



Understanding Phantom Tactile Sensation on Commercially Available Social Virtual Reality Platforms

QIJIA CHEN, University of Helsinki, Finland

MICHIEL M. SPAPÉ, University of Macau, China and University of Helsinki, Finland

GIULIO JACUCCI, University of Helsinki, Finland

Phantom tactile sensation (PTS) is usually experienced by participants in laboratory settings with the assistance and supervision of professionals. Extensive reports from users demonstrate they experience PTS on commercially available virtual reality (VR) platforms. We gathered and analyzed 2885 posts by 1408 users to understand how users obtain PTS and how they evaluate their PTS experience. We observed that users experience PTS in three ways: 1) starting to feel it naturally, 2) intentionally developing the ability to experience PTS, and 3) feeling it under substance use. Users perceive the sensation differently. Many people perceive PTS as positive, enhancing their immersion and bringing people closer. While other users consider it a negative experience as it exacerbates harassment issues, or the sensation itself is negative, even painful. We discuss the perceived causes of PTS and how social VR conditions users' evaluation of their PTS experience. We further reflect on PTS from the perspective of the risk of VR use in real-life scenarios. Finally, we provide design implications on employing PTS to enhance users' VR experience and reduce the negatives PTS brings.

CCS Concepts: • **Human-centered computing** → **Human computer interaction (HCI)**; *Empirical studies in HCI*.

Additional Key Words and Phrases: phantom tactile sensation, social virtual reality, toxicity, virtual touch

ACM Reference Format:

Qijia Chen, Michiel M. Spapé, and Giulio Jacucci. 2024. Understanding Phantom Tactile Sensation on Commercially Available Social Virtual Reality Platforms. *Proc. ACM Hum.-Comput. Interact.* 8, CSCW1, Article 141 (April 2024), 22 pages. <https://doi.org/10.1145/3637418>

1 INTRODUCTION

Phantom tactile sensation (PTS) is the phenomenon of feeling touch despite not receiving cutaneous stimulation (touched on the skin). For example, in psychological experiments on the rubber hand illusion (RHI), simultaneous stroking of a rubber glove and one's real hand causes an experience of ownership over the artificial limb [7]. Following this procedure, some participants reported feeling tactile stimulation when they saw the glove being touched [10, 14, 70, 71]. In addition, researchers have shown that PTS can be transferred to virtual reality (VR), and that the illusion experienced is stronger for human-like hands than abstract representation [78]. Previously, the PTS was usually experienced in a laboratory setting under supervision and with the assistance of professionals. However, many users have reported that they sense being physically touched by only seeing virtual

Authors' addresses: Qijia Chen, qijia.chen@helsinki.fi, University of Helsinki, Yliopistonkatu 4, Helsinki, Finland, 00100; Michiel M. Spapé, mspape@um.edu.mo, University of Macau, MacaoDaxueda Rd, Macau, China and University of Helsinki, Yliopistonkatu 4, Helsinki, Finland; Giulio Jacucci, giulio.jacucci@helsinki.fi, University of Helsinki, Yliopistonkatu 4, Helsinki, Finland.

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ACM 2573-0142/2024/4-ART141

<https://doi.org/10.1145/3637418>

touch in social VR platforms, such as VRChat¹ and RecRoom², which are commercially available and allow for multiuser interaction [28]. A study about safety in social VR by Qingxiao et al. [57] mentioned the phenomena as an example to demonstrate the potential risks of using social VR. Alexdottir and Yang [3] studied the same phenomenon by conducting a questionnaire survey with 40 VRChat users. They found that 41% of the participants were able to sense virtual touch with different body parts, such as hands and hips. However, it is unclear how users start to feel the PTS. Besides, social VR as an immersive space providing interpersonal activities satisfies users' diverse social needs [47]. It is essential to understand how the PTS that occurs for many users during interpersonal interaction is being evaluated. Here, we set out to better understand PTS in real-use, social VR scenarios. Since the phenomenon is not well understood, we aimed to explore how people perceive PTS outside the laboratory. Furthermore, by investigating phenomenological reports, we aimed to gain insights into the positive and negative implications that may arise in the social context of current and future XR platforms. Thus, our research focused on two questions:

RQ1) How do users start feeling the sensation in social VR?

RQ2) How do they evaluate the experience of feeling the phantom tactile sensation?

With the above in mind, we gathered and analyzed discussion data from “r/VRChat”³ and “r/RecRoom”⁴ -two subreddits of the most popular multi-user VR platforms. We examined 2885 posts (including threads and comments) by 1408 users. Using inductive qualitative analysis, we identified three ways that people get the sensation: 1) starting to feel PTS naturally, 2) intentionally developing the ability to experience PTS, and 3) feeling PTS under substance use. People have different perceptions of the sensation. Many users enjoy experiencing it because the phantom sensation can enhance their immersion and presence and make social interactions more meaningful. Meanwhile, others think it is negative because the sensation brings up unpleasant feelings on certain occasions and may induce harassment and discrimination. Given these findings, we discuss the perceived causes of PTS and how social VR conditions the PTS experience, and the unknown effect of VR use in the wild. We further reflect on the potential risk of employing tactile sensation in the interpersonal VR space and provide design implications. Our contributions are multifold: 1) We are among the first to conduct an empirical study on the phantom sensation phenomenon in multiuser VR environments; 2) our research supplements the previous studies on phantom sensation by revealing how people perceive and develop PTS in the interpersonal real-use scenario; 3) this research further supports the claim that widespread VR use may have unknown issues and unexpected effects on people, and it offers insights on how people perceive a novel phenomenon in VR use; and 4) we provide design implications on utilizing PTS to enhance users' VR experience, and on reducing the harms caused by PTS.

2 RELATED WORK

2.1 Social VR as an Emerging Online Social Space

2.1.1 Social VR as an Emerging Online Social Space. Social VR provides three-dimensional, immersive digital spaces where people can interact, communicate, and socialize with each other through head-mounted devices [42]. At the time of writing, popular social VR platforms include VRChat, RecRoom, and Horizon Worlds⁵. Social VR supports verbal and nonverbal interaction in real-time via a range of technologies (e.g., body tracking) [13, 41, 74] and provides a strong sensation of

¹<https://hello.vrchat.com/>

²<https://recroom.com/>

³<https://www.reddit.com/r/VRchat/>

⁴<https://www.reddit.com/r/RecRoom/>

⁵<https://www.oculus.com/horizon-worlds/>

body ownership and presence through the technical characteristics of virtual representations. People engage in a variety of social and entertainment activities afforded by those platforms in order to meet a variety of social needs [47, 68]. These activities include socializing with friends, meeting people worldwide, and creating and exploring new worlds and others [5, 47, 68]. Among them, one of the features of engaging in social VR is reexperiencing offline actions, events, and interactivity. For instance, long-distance couples have replicated their offline activities in social VR to feel virtually united [79]. In addition, social VR is used in ways researchers would not generally expect, such as the users sleeping in VR [47]. There are even worlds and avatars customized for a better sleeping experience.

2.1.2 Toxic Behavior in Social VR. Similar to conventional virtual environments, negative experiences such as harassment and antisocial behaviors happen in social VR. Harassment is a common problem in social VR, [6, 20, 63]. After observing user behavior for 11 hours and 30 minutes, researchers from the nonprofit Center for Countering Digital Hate's research found 100 potential violations of Meta's VR standards, including sexual harassment and abuse [19]. Researchers have explored the factors that lead to the prevalence of harassment in social VR. They have found that social VR applications primarily foster interactions between strangers due to VR's synchronous nature and the relatively low adoption of VR devices. As a result, more disputes may arise compared to online spaces that tend to facilitate interactions among acquaintances [6]. In addition, unhealthy elements of gaming culture (e.g., competition and trolling) are also pervasive in social VR [6, 20], which leads to a competitive and toxic environment. Besides, VR-mediated harassment may cause more harm to victims than in other social media. Blackwell et al. [6] noted that the multimodal communications in social VR, including both verbal and nonverbal interactions, such as voice, gesture, proxemics, gaze, and facial expression, support new forms of harassment beyond the more prevalent text- or voice-based harassment in online social spaces. Also, the unique affordances of VR technology, such as the feeling of embodiment and presence, exacerbate the experience of being harassed in VR, making it more severe than in other settings. Not only harassment in social VR may bring more damage to victims. It is also difficult to moderate harassment in social VR because users' perceptions of it are unique and subjective. It can be challenging to report toxic activities or avoid them [6].

2.1.3 Studies Involving PTS in Social VR. There are few studies covering phantom sensation: Qingxiao et al. [57] studied safety issues in social VR, mentioning the phenomena as an example to demonstrate the potential risks of using social VR. The research by Piitulainen et al. [56] on dance experience in social VR showed that some users experience phantom touch and which provided some sort of substitute for actual touch. In addition, Alexdottir and Yang [3] focused on exploring the methodology and provided guidelines to develop phantom touch in social VR platforms. By conducting a questionnaire with 40 VRChat users, They found that 41% of the participants could sense phantom touch. Their research revealed the sensitive body parts where users tend to feel Phantom Touch, such as hands, hips, throat, and others, and found that those areas show similarity with areas where nerve endings densely innervate. Their study also showed the relationship between the type of avatar users utilize and their ability to sense the virtual touch. The user's choice of avatar contributes to the development of PTS. The avatar relates better on an emotional and individual level. The user can better develop the sensation. They explored the types of phantom touch sensations that users experience, and the most frequently mentioned were heat and pressure. In addition, they conducted experiments confirming the existence of phantom sensation. Participants who claimed to be able to sense virtual touch showed identical heart rates with receiving interpersonal touch in real life when they were being touched virtually.

In sum, social VR can afford immersive and natural social interaction. Moreover, social VR platforms have a prevalence of harassment. Also, researchers demonstrated that social VR is used in ways that research normally would not expect. It shows the complexity and uncertainty of VR use in the wild. Few studies cover the phenomenon and confirm the existence of PTS in social VR. However, none of them focus on RQ1) how people start to have PTS in commercially available social VR platforms without assistance from professionals and RQ2) how they evaluate their PTS experience. Investigating the two research questions might deepen the understanding of PTS in VR in casual use scenarios and further provide more insights into VR use in the wild.

2.2 Haptics Research in VR

The development of VR includes not only interactive visual content and sounds but also the sensation of touch, which can enhance user experience qualitatively [77]. Due to the crucial role that haptics can play [30, 60], haptics research for immersive virtual, augmented, and mixed reality has been experiencing unprecedented growth. However, compared to the visual and audio, the haptic is a relatively underexplored modality for VR use, particularly in the context of social touch.

2.2.1 Haptics Applications and Techniques. Touch is a uniquely interactive modality, as each haptic action intrinsically returns tactile sensations as feedback. For example, the haptic perception of touching a cup of coffee involves both the kinesthetic and tactile senses. Kinesthetic information refers to the posture and position of the body parts [39]— here, particularly the limbs. Tactile sensation [39] comprises a number of different sensory sources that together allow us to extract information regarding the texture and heat of touched objects, as well as the pressure and pain caused by their touch. Many haptic devices are available based on the two senses to produce haptic feedback. Vibrotactile devices primarily produce tactile sensations and force feedback devices that mainly create kinesthetic feelings [12, 37].

Studies have demonstrated the important advantages of using haptic feedback in VR in increasing presence, performance, and learning [36, 53]. Kaul et al. [32] found that the received vibration feedback on participants' heads facilitated users to finish tasks and enhanced their sense of presence. Researchers have also paid attention to the relationship between haptic and virtual embodiment. Fröhner et al. [21] utilized both force and vibrotactile feedback with wearable haptic gloves to study the connection between haptic rendering and embodiment. They found that users with these two types of feedback have a stronger sense of embodiment than those without such feedback. In addition, by mimicking the collision (bump) between the virtual representation of participants, Krogmeier et al. [37] revealed a positive correlation between embodiment and vibrotactile feedback.

Researchers have also utilized devices to create phantom tactile sensations in hopes of enhancing user experiences [26, 29, 35]. The principles they used differ from the phenomenon we report here, while the names used remain the same. They used the illusory tactile feeling that occurs in the middle of two or more distant tactile stimuli. Employing the phantom sensation produced within a polygon encircled by multiple stimulation sites (2D) or on a line connecting two stimulation points (1D) generates the tactile feeling to enhance users' VR experiences. Extensive studies have been conducted in this field, including research on creating internal tactile feeling [34].

In conclusion, the haptic sensation is important in VR use. It can improve, for example, users' presence and embodiment. Phantom sensation has been studied to enhance the user experience in previous research, but the principles differ from what this article reports here, even though their names are the same.

2.2.2 Haptics in Affective Touch. To understand the phenomenon of PTS, it is necessary to not only consider the social and technical aspects involved in haptics but also its psychological sensitivity. Psychologists have long investigated touch for communicating emotions [24, 61]. In particular, the

phenomenon commonly known as the Midas Touch Effect suggests that even a short, incidental touch may provoke positive feelings and result in prosocial behavior [23, 65, 66]. This might be a consequence of the slower, more extended touch observed during attachment development, which has been shown to stimulate C-tactile afferent nerves and evoke intrinsically positive feelings in ourselves and other primates [27, 67]. Thus, interpersonal touch presents an intrinsically emotional signal, which may explain why users feel so strongly about its presence in VR.

Of more immediate importance to PTS, however, are findings that show that tactile perception is directly affected by experienced and perceived emotions. Thus, for example, Ellingsen et al. [16] showed that touch was experienced as more pleasurable if an image of a smiling person accompanied it. This effect may be due to an effect of emotion on the earliest processing of touch in the brain, as Montoya and Sitges [49] showed that even brain responses from the somatosensory cortex were altered when participants simultaneously viewed emotional images. This has important consequences for social VR as Ravaja et al. [58] showed that emotional expressions of affective agents in VR altered the brain responses to their touch already within 50 ms from the tactile stimulus, demonstrating this is not merely caused by demand characteristics. Support for a more implicit effect of emotion on touch was also recently obtained by Ahmed et al. [2], who showed haptic expressions to affective VR agents are likewise to be affected by emotional expressions, even when participants were instructed to make similar kinesthetic expressions.

In sum, studies from psychology and cognitive neuroscience suggest phantom tactile phenomena in VR may be more than spurious reports driven by expectations concerning touch. They may reflect enhanced sensitivity to low-level tactile perception due to the strong emotional context characterized by the virtual environment. Such an effect would be thus interpreted as a crossmodal perception phenomenon, for which the literature related to the body ownership illusion(BOI) is particularly significant, as will be discussed in the next section.

2.2.3 Body Ownership Illusion and Phantom Tactile Sensation. A BOI refers to having the experience of perceiving artificial body parts, or a completely artificial body, as belonging to one's actual body [10, 14, 70, 71]. As a result, stimuli affecting the artificial objects are interpreted as originating from one's physical body. For instance, one might feel a mannequin's hand as their own hand and have strong physiological reactions when one witnesses the hand being attached [15].

The most famous example of a BOI is the RHI, in which multimodal cues are combined to create the illusion that a fake rubber hand is actually part of the participant's body [7]. As originally reported by Botvinick and Cohen [7], the hand of healthy participants was hidden underneath a table, while a rubber hand was positioned as a substitute. After a few minutes of stroking both hands, the synchronized visual perception of the rubber hand and the tactile perception of the actual hand being stroked resulted in participants reporting they experienced the rubber hand "belonging" to them. Several findings further confirmed this experience. When asked to locate the actual hand, participant responses were biased toward the location of the fake hand [70]. In addition, when the fake hand was threatened, physiological and neural measures indicated a level of arousal and anxiety as if the real hand was threatened [15].

Researchers found the paradigm can also be transferred to VR, and that illusion experienced is stronger for human-like hands than abstract representation [4, 43, 78]. In VR, the illusion is more apparent when the hand is threatened for both amputees and normal people, which supports the assumption that body ownership is rather a top-down process, whereas experiences of phantom pains after limb loss are caused from the bottom-up between the brain and the nervous system [9, 15].

A salient feature of this illusion is that participants experienced a "phantom tactile sensation," meaning that they felt the touch where they saw it (on the rubber hand) even though they were

not being stimulated at that moment at the corresponding location [72]. Previous research on participants' subjective experiences toward PTS has shown that PTS is not "all or nothing." [40, 72]. For example, Lewis et al. [40] revealed that there appears to be an ordered progression of perceptual events over the course of the illusion. The synchronized stroking can amplify the strength of the feeling of ownership over the duration of the study, including participants feeling more of what the rubber hand feels (tactile sensation), and the PTS can spread to more body regions. Furthermore, interestingly, they found that after experiencing the first set of stroking, participants felt PTS immediately during the second round of stimulation.

In conclusion, PTS has thus far been reported in the literature in the context of laboratory settings, in which PTS is induced with the assistance of professionals. There is little to no research on how users perceive PTS and how they start sensing the sensation in the wild, such as social VR. The commercially available multiuser environments may condition users' perceptions.

3 METHOD

In this paper, we employ a qualitative research method to generate findings related to our research questions. Specifically, we collect users' posts about their experience of PTS shared in "r/VRChat" and "r/RecRoom," and then use inductive qualitative analysis to discover patterns. The research group is familiar with the two platforms. Especially the two coders they have over two years of experience in the social VR platforms due to their personal interests. Additionally, they are also regular users of the two subreddits.

3.1 Data Collection

In the CSCW community, researchers have already utilized specific subreddits for research [45, 59]. We collected data from the subreddits of two of the most popular social VR platforms. r/VRChat has 151000 users, and r/RecRoom has 46500 thousand users at the time of writing. In the two platforms, users gather and share their experiences naturally and directly, which is different from accounts that are obtained from interviews and surveys in which participants need to recount their experience in a temporally bounded setting and might be limited by recall bias [22] and social desirability bias [18]. Therefore, we consider the collection of online data appropriate and valuable as the first attempt to explore how users experience PTS. To make the collected data more comprehensive, we utilized an iterative search strategy to identify relevant threads from the subreddits. We used a Reddit API, which allowed us to fetch data by relevant keywords. The API enabled us to collect all threads containing keywords in either content or titles. We generated an initial set of keywords, including "phantom touch, phantom sensation." We repeatedly retrieved sets of threads based on the search keywords and their variants. Scraped data include each post's title, body, URL, and the total number and content of comments. Once we finished the scraping for further analysis, we read each thread to examine the relevance. Threads that are irrelevant to PTS were excluded.

During the process, we marked up the initial observation of the phantom sensation and the additional words that users use to describe the sensation for another round of keyword searching. The second set of keywords included "phantom sense" and "virtual touch." We continued this process until they reached data saturation (i.e., at the point no new information was presented in the data collection process). After that, we obtained 2885 posts (including threads and comments) from 1408 users from the two subreddits.

3.2 Data Analysis

The research team conducted an inductive qualitative analysis [38] on the collected data. Two coders met regularly throughout the entire analysis phase. First, we familiarized ourselves with the collected data by extensively reading to get a deeper understanding of the phantom sensation

in social VR. After the familiarization, we used open coding to generate initial codes with either words, sentences, or paragraphs for the identical 100 posts, including comments. The examples for the initial codes include “adding immersion,” “making one uncomfortable,” “being harassed due to having PTS,” and “hiding the fact they have PTS.” Then, we met to discuss our codes to settle disagreements and create a codebook by establishing a set of principles. Cohen’s Kappa (κ) was used to measure inter-rater reliability (IRR) [48, 73]. After settling the disagreements, the IRR was $\kappa = 0.81$, with codes ranging from strong to near-perfect agreement. After that, two coders split the rest of the data set to code separately. The next phase involved axial coding, an iterative process where the researchers reviewed the initial codes and the associated data excerpts. During axial coding, researchers continuously moved between the codes and the corresponding data. This dynamic process allowed us to delve deeper into the connections between these codes, facilitating the organization of initial codes into broader, more abstract categories. Ultimately, this methodical approach culminated in the synthesis of overarching themes from the axial codes.

Prior to collecting any data, we advised the research ethics committee of our university about the potential ethical issues with our research. The data we utilize are openly accessible and have the expectation of being publicly visible. The data gathering and analysis are thought to pose no more than minimal risk to people. Therefore, we do not need to apply for ethical approval for our research. But, the research group is aware of the HCI community’s worries about using publicly accessible data [1]. According to Fiesler [17], researchers need to be cautious and thoughtful about their interactions with data and the purposes for which they utilize them. We used a variety of approaches in this study for the benefit of the participants. We rephrased our quotes to make it more difficult to trace back to the source posts. We also excluded any and all personally identifiable data. Only members of the research team have access to the data, which is safely kept on password-protected devices. Moreover, the team’s researchers discussed this research’s possible risks and benefits. We reasoned the following: 1) The research systematically reports an unknown phenomenon of VR use in the real-use scenario and provides insights into how people interpret the effect. In addition, the research reveals negative and positive implications of experiencing the sensation, which is particularly timely, especially in the stage where head-mounted VR devices proliferate, and social VR platforms popularize quickly; and 2) the research could supplement and advance our understanding of PTS by conditioning it in multiple players’ environments with natural interaction, such as to understand ways people develop PTS without assistance from professionals.

4 FINDINGS

4.1 The Ways Users Start to Feel PTS

4.1.1 Starting Feeling PTS Naturally. Many users start to feel PTS naturally. Some users began to experience the sensation after using the platforms for a while. For example, users sense the virtual touch over time,

“It just sort of evolved on its own for me over time. I’m aware of some methods for attempting to construct it, but I’m not sure how effective they are...”

As shown in the above quote, the user started to feel virtual touch tactilely on the social VR platform over time. The user did not use any particular method or receive help from others to develop the ability to sense it. Another user echoed this fact,

“I began to experience a strong pressure/warmth/tingling sensation with touch directed at the nose or lips after a few days of using VRChat with close pals.”

The user started to be able to feel the virtual touch after using the VR platform for a while and felt tactile sensations such as warmth and pressure.

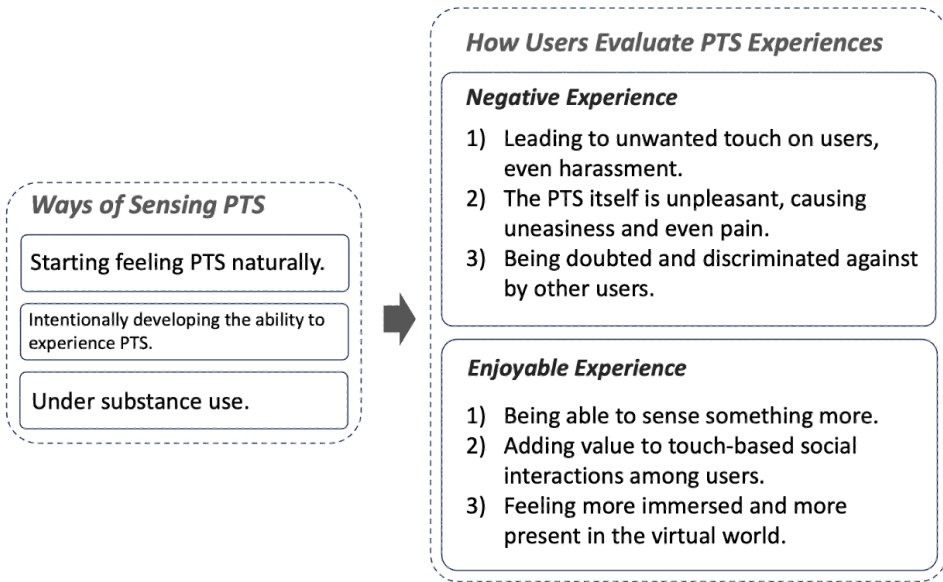


Fig. 1. Summary of findings.

Many users reported that their ability to experience others' virtual touch evolved over time. The evolution manifests as two trends. One is the area of the body part where users can feel the virtual touch. They usually expand over time. For example,

"I wouldn't call it learned; rather, it was a natural growth. I first noticed it when people touched my arms, then it moved to my face, and finally to my chest. I'm no neurologist, so I have no idea, but perhaps my brain became more familiar with my virtual body and began to fabricate sensations based on what I've felt in real life. I dunno, human minds are strange."

The user shared the experience with PTS. It was stated that the sensation occurred to the user naturally. Over time, the sensation became stronger, from only feeling in one area of the body to several others. The user suspected this was due to the brain comfortably adapting to the avatar and producing a similar sensation according to the user's experience in real life based on visual clues.

Another trend of the sensation evolving is the degree of the sensation. For many users, the sensation can grow stronger over time. For example, one user shared his experience of the sensation evolving,

"Consider it like an earthquake. You begin by developing it really strongly in one area, and then it spreads and grows stronger in other areas. Begin with the face because it is the most effective, and with enough time, you should be able to feel it stronger on your torso and subsequently lower body."

The user started to feel PTS in one area of the body, and then it spread to other sites over time, from the face to the torso, lower body, and others. Also, the sensation in each area became stronger over time.

In contrast to developing the sensation over time, some of the users started sensing phantom touch the first time they interacted with people or objects on a social VR platform. For example,

*“How did you develop phantom touch? **I bought my HTC Vive a month ago, and VRChat is the first/only VR game I’ve played so far.** I started to feel it once someone touched me or when I’m interacting with some type of object - that is petting some type of fluffy substance or someone head-patting me.”*

The above was an answer a user gave to another. The user started to sense phantom touch the first time other users touched the user and interacted with objects in VRChat, such as head-patting. Another user echoes this,

“I didn’t develop it. It was just automatic the first time I tried VR. It’s not something I attempt to get, and I can’t turn it off or ignore it.”

The user shared how they were able to sense the virtual touch. Since the first time using VR, the user experienced the PTS without trying to learn and could not control it (e.g., turning the PTS off).

Many users sensed PTS naturally. Part of them began to experience the sensation after using the platforms for some time. For many users, the sensation was stronger over time, and they could sense it from one particular area in their body to different body areas. Another part could sense others’ virtual touch at the onset of using the VR application.

4.1.2 Intentionally Developing the Ability to Experience PTS. Compared to those people who develop the ability to sense others’ virtual touch naturally, many users intentionally develop the ability to experience PTS. They described this as “tricking their brains,” essentially establishing a prior belief that virtual contact with others, either people or objects, is physical. One strategy for developing a virtual touch is through the use of mental imagery, resulting in developing over time a sense of a more physical experience. According to one user,

“I just act like I had it and attempt to mislead my mind. It eventually worked, but in my opinion, the more immersed you are in VR, the higher your chances of receiving it. I apologize if this doesn’t work.”

The user deliberately kept thinking that they had the sense, and then eventually, the user was able to sense virtual touch. This user suspected that the immersion they feel impacts whether they can have PTS. The comment was to respond to a question about how to develop the phantom sense⁶, a common question in threads related to PTS. It was echoed by another user, who replied to a similar question,

“Yeah, if you’re trying to ‘develop’ phantom touch, you just have to keep thinking it’s real, and it’ll start happening eventually.”

In the user’s experience, to develop PTS, one must think virtual touch is physical, which results in the experience.

Another way to develop the ability to feel PTS is by mimicking the RHI, which acts more like an initiator to activate users’ ability to have PTS for users instead of just experiencing it temporarily. It typically involves someone touching the one who wants to develop the ability in the real world. At the same time, another person touches their avatar in the VR world. There are many variations, but the principle is to stimulate users with tactile and visual cues to “trick” their brains into thinking that touch in the virtual world can cause a tactile sensation. For example,

“It is, so try getting cross-faded and having someone move their finger up your arm while you do it in real life without your controller. Then cease doing it in real life but continue to imagine how it feels.”

The users shared the method of gaining PTS via employing a similar procedure to that of PHI. In the RHI experiment[7], researchers make participants have the feeling that a rubber hand is

⁶“Phantom sense” here refers to the ability to sense virtual touch tactilely

indeed the participants' real hand by stroking both real and rubbery hands at the same time. The user-suggested method here is, asking a person to stroke another person who wants to develop the sense with a finger. Then the person themselves does so in real life while imagining the virtual touch is a physical one. Another user offered a different version about how to "trick the brain" into sensing the virtual touch,

"The greatest approach to develop it is to immerse yourself in the virtual environment and focus on where you are being touched. You can also touch your arm IRL as you touch your avatar's arm in VR. This can help to further trick your brain."

The user shared the experience of developing the ability to have PTS and mentioned several key components. Users need to concentrate on the body parts where they are being touched. At the same time, users selves touch their own arms so that they can both sense the physical touch in reality and the visual touch in the virtual environment. This method is different from the previous one, which requires help from other people. IRL here stands for "in real life."

In addition, they also use extra modalities to further enhance the ability to sense virtual touch, such as audio. For example, a user shared the following,

"Verbal descriptions are quite helpful; for example, if someone describes in detail the sensation of them running their hands through your hair or touching your arm, it will readily trigger."

The user shared the experience on how to better develop better the ability to sense virtual touch. An easy way is by letting a person who gives help activate the phantom sense to provide verbal descriptions of their behaviors.

Users deliberately learn how to develop their ability to have PTS. They adopt various methods, such as by purely keeping thinking the virtual touch is physical or using the twisted versions of RHI to develop the sensation.

4.1.3 Under Substance Use. Drinking alcohol on social VR platforms is not an uncommon practice. There are even worlds or events dedicated to drinking in VRchat and AltspaceVR. Some users reported that they felt PTS after partaking in drugs or alcohol, for example,

"I have no phantom sense until I am high, at which point I have to warn all my pals to back off because every touch feels strangely intense, haha."

This statement was provided by the user who sensed the PTS from no to a high level after getting high. Due to the sensation being too strong, the user needed to ask friends not to touch him. Substance use not only induces the sensation but also enhances it. Another user reported this:

"I usually have a weak sense of phantom touch. It gets worse when I start drinking. Much, much worse. And the people I hang out with are aware of this! It's intense at times. but fun!"

The user shared the experience of feeling PTS under the influence of alcohol. They initially had a weak sense of PTS. After drinking alcohol, the feeling intensified.

4.2 How Users Evaluate PTS Experiences

4.2.1 Enjoyable Experiences. For many people, having PTS is a pleasant experience. To have an extra sensation is inherently a positive experience and is perceived as making social interactions more meaningful. Many users even think that being able to feel virtual touch is the best part of interacting in social VR, as stated by a user, *"It is awesome - one of my favorite parts about VR."* In addition, the sensation enhances users' experience in social VR by making it more immersive and strengthening the sense of presence, contributing to users' positive perception of PTS.

For example, being able to feel something in other modalities, except for visual and audio, is a great experience. One user commented,

“For one thing, I can feel hugs and high-fives that people give. Any mutual and shared interaction between friends is a pleasure.”

The user expressed that the ability to sense others’ virtual touch enhances mutual social contact among people, making interactions such as high-fives and hugs more meaningful. Another user echoed this,

“Cuddly things like head pats and anything that may cause phantom touch will draw you closer together. It provides a positive feeling.”

As shown above, the user perceived that sensing virtual touch brings positive feelings. The sensation triggered by users’ social interaction, such as a head pat, could bring people closer. Head patting is a common practice in social VR platforms, especially in VRChat, people use it as a form of greeting.

Besides, the addition of the tactile sensation (even if it is a “thing” in the mind) allows users to feel more immersed in the virtual world. For example, one user shared, *“Yeah, being able to feel virtual touch really adds to the immersion and fun.”* According to the user, the phantom sensation enhanced their immersion in the virtual world. Although the sensation experienced here is not physical, it makes the experience more fun.

Furthermore, the ability to sense virtual touch allows many users to feel more present in the virtual world. For example, as described by one user: *“I like it because it makes me feel like I’m physically present in the virtual world.”* The user thought the sensation made them more present in the virtual environment. Due to the above reasons, people who are unable to sense virtual touch are jealous of others who can. One user said,

“I’m very jealous of my friend who got it. My mind knows far too much, understands VR isn’t real, and knows there are people behind the avatars, so hugging and head patting are strange for me (on both ends). I can’t immerse myself... At the very least...”

The user did not have the ability to sense virtual touch and felt jealous of others who could. The user suspected this was because he could not immerse himself in the virtual environment. A user who could not experience PTS commented on the same post,

“Agreed. It’s one of the things I crave the most in VRChat, being able to feel a head pat or hug. It’s probably the main reason why I’m trying to develop phantom touch.”

The user expressed the wish to be able to sense PTS, especially for feeling a head pat or hug during social interactions. In addition, massive numbers of users asked for help in developing the sensation. For example,

“Hello, I’ve used VRChat for a long time and have always wondered how it would work with phantom sense. So I was wondering if anyone here knew of anyone who could help me with developing it.”

The users asked for help in developing their ability to sense virtual touch. It is a common question in threads related to phantom touch. There are YouTubers demonstrating how to develop the ability to experience PTS.

Many users perceive that to sense additional modalities except audio and visual content is inherently more quality. In addition, the PTS enhances users’ immersion and sense of presence. As part of the consequence, many users want to learn how to develop the ability to sense virtual touch.

4.2.2 Negative Experiences. Besides the positive impressions, some users perceive PTS as unfavorable. One of the reasons is that PTS may lead to unwanted touch on users, even harassment, despite the knowledge of it being unreal. As stated by one user,

“When it comes to having phantom sense, however, there are more negatives than positives. I have to conceal the fact that I have it because random strangers will want to touch me without my permission.”

According to the user’s experience, having PTS is more damaging than positive. The user intended to hide the fact that they had the ability to sense PTS because people tended to touch the user without consent once they knew the user could sense their touch. According to another user,

“I’ve never seen anyone not give someone the benefit of the doubt to begin with, but I’ve had times when someone touches me, and I ask them not to and explain that I can feel it, only for them to respond by literally groping me in ways that would land them in prison IRL, and I’m not sure how they thought that was appropriate in any situation.”

The user shared that after they explained to others they could feel their touch, the others more aggressively “groped” them in an illegal way to the extent that the harassers would have been arrested if the groping had occurred in the real world.

Another reason for users’ undesirable perception of PTS is that PTS causes unpleasant feelings for many users. The unpleasant experiences are divided into two kinds. One happens on some occasions, as suggested by one user,

“I have an unusual habit of moving around people rather than through them. People occasionally walk into my avatar, causing me to move physically. The sensation of someone running through me is extremely strange.”

The user highlighted that being passed through is not a good experience. They tended to move around people instead of moving through them. Another user shared a similar experience wherein they encountered the discomfort of an accident,

“Definitely, the worst pain I felt was my partner accidentally elbowing my face in VR once, and it was a sharp stabby pain for a moment. It’s hard to purposefully trigger it, usually just an accident.”

According to the user, accidentally being elbowed by their partner caused them pain for a short time. The user also expressed that the pain is difficult to activate. It tends to happen accidentally.

In addition to the above, PTS is perceived as uncomfortable on certain occasions. The sensation itself always causes users to feel discomfort. For some people, PTS causes uneasiness and even pain. For example,

“It makes it difficult for me to be touched by others. It’s similar to the pins-and-needles sensation you get when your leg falls asleep and you touch it... there are many positive aspects for other people, but it’s largely terrible for me.”

The user compared the feeling of PTS with the pins and needles feeling. The feeling makes being touched by others more difficult. However, the user acknowledged that the sensation has many good merits, but it was mostly a negative feeling for the user.

Another reason for being perceived as negative is that people with the sensation tend to be suspected and discriminated against by others who do not have the sense. For example, as one user shared,

“As for the drawbacks, I believe the two most significant are that if you develop it strongly enough, you can sense if someone is touching you and you don’t like it, (This is plainly fixable with a block) and the other is being called cringe.”

The user described two negative consequences of having the sensation. One is the unwanted touch, which they thought could be remedied with safety tools. Another is receiving doubt from other people who do not have the sensation if the PTS they experience is true. A sense of exclusion is

therefore expected from people viewing reports as attention-seeking, resulting in peer disapproval. Another user's comment reflects the issue,

“Any person who has phantom sense has a small brain - because your brain cannot distinguish between what is real and what is not.”

The user shared their view on people who have the ability to sense virtual touch, which shows that some users discriminate against people who can feel PTS.

Various causes thus cause users to evaluate the sensation as unfavorable. The sensation can sometimes itself be experienced as uncomfortable or undesirable due to the context or end result. That is, the sensation may be perceived as negative due to its potential role in social interaction, such as it creating a potential for harassment. A further, later negative outcome is derived from feelings of exclusion and a social stigma derived from disbelief: People who have the ability to sense virtual touch are commonly doubted by those who do not.

5 DISCUSSION

Our study investigates the PTS many users experience in commercially available VR applications. We identify how users start to feel PTS and reveal users' evaluation of their PTS experience, as shown in [Figure 1](#). In this section, we will further discuss our findings.

5.1 Perceived Causes of PTS

PTS, being a novel phenomenon in social VR, remains an under-researched topic in the literature, making it uncertain as to how exactly it arises and why some people experience it while others do not. Our qualitative data provide new insights by exploring what users perceive as causing PTS that may serve as a starting point for future research. We identified three principal ways in which users experience PTS in social VR: intentionally, incidentally, and through altered states of consciousness via substance use. Here, we will attempt to connect the existing literature and suggest possible connections that may account for the novel phenomenon.

In intentionally developing PTS, we discovered that users experience it through two strategies. The first strategy involves partially replicating the setup of the rubber hand illusion (RHI) [7]. Researchers have found that people feel an illusion in the RHI largely due to bottom-up mechanisms that involve automatic multisensory and perceptual integration [69]. It appears that the sensation of touch is being attributed to the fake arm based on its synchronization with visual inputs. This means that the impact of sight on the RHI is contingent on the temporal coupling between sensations [31, 62]. In social VR, users replicate RHI by using both visual and tactile stimuli at the same time to feel PTS. That is, similar to the previous finding of tactile perceptions induced by the RHI, the embodiment of a virtual avatar seems to carry over to illusory multisensory perception [40]. Intriguingly, our research indicates that this carry-over effect can be maintained over an extended period of time after the initial RHI setup is abandoned. Indeed, users indicated they do not merely feel the PTS temporarily after the RHI induction but continue to develop the PTS in other scenarios. Since this stands in contrast to previous literature on the RHI, this finding clearly requires further investigation. It is possible that the divergence is due to the fact that studies on the RHI were conducted within a single, short period of time, while social VR users repeatedly spend time within the same environment on a daily basis. Users in the present study were furthermore likely more motivated than paid volunteers in psychological experiments, engaging more with what they perceived as developing a new ability. These factors may both have contributed to developing sustained PTS experiences.

The second strategy users describe is to “mentally convince themselves” or “trick the brain” into believing that the virtual touch they are experiencing is a real, physical touch, which then brings

about a tactile sensation. This may be understood from the psychological literature as a strategy based on *mental imagery*, which has typically (c.f. [54]) been exemplified as using “the mind’s eye” to visualize an object (e.g., a face), although other modalities of imagery, such as movement imagery [25] and tactile imagery [51] are likewise well-known. Studies have shown that mental imagery of sensory stimuli activates brain areas related to those sensations, which has been suggested to increase sensitivity and specificity to stimuli within the particular modality. Thus, for example, visually imagining a face has been suggested to increase sensitivity toward ambiguous face stimuli [44]. Conversely, people with *aphantasia* - a reduced experience of mental imagery - have an enhanced tendency for lower sensory sensitivity [11]. It thus seems plausible that the use of tactile mental imagery may have caused top-down engagement of tactile processing of otherwise ignored cutaneous stimuli (e.g., caused by clothing or air), combined with parallel visual signals suggesting personal contact to provide an illusion of social touch.

A similar process may give rise to the reports of users who experience touch naturally, that is, incidental to their normal interaction in social VR. Here, the normal interaction as playing out in VR will typically involve many moments during which tactile sensations would be expected from visual and auditory cues in the immersive experience. Attentional engagement [58] here likewise contributes to the PTS, although more data would be required to determine exactly which circumstances trigger these incidental events. Furthermore, it is unclear why some people seem to have these experiences “naturally” while others require specific strategies for inducing them, for which reason future studies should aim to identify interpersonal differences. One avenue worth exploring here is to investigate whether those who are most unlike those with *aphantasia* [11] and/or have heightened sensory sensitivity are also most likely to be the ones whose first PTS encounters were incidental.

Besides incidentally and by means of strategies, PTS is also commonly attributed to deliberately induced altered states of consciousness. Many users reported feeling virtual touch while under the influence of substances, even if they do not normally experience PTS. Previous research has suggested that substances such as alcohol and marijuana increase sensitivity to illusions, potentially by impairing executive functioning or reducing inhibitory control [52]. Marijuana, in particular, has previously been suggested to increase cutaneous sensitivity [42]. For example, if an incidental cutaneous stimulus (such as a brush of clothing) occurs simultaneously with the perception of visual contact, this would normally likely be inhibited by executive control so that impairments in this function could result in touch-originated tactile perception. Some substances may further increase embodiment itself. For example, studies on the RHI have demonstrated that using substances such as ketamine [50] increases the strength of the illusion, which may mean that the suggested increased artificial body ownership simultaneously increases proneness to PTS.

Presently, although these speculations are informed by user reports in natural interaction in social VR in the light of the current literature, the scarcity of research on PTS means that few specific hypotheses can be stated. Further effort towards a clear theory on PTS would strongly benefit from further monitoring of users to determine the exact circumstances and requirements for experiencing PTS in social VR. Psychological, psychophysical, and psychophysiological studies may then advance a full-fledged understanding of PTS as a phenomenon and its relation to sensation, perception, attention, and embodiment.

5.2 Social VR Conditions PTS Experience

Previous research on the subjective experience of PTS has typically been conducted in experimental settings where researchers investigate, for example, the quality of PTS sensations, such as whether it is experienced as tickling, numbness, or pain [40, 72]. Our research shows the user’s evaluation of this sensation in interpersonal interaction scenes in social VR. Our findings suggest the evaluation

is influenced by the technical aspects, the social aspects, and the feelings of PTS itself. As a result, users assess their PTS experience in varying ways.

Social VR can provide an impressive experience in terms of both visual and audio elements, but, like many other VR applications [76], it falls short when it comes to other modalities, particularly touch. Touch is an essential component of the overall VR experience for users [8]. In the absence of touch, many users have stated that experiencing more modalities via PTS enhances the overall user experience. This additional sensation adds depth and meaning to social interactions. These findings are consistent with prior research on users' dancing experience in social VR, which suggests that users use phantom sense to supplement their sensory experiences while dancing, providing a substitute for actual touch [56]. In addition, touch sensation enhances VR users' sense of presence and embodiment [12]. And PTS in social VR is perceived to be able to make them feel more sense of presence and embodiment, which makes users find PTS favorable.

Individuals' evaluation of PTS in the interpersonal space is also affected by the social aspect. Studies have shown that harassment is a prevalent issue across social VR platforms, and the behavior of touch can be a uniquely intrusive form of social VR harassment [6]. In an environment where malicious interaction is common, PTS exacerbates the issue by prompting more unwanted touch and intensifying feelings of being harassed. In addition, PTS, as a novel phenomenon lacking a well-defined status, causes many users who can sense this sensation to be doubted and insulted against by others who cannot. Our research has shown that this can be a significant issue for these individuals (e.g., those who report being called "small-brained"). All of the above social factors caused users to perceive PTS negatively. However, the social aspect also caused users to perceive PTS more positively through prosocial behaviors (e.g., head taps and hugs). Finally, the PTS itself is another aspect that conditions users' PTS experience. Some users do not enjoy PTS due to the negative feelings it brings up. For some users, the feeling is quite an "odd sensation" and can cause uneasiness or even pain, which echoes previous literature on PTS [40].

5.3 Unknown Effects of VR Use in the Wild

Former studies on BOI in VR have been primarily lab-based, where participants usually experience PTS under supervision and with the assistance of professionals [10, 33, 70, 71]. Our study reports a phenomenon wherein users are able to feel PTS in commercially available VR applications. Even though users know that the touch is not physical, they can still sense others' touch based only on visual cues. In many cases, users found PTS undesirable but could not turn it off. Many users even experienced PTS as painful. Furthermore, our research indicates that consuming substances such as alcohol and drugs may induce and enhance PTS in VR. Many users under the influence of substances reported feeling the sensation but not when they were sober. Some users even suggested that while being intoxicated, the PTS was so strong that they had to exit the social VR platform. Taking substance while experiencing PTS in VR is understudied in previous research. It manifests the complexity and uncertainty of VR use in the wild. Also, enhancement of substance use in PTS suggests that unexpected VR use may have different and uncovered effects on users in various aspects, such as cognitive and psychological changes.

In addition, one of the concerns of VR use is the blurry line between reality and the virtual world in users' perception [64]. Sensing virtual touches, by inference, can both enhance the "blurriness" and indicate people having a hard time differentiating reality and the virtual world. As reported in our finding section, the PTS may enhance the presence and the embodiment of users, which may, thus, further enhance the blurriness between reality and the virtual world. Besides, previous research has shown that PTS is a signal of BOI, which indicates users cannot distinguish whether the virtual body is their real body.

The above demonstrates the unexpected effect of VR use on people in the wild. It evidences the argument Slater et al. [64] gave that completely novel issues and phenomena will appear with VR becoming a common tool widely used in society. As with any emerging technology that popularizes, new issues and impacts on people rise. It further supports the arguments that there is a possibility that VR technology causes users negative repercussions [46, 64, 75], although VR research on cognitive changes to date generally is regarded as beneficial to individuals and society [64], for example, Peck et al. [55] showed that using dark-skinned virtual presentation decreases implicit racial bias.

However, it is worth noticing that when an unknown phenomenon appears, it may also be perceived positively by users. In our case, although from a general point of view, having an extra unknown sensation can be scary and worrying. But as shown in our data, many users perceive it as positive and deliberately develop the ability to feel it. There even are YouTubers and experienced users to teach other users how to sense PTS. To do so, users utilize methods that are present in academic papers, which amazes us as researchers.

5.4 Various Potential Risks of Utilizing Tactile Sensation

Haptics is a popular topic for HCI researchers, but no research has focused on how people perceive the use of tactile sensation in the wild. Although PTS is not physical, viewers' perceptions of it may provide valuable insights into the impacts of tactile sensation on users in multiuser VR platforms, particularly on harassment.

As shown in our findings section, the use of tactile sensation has many adverse effects on users. Previous studies on harassment in multiuser VR applications have demonstrated that harassment has been a severe issue across different platforms [6, 20, 63]. One way of harassing others in social VR is through nonverbal actions such as mimicking harassment behaviors [6, 20] and touching other people virtually without consent. The tactile sensation may exacerbate the harassment issues. According to our data, with tactile sensation, users perceive touch-based harassment can cause more harm to them. Besides, one of the reasons for making harassment in social VR more harmful than in other social media is due to the embodiment and presence social VR induces [6]. The tactile sensation in social VR enhances the feeling of presence and the sense of body ownership illusion, thus which may further strengthen the harassment.

In addition, as shown in our findings, when malicious users know that an individual can sense touch, they tend to touch the person more, even without consent. For example, after users told others they could feel the tactile sensation of virtual touch and asked them to stop, those toxic users responded with more touch. A user used the word "groping" to describe their behaviors and believed those behaviors would be considered illegal and harassers would have been imprisoned if they happened in the real world. Therefore, when integrating tactile sensation (whether induced through a device or via phantom sensation) into a multiuser VR space, the developers may need to consider the harassment problems. In addition, the users may need to be more careful when sharing that they can feel tactile sensations. Besides malicious harassment, other negative feelings are induced by the tactile sensation in specific scenarios, such as passing through by other users, which many users perceived as unpleasant. The above findings hint that the actual use of tactile sensation may still need to be investigated in the wild to determine its potential risks in multiuser contexts.

5.5 Design Implications

Given our findings, the design implication mainly focuses on two key aspects. The first is to use PTS to supplement tactile sensation to enhance users' experience. Another is to focus on reducing

the negative impacts caused by PTS on users, such as unwanted touch and doubt from others who cannot sense the tactile sensation.

5.5.1 Employing PTS to Enhance Users' Immersion and Presence. We discovered that PTS is perceived as a valuable tool for enhancing the VR user experience. It heightens immersion and presence while also adding value to social interactions. The use of haptic devices to enhance sensory perceptions has been studied. However, these devices often require users to wear them all the time and tend to be bulky [76]. PTS offers an alternative method to experiencing tactile sensations in VR. According to the findings, users can develop the ability to feel PTS by “tricking” their brain, such as by imitating the modified version of the RHI experience in social VR. However, this mimicking typically requires help from others. It normally requires a user to touch them on VRChat and someone else to stroke them in the real world to develop phantom sensations. This provides an opportunity for researchers to design a device that can provide simultaneous visual and tactile stimuli in facilitating users to develop their abilities rather than through other people’s help. In addition, the PTS felt by users has the spreading and enhancing features. Many users perceive that they sensed the sensation from a small area of their body, which then stretched to the more significant body part and the sensation they experienced tends to be more intense over time. The above is in line with previous works [40, 72] showing that PTS is more evident as the duration of synchronous stroking gradually lengthens. Furthermore, Lewis et al. [40] found that after experiencing this illusory touch once, participants were more likely to feel this illusory touch in the second round. These findings further prove the rationality of this design opportunity. Haptic device designs that employ phantom sensation already exist, but their principles differ from those we report [26, 29, 35]. They use the illusory tactile feeling that occurs in the middle of two or more distant tactile stimuli. A device can help users to develop the PTS we report can benefit users’ VR experience.

5.5.2 PTS and Safe Spaces in VR. PTS presents a critical challenge for the goal of establishing safe spaces in VR. Here, we reiterate that even though the literature on affective touch in VR has mainly focused on positive evaluations of social touch, the experience can as easily be a negative one. Central to the phenomenon in social engagement is that it opens new conversations on establishing consent for PTS to occur, without which it may exacerbate negative forms of social interaction, such as harassment and discriminatory behavior. Considering VR is an emerging social space, platforms have a critical role both in investigating the existence of the novel phenomenon and taking active steps toward ensuring it is only used as part of safe, inclusive interaction.

Our research shows that some users who experience PTS face skepticism and doubt from those who cannot feel it, which further leads to insulting behaviors against them such as being called “cringe” and “small brain”. As a result, many users hid the fact that they have the ability to sense virtual touch. A major reason for that is the underdefined status of the novel phenomenon. Platforms should utilize their authority in establishing designs to explain this situation and urge not to discriminate against those users. In addition, considering that social VR is an emerging social space, it is important to inform newcomers about PTS. It is reasonable to assume that some newcomers may not know the norms and novel aspects of the social VR space and may not be aware that such a phenomenon exists that is beyond common sense. Therefore, it is essential for the platforms to guide them. Other new and unexpected phenomena may appear in the future. It is crucial to have a design that addresses and clarifies these occurrences.

Furthermore, PTS as a phenomenon underlines how the enhanced immersion of VR simultaneously brings significant risks to social experiences. For this reason, platforms that aim to create truly open and inclusive social VR spaces must implement strategies to prevent the misuse of PTS. Our findings confirm that touch-based harassment can be resolved through safety tools integrated by social VR platforms, such as blocking and safety bubbles. These tools can prevent others from

getting too close or passing through, thus effectively eliminating touch-based harassment. This underlines that it is essential for all social VR platforms to have this feature.

6 LIMITATIONS AND FUTURE WORKS

In this study, we retrieved and analyzed data from r/VRchat and r/RecRoom, two of the most popular social VR platforms, to report the phenomenon that users feel PTS. A drawback of our research method is we only utilized the discussion data from forums, which might have limited us from initiating a more profound investigation comparable to face-to-face interviews. Besides, there are research questions that still elude us, and we deem them as valuable as the next research steps. 1) RHI employs visual cues to make users feel physically touched. Previous research has shown that the PTS can be replicated in VR settings with visual and haptic stimulation. It is reasonable to assume that the use of haptic devices in VR has the potential to cause some people to have PTS, whether users are willing to have it or not, even after closing the haptic devices. Haptic devices, in combination with VR, have the most salient features of RHI experiments: haptic and visual cues, and they are synchronous. Previous research is conducted in the laboratory environment, which might limit conditions such as random touch or multiple user interactions from happening. Thus, they might be unable to demonstrate the real repercussions of the PTS in casual use. In addition, as reported in our findings and discussed in the previous section, users' ability to sense virtual touch might last for a long time. Some viewers stated that their PTS became stronger, which aligns with previous studies on RHI, demonstrating that the PTS people perceive could evolve over time [40, 72]. It potentially strengthens the repercussions of PTS. But this claim needs to be further investigated in the future. 2) Future researchers could also investigate if the phantom sensation exists in other VR applications besides these multiuser VR platforms. If they do not, what are the reasons? What unique parts of social VR activate the sensation for users? Is it the strong social presence or the fact that these social interactions are more unpredictable than regular and predictable interactions with non-player characters? 3) In social VR, users often feel PTS through various body parts. Additionally, the sensation can become more intense and expand from a small body area to a larger one over time. Previous studies, such as Alexdotir et al. [3], have explored which body parts tend to feel these sensations with 40 participants. Lewis et al. [40], in a controlled experiment, found that participants' PTS was enhanced, and spread to larger areas over the duration of the study. However, these studies have limitations, such as a small sample size or not being conducted in the context of social VR. We reason that exploring these phenomena through conducting a survey with an appropriate amount of social VR users can provide a better understanding of PTS.

7 CONCLUSION

Our findings show that users generally start to sense PTS in three ways: starting to have the sensation naturally, intentionally using strategies to develop the ability to feel PTS, and using alcohol or drugs. Users have different perceptions of PTS. People who have positive perceptions are due to the enhancement effect of PTS on the feeling of immersion and presence. Also, for many users, PTS makes some social interactions more meaningful. Many people perceive PTS as unfavorable because of the harassment and discrimination it may cause. PTS itself is undesirable for many users, as it might cause a pin-and-needle sensation or result in odd feelings on certain occasions, such as when the users are being passed through. Given these findings, we discuss the perceived causes of PTS and how social VR affects the experience. Our study advances the understanding of PTS by providing insights into how people perceive the sensation in real-use scenarios. Additionally, we supplement research on risks and concerns of VR use by investigating an unknown phenomenon in social VR and shed light on the potential risks of employing tactile

sensation in multiuser contexts. Finally, We provide design implications on utilizing PTS to enhance users' VR experience and on reducing the harms caused by PTS.

ACKNOWLEDGEMENT

We thank the anonymous reviewers for their insightful and constructive comments, which significantly strengthened the paper. This work was supported in part by the EU Grant #824128 (VIRTUALTIMES) and by the Research Council of Finland (#357270).

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Received January 2023; revised July 2023; accepted November 2023