaque, S., Zimmons, P., Insko, B., Combe, G., Lok, B., Scheuermann, T., Naik, S., Jerald, J., et al. (2002). *Physiological reaction and presence in stressful virtual environments*. In ACM SIGGRAPH 2002 Conference Abstracts and Applications (p. 75). https://doi.org/10.1145/1242073.1242110

Michaelides, C., Casasnovas, M., Nunez, D., & Bellalta, B. (2025). Lessons learned from a large-scale virtual reality experience over Wi-Fi. *IEEE Transactions on Networking*, *33*(6), 3257–3269. https://doi.org/10.1109/TON.2025.3582033

Nolte, D., Hjoj, R., Sánchez Pacheco, T., Huang, A., & König, P. (2025). Investigating proxemics behaviors towards individuals, pairs, and groups in virtual reality. *Virtual Reality*, *29*(2), 58. https://doi.org/10.1007/s10055-025-01127-y

Norenzayan, A., & Heine, S. J. (2005). Psychological universals: What are they and how can we know? *Psychological Bulletin*, *131*(5), 763–784. https://doi.org/10.1037/0033-2909.131.5.763

North, M. M., North, S. M., & Coble, J. R. (1998). Virtual reality therapy: An effective treatment for the fear of public speaking. *International Journal of Virtual Reality*, *3*(3), 1–6. https://doi.org/10.20870/IJVR.1998.3.3.2625

Nowak, K. L., & Biocca, F. (2003). The effect of the agency and anthropomorphism on users' sense of telepresence, copresence, and social presence in virtual environments. *Presence: Teleoperators and Virtual Environments*, *12*(5), 481–494. https://doi.org/10.1162/105474603322761289

Obeada, I., Cronin, J., & Piacentini, M. (2026). From edgework to edgeworking: The interplay of risk and the life course. *Sociology*, *60*(2), 291–308. https://doi.org/10.1177/00380385251357193

Oh, C. S., Bailenson, J. N., & Welch, G. F. (2018). A systematic review of social presence: Definition, antecedents, and implications. *Frontiers in Robotics and AI*, *5*, Article 114. https://doi.org/10.3389/frobt.2018.00114

Patton, M. Q. (1990). *Qualitative evaluation and research methods* (2nd ed.). SAGE Publications.

Peck, T. C., Seinfeld, S., Aglioti, S. M., & Slater, M. (2013). Putting yourself in the skin of a black avatar reduces implicit racial bias. *Consciousness and Cognition*, *22*(3), 779–787. https://doi.org/10.1016/j.concog.2013.04.016

Penaud, S., Yeh, D., Gaston-Bellegarde, A., & Piolino, P. (2023). The role of bodily self-consciousness in episodic memory of naturalistic events: An immersive virtual reality study. *Scientific Reports*, *13*(1), 17013. https://doi.org/10.1038/s41598-023-43823-2

Perron, B. (2012). *Silent hill: The terror engine*. University of Michigan Press. https://doi.org/10.3998/lvg.11053908.0001.001

Pimentel, D., & Kalyanaraman, S. (2024). How cognitive absorption influences responses to immersive narratives of environmental threats. *Cyberpsychology, Behavior and Social Networking*, *27*(1), 83–90. https://doi.org/10.1089/cyber.2022.0401

Podkosova, I., & Kaufmann, H. (2018). Mutual collision avoidance during walking in real and collaborative virtual environments. In *Proceedings of the ACM SIGGRAPH Symposium on Interactive 3D Graphics and Games* (pp. 1–9). https://doi.org/10.1145/3190834.3190845

Pritchard, S. C., Zopf, R., Polito, V., Kaplan, D. M., & Williams, M. A. (2016). Non-hierarchical influence of visual form, touch, and position cues on embodiment, agency, and presence in virtual reality. *Frontiers in Psychology*, *7*, Article 1649. https://doi.org/10.3389/fpsyg.2016.01649

Raggiotto, F., & Scarpi, D. (2023). It's not just a game: Virtual edgework and subjective well-being in e-sports. *Journal of Interactive Marketing*, *58*(2-3), 185–197. https://doi.org/10.1177/10949968221127897

Razzaque, S., Swapp, D., Slater, M., Whitton, M. C., & Steed, A. (2002). Redirected walking in place. In *Egve.*, volume 2, pages123–130.

Riva, G., Mantovani, F., Capideville, C. S., Preziosa, A., Morganti, F., Villani, D., Gaggioli, A., Botella, C., & Alcañiz, M. (2007). Affective interactions using virtual reality: The link between presence and emotions. *Cyberpsychology & Behavior: The Impact of the Internet, Multimedia and Virtual Reality on Behavior and Society*, *10*(1), 45–56. https://doi.org/10.1089/cpb.2006.9993

Sayyad, E., Sra, M., & Höllerer, T. (2020). *Walking and teleportation in wide-area virtual reality experiences* [Paper presentation]. In 2020 IEEE International Symposium on Mixed and Augmented Reality (ISMAR) (pp. 608–617). IEEE. https://doi.org/10.1109/ISMAR50242.2020.00088

Scavarelli, A., & Teather, R. J. (2017). Vr collide! comparing collision-avoidance methods between co-located virtual reality users. In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (pp. 2915–2921). https://doi.org/10.1145/3027063.3053180

Shay, H. (2017). Virtual edgework: Negotiating risk in role-playing gaming. *Journal of Contemporary Ethnography*, *46*(2), 203–229. https://doi.org/10.1177/0891241615603448

Short, J., Williams, E., & Christie, B. (1976). *The social psychology of telecommunications*. John Wiley & Sons.

Singh, N. K., Ray, R. K., Silayach, N., Dash, D. P., & Singh, A. (2025). Avatars at risk: Exploring public response to sexual violence in immersive digital spaces. *Computers in Human Behavior*, *163*, Article 108500. https://doi.org/10.1016/j.chb.2024.108500

Slater, M. (2009). Place illusion and plausibility can lead to realistic behaviour in immersive virtual environments. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *364*(1535), 3549–3557. https://doi.org/10.1098/rstb.2009.0138

Slater, M., & Sanchez-Vives, M. V. (2016). Enhancing our lives with immersive virtual reality. *Frontiers in Robotics and AI*, *3*, Article 74. https://doi.org/10.3389/frobt.2016.00074

Smith, E. R., & Mackie, D. M. (2015). Dynamics of group-based emotions: Insights from intergroup emotions theory. *Emotion Review*, *7*(4), 349–354. https://doi.org/10.1177/1754073915590614

Steinicke, F., Bruder, G., Jerald, J., Frenz, H., & Lappe, M. (2010). Estimation of detection thresholds for redirected walking techniques. *IEEE Transactions on Visualization and Computer Graphics*, *16*(1), 17–27. https://doi.org/10.1109/TVCG.2009.62

Strojny, P. M., Dużmańska-Misiarczyk, N., Lipp, N., & Strojny, A. (2020). Moderators of social facilitation effect in virtual reality: Co-presence and realism of virtual agents. *Frontiers in Psychology*, *11*, Article 1252. https://doi.org/10.3389/fpsyg.2020.01252

Sun, Q., Patney, A., Wei, L.-Y., Shapira, O., Lu, J., Asente, P., Zhu, S., McGuire, M., Luebke, D., & Kaufman, A. (2018). Towards virtual reality infinite walking: Dynamic saccadic redirection. *ACM Transactions on Graphics*, *37*(4), 1–13. https://doi.org/10.1145/3197517.3201294

Sykownik, P., Karaosmanoglu, S., Emmerich, K., Steinicke, F., & Masuch, M. (2023). Vr almost there: Simulating co-located multiplayer experiences in social virtual reality. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (pp. 1–19). https://doi.org/10.1145/3544548.3581230

Tietenberg, J., Ring, P., & Masuch, M. (2025). Virtual proximity, real anxiety: How co-located vr gameplay increases mutual player distance and fear of colliding. In *Proceedings of the 20th International Conference on the Foundations of Digital Games* (pp. 1–14). https://doi.org/10.1145/3723498.3723800

Triandis, H. C. (2018). *Individualism and collectivism*. Routledge. https://doi.org/10.4324/9780429499845

Turkay, S., Formosa, J., Cuthbert, R., Adinolf, S., & Brown, R. A. (2021). Virtual reality esports-understanding competitive players' perceptions of location based vr esports. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (pp. 1–15). https://doi.org/10.1145/3411764.3445073

Van Gemert, T., Nilsson, N. C., Hirzle, T., & Bergström, J. (2024). Sicknificant steps: A systematic review and meta-analysis of vr sickness in walking-based locomotion for virtual reality. In *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems* (pp. 1–36). https://doi.org/10.1145/3613904.3641974

Wienrich, C., Schindler, K., Döllinqer, N., Kock, S., & Traupe, O. (2018). *Social presence and cooperation in large-scale multi-user virtual reality-the relevance of social interdependence for location-based environments* [Paper presentation]. In 2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR) (pp. 207–214). IEEE. https://doi.org/10.1109/VR.2018.8446575

Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and Virtual Environments*, *7*(3), 225–240. https://doi.org/10.1162/105474698565686

Xu, C., & Ge, X. (2025). Reimagining digital well-being: A theoretical framework based on the psychology of felt structure and illustrated through creative storytelling. *Proceedings of the ACM on Human-Computer Interaction*, *9*(7), 1–19. https://doi.org/10.1145/3757396

Xu, K., Chen, Y., Li, J., Liao, T., & Chan-Olmsted, S. (2025). Tracked but not trapped: Negotiating body tracking technologies for embodiment and privacy protection in vr. *Computers in Human Behavior*, *170*, Article 108706. https://doi.org/10.1016/j.chb.2025.108706

Yee, N., Bailenson, J. N., & Ducheneaut, N. (2009). The proteus effect: Implications of transformed digital self-representation on online and offline behavior. *Communication Research*, *36*(2), 285–312. https://doi.org/10.1177/0093650208330254

Yee, N., Bailenson, J. N., Urbanek, M., Chang, F., & Merget, D. (2007). The unbearable likeness of being digital: The persistence of nonverbal social norms in online virtual environments. *Cyberpsychology & Behavior: The Impact of the Internet, Multimedia and Virtual Reality on Behavior and Society*, *10*(1), 115–121. https://doi.org/10.1089/cpb.2006.9984

Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology*, *18*(5), 459–482. https://doi.org/10.1002/cne.920180503

Zhang, Z., Niu, P., Li, C., & Feng, Y. (2024). Does using a green gaming system make people more environmentally friendly? *Computers in Human Behavior*, *161*, Article 108392. https://doi.org/10.1016/j.chb.2024.108392

About the authors

Zhiyun Lei is an artist–researcher with a PhD in Digital Media from Macau University of Science and Technology. His research interests include immersive experience, cultural communication, and human–computer interaction. His work examines how media technologies shape perception, engagement, and social interaction in cultural and creative contexts.

Shuyue Li is an artist-researcher in Computational Media and Arts at The Hong Kong University of Science and Technology (Guangzhou). Her research interests include immersive media, extended reality (XR), human–computer interaction, and computational creativity, with a particular focus on embodiment, safety perception, and user experience in immersive environments.