PetPresence: Investigating the Integration of Real-World Pet Activities in Virtual Reality

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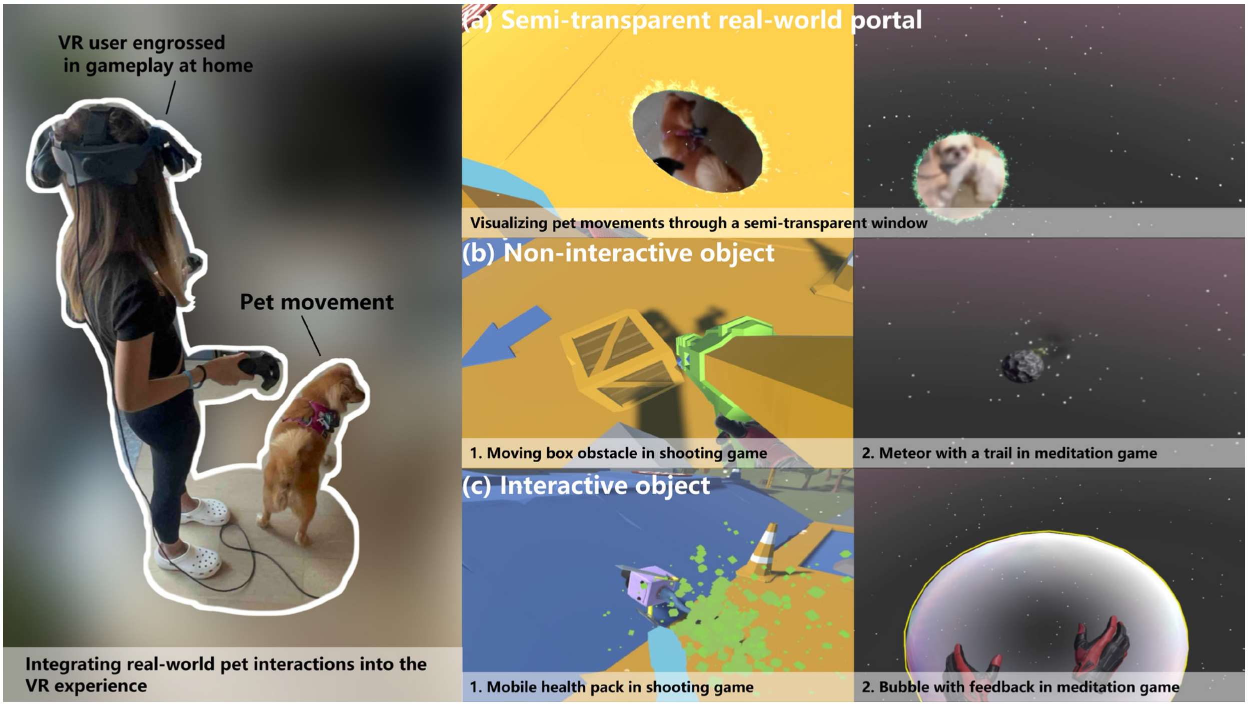

Fig. 1: We explore the integration of real-world pet activities into immersive VR experiences. The proposed pet-integration strategies include: (a) visualizing the pet through a semi-transparent portal; (b) embedding pet behaviors as dynamic non-interactive game environment components; and (c) incorporating pet movements as interactive game elements.

Abstract—For VR interaction, the home environment with complicated spatial setup and dynamics may hinder the VR user experience. In particular, pets' movement may be more unpredictable. In this paper, we investigate the integration of real-world pet activities into immersive VR interaction. Our pilot study showed that the active pet movements, especially dogs, could negatively impact users' performance and experience in immersive VR. We proposed three different types of pet integration, namely semitransparent real-world portal, non-interactive object in VR, and interactive object in VR. We conducted the user study with 16 pet owners and their pets. The results showed that compared to the baseline condition without any pet-integration technique, the approach of integrating the pet as interactive objects in VR yielded significantly higher participant ratings in perceived realism, joy, multisensory engagement, and connection with their pets in VR.

Index Terms—Virtual Reality, Haptics, Distractions, Presence, Pet

1 Introduction

Virtual reality (VR) has evolved significantly in the past decade, providing immersive and interactive experiences for users. The primary goal of VR is to create a sense of presence [49,51], making users feel as if they are truly inside the simulated environment. However, one major challenge in achieving this goal lies in handling the mismatching between the virtual and the real world. Such mismatching may break the sense of presence in VR, and cause distractions [23]. Existing VR systems in the market provide the design feature of guardian, the pre-defined boundaries around users, to remind the users to stay within the designated area and avoid collision with the surrounding physical environments. However, the guardian visualization is typically only visible to VR users, not the bystanders or other moving objects which may accidentally break the guardian boundary and collide with VR users [6,9,55]. While the by-standing/passing persons may consciously try to avoid the physical contact with the VR user, other non-human moving objects, such as pets, may not be able to understand the owner's situation and potentially interupt the VR users with their intentions of interacting with their owners. Slack and Steed identified two main types of distractions in VR, "external sound" and "external touch" [45]. Compared to the external sound which could be blocked through noise-

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cancelling headphones, the external touch, either static items (e.g., furniture and cables) or moving objects (e.g., human and pets), is more difficult to avoid. To this end, researchers have explored methods like real-world object detection and representation [4, 16, 48, 50], in-VR special notifications [5, 10, 52], and haptic adjustments [7, 18], to mitigate the external-touch distractions.

Pets play an important role in human's daily lives, offering profound emotional and psychological benefits [40]. Compared to the external touch caused by human and statistic items, the accidental collision with pets may pose a unique challenge. Pets are more dynamic and unpredictable, and tend to act instinctively, driven by motivations like curiosity, playfulness, or seeking attention. For example, a dog might inadvertently nudge its owner during play, and a curious cat might be drawn to the movement of VR controllers. Unlike predictable human movements or static objects, pets exhibit spontaneous behaviors that can change rapidly in direction and speed. Applebaum et al. revealed that during COVID-19, the pets may interrupt their owners' video conferences in the situation of working at home [1]. This unpredictability, combined with their close bond to the owners, might lead to unexpected interruptions in VR. These challenges underscore the need for in-depth investigation to ensure a seamless VR experience in the physical environments where pets are present.

In this paper, as shown in Fig. 1, we investigated the potential impact of the pets on the user experience in immersive VR, and studied the feasible integration techniques. We first conducted the pilot study with 14 users, comparing their performance and experience in different types of VR activities with and without their pets around. The results confirmed that the in-VR performance was significantly affected by the pet presence, especially for dogs. As follow, we designed three techniques of pet integration in VR: a) a semi-transparent real-world portal to visualize the pet movements, b) representing pets as non-interactive objects in VR, and c) mapping the pet movements to an interactive VR component. We conducted a user study with 16 pet owners and their pets to study the effectiveness of our proposed integration techniques. Our findings indicated that, compared to a baseline condition without any pet-integration technique, the approach of integrating pets as interactive objects in VR led to significantly higher participant ratings in presence multisensory engagement, and a sense of connection with their pets in the virtual environment.

2 Related Work

Our research was inspired and motivated by the relevant works on VR distractions, the corresponding techniques of distraction representation and integration, and animal-human interaction.

2.1 Distractions in Virtual Reality

The primary goal of VR experiences is to immerse the user fully within the virtual world. To achieve a good VR immersion, it's crucial to enhance the user's sense of presence within the virtual environment. However, when users are immersed in virtual reality with their head-mounted displays, they concurrently receive dual bands of sensory information [45]. One originates from the virtual environment presented by the VR hardware, while the other comes from the real-world environment in which the user is physically situated [45]. This duality could lead to distractions that divert the user's attention away from the virtual world [9, 51]. These distractions can be broadly categorized into two main factors: human-induced and environmental.

Human-induced distractions primarily refer to the disturbances caused by other individuals sharing the same physical space. For instance, the presence of a bystander might lead to potential collisions [3, 24, 55], or individuals attempting to communicate with the VR user could interrupt their experience [10, 36]. Recognizing this, prior research has explored various methods to notify VR users of the presence of bystanders [24, 36, 52]. Simeone [42] employed depth sensing to detect people within the tracking space, effectively alerting VR users of their movements, thus adding an additional layer of awareness to the VR experience. Building on this, Zenner et al. [56] recommended strategies for informing users of such distractions in a manner that preserves their immersion, suggesting a balanced approach to alerting users without unnecessarily disrupting the VR experience. Kudo et al. [24] explored visualization techniques to maintain VR user awareness of bystanders, finding a see-through avatar representation to be effective, albeit at a slight cost to immersion.O'Hagan et al. [36] ventured into understanding the social dynamics of bystander interruptions in VR experiences. Their research indicated that the relationship between the VR user and the bystander was a more influential factor than the setting when considering the comfort and strategy of interruption. Gottsacker et al. [14] expanded upon this by exploring BIP (Breaking Immersion Point) interruptions that pull VR users from their immersion, introducing the diegesis concept to frame these interruptions within the narrative of the VR experience itself, thereby reducing the jarring effect of such disruptions. Willich and team [52] addressed the challenge of physical passersby inadvertently breaking a VR user's immersion. Their research proposed three methods to represent physical passersby within the Virtual Environment.Such findings emphasize the need for seamless integration techniques that do not compromise the immersive quality of VR.

The environmental distractions cover a range of real-world objects and phenomena that could disrupt the sense of presence in VR. Examples include the sensation of wind, vibrations, phone ring tones, ambient noise, touch of static items (e.g. furniture), and even scents [8, 12, 35]. These elements not only act as potential distractions in VR but also heighten the VR user's awareness of their real-world context [13, 15]. Compared to the human-based distractions, the environmental influence to the VR users could be more uncontrollable and unpredictable. To this end, the pet's presence and movement in the physical space could be regarded as the environmental factor that could potentially affecting the sence of presence in immersive VR.

2.2 Representing and Integrating Distractions in VR

There have been increasing research interests in mapping real-world objects into immersive VR. A notable example of this is the concept of Substitutional Reality (SR) in VR, as explored by Simeone et al. [43]. In SR, every physical object is mirrored by a virtual counterpart in the virtual space.

Specifically, Insko et al. [19] and Azmandian et al. [2] demonstrated that the introduction of passive haptics can significantly enhance the sense of presence and immersion in virtual environments. McGill et al. [30] noted that "the more a user engages with a real interactive object, the more it can be blended into the VR view." Replicating real-world sensations like wind and temperature in VR can also intensify users' sense of presence, as highlighted by Cheng et al [4]. Piumsomboon et al. [38] underlined the importance of VR users retaining real-world awareness and proposed methods to assist them in smoothly exiting immersive virtual environments. This reinforces the need for VR experiences to not only provide immersion but also facilitate a seamless transition between the virtual and real worlds, acknowledging the importance of maintaining a balance between the two. Sra et al. [48] extended the research by reconstructing the surrounding environment in 3D within VR. This allowed players to feel the tactile sensation of corresponding objects in VR and interact with them. Liu et al. [28] utilized the arrangement of the surrounding environment to propose a method of generating virtual worlds based on the real world. Their research found that this approach effectively prevents collisions in the real world. This method was further refined to capture the real world in real-time through cameras and generate corresponding objects in VR, merging the virtual and real worlds. In recent research by Fang et al. [7], household items were not only displayed in VR but were also utilized as an interactive component based on their characteristics, allowing interactions like simulating the firing of projectiles and petting virtual cats.

Besides static real-world objects, other environmental disturbances have also garnered attention from researchers. Tao et al. [50] integrated the environmental phenomena, such as noise, temperature changes, and wind, into VR. This approach offers a novel perspective on handling uncontrollable environmental elements in the real world during VR gameplay. Additionally, researchers investigated the solutions of reducing the disturbances from bystanders and intruders in the same physical space [10, 24, 36, 47, 55]. Ghosh et al. [10] designed different alert mechanisms to notify VR users, while Kudo et al. [24] detected the intention of the bystander before deciding whether to send an alert. While existing research extensively studied how to represent or integrate the real-world houehold items and other humans into VR, they did not yet look into the distractions caused by pets which are becoming an integral part of many households. Compared to human, pets are more difficult to be tracked and predicted. In this paper, we investigated the impact of pets in VR experience, and propose potential approaches for VR pet integration.

2.3 Animal-Human Interaction in Virtual Reality

Over the years, the digitally-mediated interactions between humans and animals have attracted significant amount of research attention. As one of the early work, Vormbrock et al. [53] studied the the therapeutic advantages of engaging patients in the actitivities of playing with pets. The field of Animal-Computer Interaction (ACI) initially aimed to comprehend the interactions between animals and computing technology within their habitual contexts [29]. Yet, the nuances of an animal's interactions with technology, termed the 'gulf of execution', remain uncharted in ACI [39].

The emergence of virtual-reality (VR) and mixed-reality (MR) technologies has spurred interest in replicating or enhancing traditional animal-human interactions within virtual spaces [17, 21]. Lee et al. [25] introduced a human-computer-pet interaction system that conveys human interactions to pets over the Internet, simultaneously representing the pet's movements either through a physical doll on an XY positioning table or as a real-time 3D visualization in a virtual garden. Na and Dong [32] delved into a MR approach where the participants were engaged with a virtual cat using gestures and voice commands, aiming to alleviate mental stress. Their subsequent research reaffirmed the potential of MR-based human-animal interactions in stress reduction, emphasizing the pronounced benefits when virtual animals provided audiovisual feedback [31]. Similarly, Norouzi et al. demonstrated that Augmented-Reality (AR) animals could offer companionship and support [33, 34]. Judistira et al. ventured into AR technology with speech recognition, creating an interactive multimedia application for animal knowledge on Android platforms [20]. However, their focus was primarily on virtual pets, not their real-world counterparts. Yet, as VR continues to evolve with its primary objective of fostering a profound sense of presence, one pertinent question arises: Should the virtual realm estrange users from their real-world pets, or can it serve as a bridge to enhance this bond?

In our research, we delved into this critical intersection of VR technology and human-pet interaction. We explored how the integration of real-world pets into the VR environment can not only mitigate potential distractions but also strengthen the emotional bond between owners and their pets. By examining different methods of incorporating pet awareness into VR, our study aimed to support a harmonious coexistence of pets and users within the same space.

3 Pilot Study on Pets' Impact on VR User Experience and Performance

We first conducted a pilot study to investigate the potential impact that pets may place on immersive VR. Existing research showed that the pet's presence could affect the working efficiency of the owner [1]. VR interaction is different from the normal working situation, as the VR users' vision is usually disconnected from the real world. To this end, it is unknown that how users may perceive the presence of their pets while interacting with immersive VR.

3.1 Participants

We recruited 14 participants (6 females, and 8 males) from the word of mouth. Their ages ranged from 23 to 42 (M=29), and 8 of them had previous VR experience. Ten participants were dog owners and four were cat owners. The dogs in our pilot study ranged from miniature breeds, such as Bichon Frises and Cairn Terriers, to large breeds like Labradors and Samoyeds. Their body lengths range from 40.4 to 78.4 *cm* (M = 57.41, SD = 18.08), and heights extending from 26.4 to 60.2 *cm* (M = 39.48, SD = 12.79). As for the cats, they are one Maine Coon and three Domestic Shorthair cats. Their lengths range from 38.5 to 67.3 *cm* (M = 48.45, SD = 12.97), and heights extending from 20.7 to 32.5 *cm* (M = 26.65, SD = 4.90).

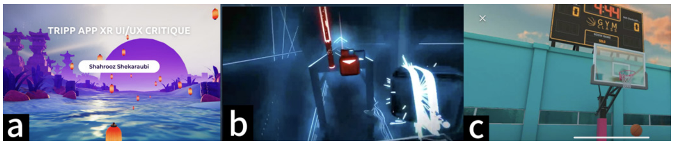

Fig. 2: Three different VR applications, which is (a) Tripp, (b) Beat Saber and Gym Class:Basketball

3.2 Apparatus and Setup

The experiments were conducted in the participants' own home. These households are spread across the city, with dwelling types including apartments and standalone houses. The designated spaces, primarily located in living rooms or halls, serve as the activity areas for pets. These areas vary in size, ranging from 4 to 10 m^2(M = 6.64, SD = 1.74). This was to ensure the comfort of the pets and reduce the pets' stress reaction induced by unfamiliar environments. The VR applications were rendered using the Meta Oculus Quest 2 with two handheld controllers. We selected three different VR applications from the market, with different levels of activeness and engagement, as described below.

- **Tripp**[1]: Tripp (Fig. 2a) is a VR meditation application to help users relax and achieve a calm state of mind. The system provides slow and calm visual effects, and the user only needs to sit down without any movement.
- **Beat Saber**[2]: In Beat Saber (Fig. 2b), players slice the blocks representing musical beats with a pair of light sabers using the handheld controllers. During the game play, the player doesn't need to move around in the physical space. In our pilot study, we set the game to be "Easy" mode, and selected the song "Turn Me On" due to its simplicity in terms of rhythm and speed.
- **Gym Class: Basketball**[3]: In this VR basketball simulation (Fig. 2c), the users are required to move around and make shots using the handheld controllers.

While the users need to actively move around in the physical space in the basketball simulation, it may increase the chance of colliding with their pets. As the music game and the meditation application only engages the hand movements and no body action, it might be less likely for the users to hit their pets.

3.3 Procedure

Each experiment session included one participant, one pet, and one facilitator. Upon arriving at the participant's own place, the facilitator introduced the procedure of the experiment, and collected the participant's personal information and consensus of video recording. The experiment session was divided into two sub-sessions, with and without the pet. The order of with and without the pet was counter-balanced in Latin square. In each sub-session, the participant was instructed to use/play the three VR application in a random order. For each VR application, the facilitator first taught the participant how to use/play, and the participant could practice as much as he/she wanted before the actual test trial. We recorded the score achieved by the participants for the musical and the basketball game. For the VR meditation, the participant rated his/her calmness level in a 7-likert scale (1: not calm at all, 7: very calm) after the trial. For the sub-session with the pet, the pet can freely move around, as for the sub-session without the pet, it

[1]https://www.tripp.com/
[2]https://beatsaber.com/
[3]https://www.gymclassvr.com/

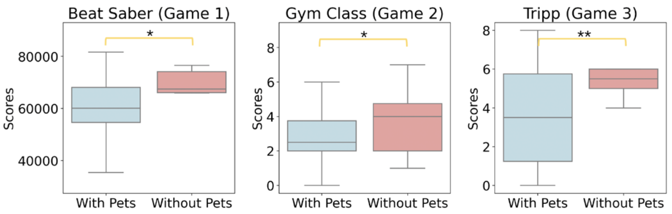

Fig. 3: Game Performance with and without Pets Presence. The distribution of scores for participants playing Beat Saber (Game 1), Gym Class (Game 2), and Tripp (Game 3) with and without the presence of pets. (⋆ = $p < 0.05$, ⋆⋆ = $p < 0.01$)

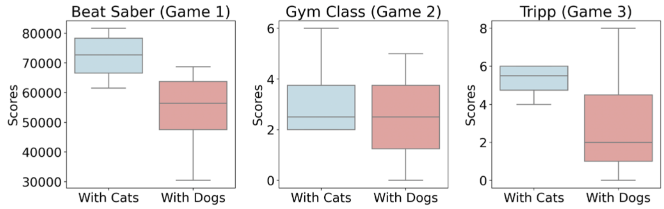

Fig. 4: User Game Performance by Pet Type (Cats vs. Dogs).

was taken outdoor by the family member of the participant. After the whole experiment, the participant was interviewed to provide his/her feedback on the VR experience with and without his/her pet around.

3.4 Results

3.4.1 Impact of Pets on VR Performance/Experience

As illustrated in Fig. 3, the participants' performance in VR showcased distinct variations depending on the presence or absence of pets. Wilcoxon Signed Ranks Tests showed that the condition of pets' presence (with/without pets) significantly affected the participants' scores achieved in the musical and the basketball games (musical game: $Z = -2.417$, $p < 0.05$; basketball game: $Z = -2.555$, $p < 0.05$), and the calmness rating for the VR meditation ($Z = -2.623$, $p < 0.01$). Specifically, the pets' presence yielded significantly lower scores and calmness ratings than the situation of without pets. This indicated that the pets' presence may place negative impact on the VR user experience.

The influence of pets on VR users in our pilot study could be associated with the pet's temperament. During the experiment, it was observed that most pets, initially driven by curiosity, would hover around their owners or even try to pounce on them, especially during active games such as the basketball game. The participants' comments included, *"Yes, I can feel him sticking his tongue out and standing up and wanting me to touch it."*, *"When moving in a game, I need to consider whether i might step on the dog"*, *"I can hear it meow"*, and so on.

3.4.2 Dogs vs Cats

We observed that dogs and cats behaved differently while seeing their parents using VR. Fig. 4 elucidates the comparison of participants' performance and ratings with cats versus those with dogs across the three VR applications. For the games with active body actions (i.e., music and basketball), dogs were actively curious, causing more distractions for participants, while cats were more like passive observers. Dogs' playful nature might have caused them to perceive the participants' movements as an invitation to play, thus engaging more actively with users. In contrast, cats remained distant observers, seldom getting involved even in dynamic scenarios. On the other hand, we noticed that dogs could quickly settle down beside their VR-engaged owners in the VR meditation. Yet, the participants rated their calmness significantly lower when their pets were around. This could be because the very stillness during meditation might have made players more aware of any subtle disturbances, such as the pets brushing against them or making a soft sound.

3.4.3 Pets in VR

In our post-experiment interview, all the participants expressed their interests in the possibility of involving their pets in the VR interaction. One participant mentioned, *"I don't like to play the game and ignore it."*, echoing another feedback *"Yes, because I don't want her to be bored"*. Another participant said, *"I actually wonder what he's doing while I am in VR."* One participant strongly expressed, *"I eagerly anticipate the inclusion of my pets in VR games as I believe it would improve my gaming experience and foster greater focus. Moreover, the incorporation of pet elements has the potential to heighten my sense of immersion and alleviate dizziness to some extent."*

In summary, our pilot study revealed the influence of pets' presence on the VR user performance and experience. It also shed insights into the participants' needs to integrating their pets in the immersive VR interaction, motivating our next step of designing the pet-integration techniques for VR.

4 Integrating Pets in Immersive VR

Our pilot study indicated the need of integrating pets in VR. In the realm of VR, a unique challenge arises when the user's attention is immersed in the virtual space while their pet remains in the physical world. When the pet's physical activity overlaps with the user's, an inevitable collision occurs. This collision disrupts the user's immersion, pulling them back into reality and hindering their VR experience. To this end, we proposed three pet-integration strategies: *Semi-Transparent Real-World Portal*, *Non-interactive Object*, and *Interactive Object* in VR. We implemented these techniques using HTC VIVE Pro and Unity 2019.4.39f1, on a VR-ready desktop PC with Xeon E5-2630 V3, 64GB RAM and Quadro M4000.

4.1 Semi-Transparent Real-World Portal

In our pilot study, the participants indicated that the VR HMD isolated them from external information, causing concerns about stepping on their pets, especially when the pets silently moved close to them. Inspired by the previous work on toggling the the physical-world view in VR [52, 54], we designed a small real-world window to display the real-time pet activities, as shown in Fig. 5b and Fig. 6b. This mini portal, serving as a rich source of information, shows a small area around the pet. On one hand, it helps users determine their relative position to their pets, and the pet's posture in the small window allows users to avoid stepping on the pet's limbs or tail. On the other hand, the small window also provides a view of the real world around the pet, enabling users to judge whether the pet is engaging in dangerous or disruptive behavior, such as chewing on electrical wires or tipping over trash cans.

To capture the real-world images, we utilize the front-facing dual cameras on the HTC VIVE Pro and the HTC SRworks SDK[4]. The SRworks SDK can crop the video captured by the front-facing dual cameras, displaying the real-time images from specific locations, thereby creating a elliptical portal effect in the virtual environment. By binding the portal's location information to the HTC VIVE tracker on the pet's back, the portal can display the real-world images of the pet and its immediate surroundings. When the pet approaches the user, the mini portal gradually transitions from transparent to fully visible based on the distance between the pet and the user, allowing the user to see the pet in real-time within the VR environment.

4.2 Non-Interactive Object in VR

Prior research has investigated the integration of real-world environments into VR, specifically through the use of Non-Interactive Objects in VR. Simeone et al. [43] introduced the concept of Substitutional Reality, wherein physical objects and architectural features can be replaced with their VR equivalents. Similarly, Willich et al. [52] utilized non-interactive avatars in VR to represent passers-by. Our research focuses on depicting pets as virtual entities in the immersive virtual environments. Drawing from previous studies, we have designed Non-Interactive Objects in VR to portray pets as passive elements within the

[4]https://hub.vive.com/storage/srworks/

virtual environment, akin to crates situated in an outdoor courtyard or comets traversing outer space in virtual settings.

In the setting where pets are mapped as the non-interactive environmental objects, users can maneuver their virtual characters to dodge obstacles in the VR world by moving their bodies. Simultaneously, users are also avoiding their pets in the real world. The consistency between the virtual and real worlds aids in maintaining the user's immersive experience. On the other hand, the non-interactive environmental objects may reduce the cognitive load on the user, minimizing the potential for distraction that could degrade the gaming experience.

Similar to the real-world portal, we attached a HTC VIVE Tracker to the pet to record their location information. To further minimize the distractions, the visual design of the non-interactive objects was made to match the style of the virtual environments. Additionally, the scale of the non-interactive objects can be adjusted to match the size of the pets, allowing users to accurately avoid the moving pets in the physical world.

4.3 Interactive Object in VR

Previous research has explored the addition of interaction and feedback effects for real-world objects in virtual environments. In *Metaspace* [49], the concept of representing other users as interactive VR avatars was proposed. Hartmann et al. [16] introduced the concept of *RealityCheck*, which combines 3D reconstruction of the real world with the virtual environment. This allows users to pick up objects in their vicinity and interact with them in VR. In a similar vein, Fang et al. [7] proposed transforming household objects into interactive objects within VR.

Inspired by these previous works and taking into account the active and unpredictable movements of pets, we integrated pets into VR as interactive objects (e.g., enemies or teammates in a shooting game, mysterious chests filled with treasure or curses) , which allowing users to interact with their pets' virtual avatars within the VR environment. This integration transforms pets into active entities in the VR space, enabling users and their pets to share the same physical space while also engaging in VR games together. The unpredictable and random nature of a pet's movements and behaviors may potentially add an element of fun and excitement to the VR game.

Besides tracking the pet's movement using the HTC Vive tracker, we also added interactions to the pets' virtual avatars in VR that align with the game's background and objectives. For instance, in a shooting game, the pet's virtual avatar can become a special non-playable character(NPC) that players need to shoot. Players must avoid the pet's virtual avatar, and hitting it will either increase their life or provide them with ammunition. Moreover, in games with a meditative atmosphere, touching the pet's virtual avatar generates soothing and stress-relieving audiovisual effects, aligning with the goal of helping players relax and find tranquility.

5 User Studies on VR Pet-Integration Strategies

To compare the aforementioned strategies of pet integration in VR, we conducted the user study with 16 pairs of owners and pets using two types of VR activities, namely shooting game and meditation.

5.1 Participants

We recruited 16 dog owners (12 female, 4 male) with an average age of 28.19 (range from 20 to 45, SD = 7.57) and their own pets to join the user experiment. We only considered dogs in this study, since we observed that dogs are more active than cats in our pilot study. Two participants have never used VR before, 12 used one less than 5 times, and two participants used VR from 6 to 10 times. Participants have raised pet dogs for an average of 2.32 years(from two months to 12 years, SD = 2.72). None of them participated in our pilot study.

The dogs participating in our study ranged from miniature breeds, such as teacup dogs, to large breeds like Labradors. The age of these dogs varied from one to eight years (M = 3.31, SD = 1.99), with their heights ranging from 17.6 to 65.6 *cm* (M = 37.52, SD = 14.01), and body lengths extending from 27.9 to 102.7 *cm* (M = 57.79, SD = 22.66).

5.2 Apparatus

All user studies were conducted in the same household environment, with a floor space measuring $2.5m \times 3m$. This space is situated within a flat and is flanked by furniture on two sides, allowing pets to move in and out freely. A set of HTC VIVE Pro was used to provide VR experience. An HTC VIVE Tracker (2018 ver.) was attached to the pet dog's carrier to track their movement. Two modified VR applications, including the VR shooting game[5] and the VR meditation[6] were used in the user experiment. The applications were installed on a VR-ready Laptop with 64 GB RAM and RTX 3080 Ti GPU. As shown in our pilot study, pets may behave differently when their owners were engaged in the VR activities with different level of body activeness. We implemented two VR applications for our study, the shooting game which requires intensive body movements and the meditation which involves less or even no active body movements.

This selection was made due to the flexibility in customization and the contrasting levels of physical activity required by these two games. Unlike the games used in the pilot study, which were not open-source and thus limited in adaptability, these applications allowed for greater control and modification to suit our research needs. The shooting game, requiring intensive body movements, and the meditation app, involving minimal to no movement, provided a stark contrast. Furthermore, the contrasting levels of physical activity in these two applications – from the active engagement in the shooting game to the passive nature of the meditation – provided a comprehensive spectrum of user experiences. This range enabled us to observe and analyze the varying impacts of different VR activities on pet behavior and user-pet interaction in the same household environment.

5.2.1 Shooting Game

As depicted in Fig. 5a, the shooting game operates within a designated activity zone and is characterized by its cartoonish visual style. In this game, players are required to exhibit heightened concentration as they navigate the virtual environment. Adversaries randomly appear and move about erratically, adding to the game's unpredictability. The primary gameplay mechanic involves aiming and shooting at these adversaries multiple times to eliminate them. However, players must also be wary: if adversaries come into contact with the player, the player's health diminishes. This dynamic creates an environment where players must maintain a balance between offense (eliminating enemies) and defense (avoiding enemy contact). The game's design inherently demands swift reflexes and spatial awareness, underlining the immersive and challenging nature of VR experiences.

Fig. 5b shows the real-world portal in the shooting game. For the strategy of integrating the pets as non-interactive objects, we had the pets play the role of a crate in the environment, as shown in Fig. 5c. When the pets become the interactive objects, the pet appears as a small walking character, as shown in Fig. 5d. If users get too close to it, they will lose health in the game, encouraging them to consciously avoid it. Moreover, when users send signals to the walking character by using virtual guns, they can regain health. We have deliberately chosen not to portray pets as enemies in shooting games, considering that users might be reluctant to perform aggressive actions towards their own pets.

5.2.2 Meditation Game

In the Meditation Game, as depicted in Fig. 6a, players find themselves immersed in a vast starry expanse. The ambiance of this virtual space is further accentuated by soothing music, facilitating a meditative state for the players. Randomly appearing twinkling stars not only add to the visual allure but also serve as focal points to assist players with their breathing, synchronizing inhalation and exhalation with the gentle pulsating of these stars. The primary objective of this game is not about scoring or competition but rather about achieving a deep state of focused meditation. Through this serene environment, players are encouraged to immerse themselves fully in the tranquility of the virtual cosmos. The real-world portal for VR meditation (Fig. 6b) was similar to the

[5]https://github.com/GameDevChef/VRShooter
[6]https://github.com/Reality-Hack-2023/mindflow

Fig. 5: **(a)** Screenshot of the *VR Shooting Game*, showcasing an activity zone gameplay. The dynamic environment and action-oriented tasks emphasize the user's engagement and focus. **(b)** Integrating pets into VR via *Semi-Transparent Real-World Portals* in the shooting game. **(c)** Integrating pets into the VR shooting as *Non-Interactive Objects*, pet appear as crates in an outdoor courtyard. **(d)** Integrating pets into the VR shooting as *Interactive Objects*. The pet appears as a small walking NPC, user can regained in-game health by signaling the NPC with virtual guns, which is indicated by green sparkling.

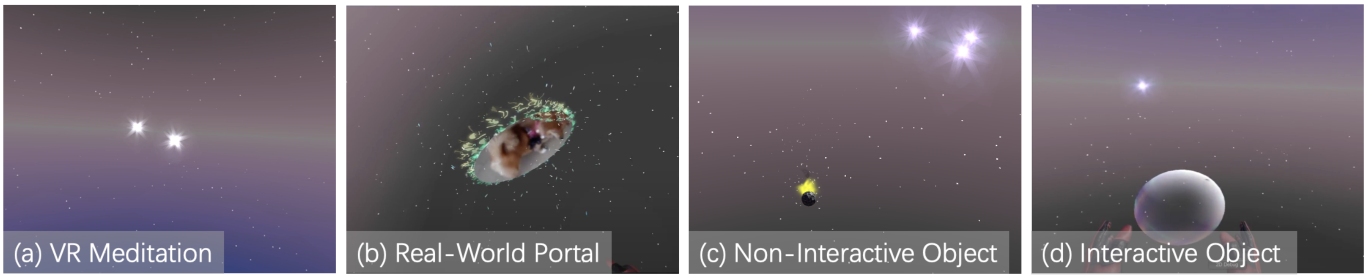

Fig. 6: **(a)** Screenshot of the *VR Meditation*. The user floats in the starry sky, having a VR experience tailored for relaxation. **(b)** Integrating pets into the VR meditation via *Semi-Transparent Real-World Portals*. **(c)** Integrating pets into the VR meditation as *Non-Interactive Objects*. The pet is depicted as a comet with a tail traversing outer space. **(d)** Integrating pets into VR meditation as *Interactive Objects*. The pet appears as a floating touchable bubble. When user touches the bubble, it pulses and emits soothing sounds.

setting in the shooting game. For the pets as non-interactive objects, the pets became comets in a space setting, as shown in Fig. 6c. While being represented as interactive VR objects, the pet is represented as a floating bubble, as shown in Fig. 6d. This bubble emits specific sound effects, and when players touch the bubble in the VR environment, it pulses and produces unique sounds. The interaction with the bubble is designed to provide players with a relaxing and stress-relieving experience, potentially enhancing the overall meditation experience.

5.3 Study Design

The experiment employed a within-subjects design, wherein the participants engaged with the two aforementioned VR applications. Each VR application incorporated four pet-integration conditions: *Semi-Transparent Real-World Portal*, *Non-Interactive Object*, *Interactive Object in VR*, and a *Baseline* condition without any pet-integration strategy. To this end, each participant underwent 2 VR applications $\times$ 4 pet-integration conditions $=$ 8 trial sessions. The order of these trials was counter balanced in Latin Square for the participants.

5.4 Procedure

Each experiment involved one participant and his/her dog, and one facilitator. After greeting the participant and his/her pet, the facilitator introduced the study procedure and the two games. We also offered small treats to the pet dog and inquired about its preferences. After the participant and the pet dog were acquainted with the experiment environment, the facilitator demonstrated the VR shooting game and VR meditation to the participants. We measured the body size of the pet dog in order to adjust the scales of three pet integrations' components in two VR applications. We attached the VIVE Tracker to the carrier on the pet dog's back, for tracking its real-time position.

In each trial session, the facilitator taught the participant how to play/use the VR application, and described the pet-integration strategy correspondingly. After the participant familiarized his/herself with the VR application, the actual trial started and lasted for 3 minutes. After each trial session, the participant filled up the post-trial questionnaire containing the items from the Slater-Usoh-Steed (SUS) questionnaire [46, 51] for his/her perceived sense of presence, and other questionnaire items regarding his/her perceived realism enhancement, joy, and connection with his/her pet, in the 7-point Likert scale (1: Strongly Disagree, 7: Strongly Agree). The participant and the pet took a 3-minute compulsory break before starting the next session. After finishing all the sessions, the participant was instructed to complete the post-experiment questionnaire to rating their preference on the presented pet-integration strategies. The facilitator also conducted a semi-structured interview for about 15 minutes to gather the participant's thoughts on the overall experiment and the interaction with the pet dog in VR. The whole experiment procedure ranged from 60 to 90 minutes.

5.5 Results

Due to the ordinal nature of the questionnaire data, we conducted non-parametric statistical analysis on the participants' ratings.

5.5.1 Sense of Presence

To assess the sense of presence across different conditions, we adopted the Slater-Usoh-Steed Questionnaire includes six questions about presence [46,51]. The presence score could be computed by the count of the questionnaire items receiving the ratings of 6 or above. The computed presence score for each method was shown in Fig. 7. Fig. 8 shows the specific rating of each question from Item1 to Item6. Friedman Tests revealed that the pet-integration strategy significantly affected the presence score for the shooting game ($\chi^2 = 13.75$, $p < 0.005$), while there was no significant effect of the pet-integration strategy on the presence score for the meditation. Wilcoxon Signed Ranks Test showed that in the shooting game, the strategy of presenting the pet as an interactive VR object yielded significantly higher presence score than the ones of non-interactive object ($Z = -2.512$, $p < 0.05$), real-world portal ($Z = -2.976$, $p < 0.005$), and no integration ($Z = -2.155$, $p < 0.05$), while there was no significant difference among the presence scores of these three conditions.

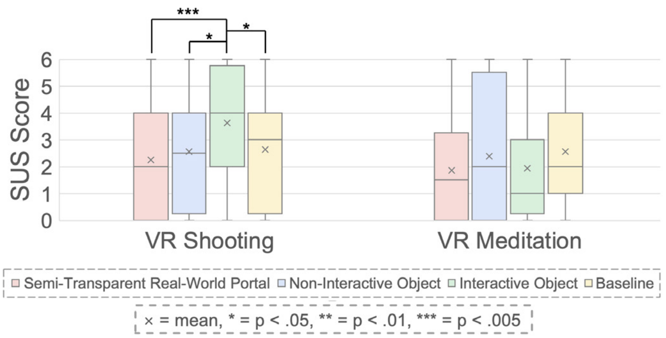

Fig. 7: Result of *Slater-Usoh-Steed (SUS) Presence Score* in VR shooting and VR meditation with four conditions.

Looking into the rating of each item in the SUS questionnaire, the pet-integration strategy placed a significant effect on the rated similarity between the interaction in the virtual and the real worlds ($\chi^2 = 8.771$, $p < 0.05$), and the rated familiarity of the virtual world based on the prior memory ($\chi^2 = 9.259$, $p < 0.05$), while there was no significant effect of the the pet-integration strategy on all the SUS questionnaire items for VR meditation. The pair-wise comparison by Wilcoxon Signed Ranks Tests showed that the strategy of integrating the pets as the interactive objects in the VR shooting game was rated significantly more similar to the real-world interaction than the conditions of pets being non-interactive objects ($Z = -2.546$, $p < 0.05$) and no integration ($Z = -2.145$, $p < 0.05$) were. In terms of the familiarity of the virtual world based on the prior memory, integrating pets as interactive VR objects in the shooting game received significantly higher ratings than the conditions of real-world portal ($Z = -2.058$, $p < 0.05$) and no integration ($Z = -2.081$, $p < 0.05$).

5.5.2 Realism Enhancement and Joy

The participants also rated how the pet-integration strategy enhanced the realism of the VR activities and their perceived joy, as shown in the first and second chart in Fig. 9 respectively. Friedman Tests showed that the pet-integration strategy significantly affected the ratings of realism enhancement for both shooting game ($\chi^2 = 8.459$, $p < 0.05$) and meditation ($\chi^2 = 8.750$, $p < 0.05$) in VR. For the VR meditation, the integration of pets as the interactive objects was rated significantly more effective in realism enhancement than the baseline condition without any pet integration (Wilcoxon Signed Ranks Test: $Z = -2.213$, $p < 0.05$). Additionally, pets being interactive VR objects in the shooting game yielded significantly higher ratings in terms of realism enhancement than the conditions of pets being non-interactive ($Z = -2.355$, $p < 0.05$) and no integration ($Z = -2.671$, $p < 0.01$).

For the rated joy, Friedman Test revealed the significant effect of the pet-integration strategy in the VR shooting game ($\chi^2 = 8.459$, $p < 0.05$). Wilcoxon Signed Ranks Tests indicated that pets being interactive VR objects in the shooting game was rated significantly more joyful than the baseline condition without any pet integration ($Z = -2.213$, $p < 0.05$).

Participants provided qualitative feedback that further bolstered the quantitative findings. In terms of realism, one participant noted, *"Having my pet in the game made it feel more real. It was as if I was actually playing with my pet in a different world."* Another participant echoed this sentiment, stating, *"The pet integration made the VR experience incredibly realistic for me. It felt as though I was genuinely interacting with my pet in the game."*

When it came to joy, participants also reported positive experiences. One participant shared, *"The shooting game was so much more enjoyable with my pet involved."* Another participant commented, *"I felt happier playing the game with my pet. It was as if we were having fun together in the game."* Conversely, two participants mentioned that in the Baseline condition, they kept looking for their pets around them, which may make the game less enjoyable.

5.5.3 Pet-Owner Connection/Bonding

As the participants in our pilot study stated the in-VR pet integration may enhance their connection/bonding with the pets, we also investigated how different integration strategies may affect the perception of pet-owner connection in VR. The result of pet-owner connection/bonding is shown in the third chat in Fig. 9. Friedman Tests revealed the significant effect of the pet-integration strategy for both shooting game ($\chi^2 = 14.064$, $p < 0.005$) and meditation ($\chi^2 = 19.324$, $p < 0.005$). Wilcoxon Signed Ranks Tests showed for the VR shooting game, all the three pet-integration strategies yielded significantly stronger pet-owner connection than the baseline condition (real-world portal: $Z = -2.717$, $p < 0.01$; pets as non-interactive objects: $Z = -2.068$, $p < 0.05$; pets as interactive objects: $Z = -2.669$, $p < 0.01$). Whereas for the VR mediation, the baseline condition was rated with significantly lower pet-owner connection than the real-world portal ($Z = -2.968$, $p < 0.01$) and the condition of pets as interactive objects ($Z = -2.969$, $p < 0.01$).

The participants' feedback also echoed with the statistical analysis. For instance, the participants who described their pets as *"very attached"* or *"clingy"* found the VR integration techniques particularly beneficial, indicating the methods' ability to cater to diverse user-pet dynamics. Additionally, the participants' qualitative feedback, such as *"felt more connected to my pet in VR than I expected"* or *"enjoyed the added layer of realism with my pet's presence"*, further affirms the positive impact of our techniques. These comments evidenced that our pet-integration techniques could not only enhance the VR experience but also foster a deeper, more meaningful emotional connection between participants and their pets.

5.5.4 User Preferences

At the end of the experiment, the participant was asked to rate his/her preferences on the tested pet-integration conditions for the shooting game and the mediation separately, in a 7-point Likert scale (1: lowest preference, 7: highest preference). Friedman Test showed that the pet-integration condition significantly affected the participants' preference ratings ($\chi^2 = 14.474$, $p < 0.005$). The Wilcoxon Signed Ranks Tests revealed that the pet integration as the interactive object was significantly more preferred than the other three conditions (real-world portal: $Z = -2.706$, $p < 0.01$; pets as non-interaction objects: $Z = -2.777$, $p < 0.005$; baseline without any pet integration: $Z = -3.185$, $p < 0.001$). In the post-experiment interview, one participant mentioned, "It is more relaxing to interact with the pet as a virtual character in the shooting game." While there was no significant difference among the four conditions in terms of the participants' preference for VR meditation, the pet integration as the interaction objects yielded the highest preference ratings. The rightmost chart in Fig. 9 depicts the descriptive results of the participants' preference ratings.

In summary, our user study showed that integrating pets as interactive objects in VR could significantly improve the sense of presence, the realism, the joy, and the pet-owner connection, especially for the VR activity with intensive body actions, such as the shooting game. On the other hand, we noticed that in VR meditation, the basedline condition received the highest rating on the sense of "being there" in VR, with the significant difference with the condition of real-world portal (Wilcoxon Signed Ranks Test: $Z = -2.381$, $p < 0.05$), and the pet integration as non-interactive objects received the second highest rating for this item. This may indicate that for the VR activities that require high-level concentration but less body actions, the user may prefer not seeing or interacting with the pet. This also echoed with our findings in the pilot study that the pets tended to stay still when their owners had less or no body movement. More importantly, the difference of the participants' ratings for the shooting game and the meditation suggested the need of application-specific design for pet integration in VR.

6 Discussion

6.1 Implications on Pet-Owner Interaction

The integration of real-world pet activities into virtual environments presents a multifaceted dimension to the realms of HCI, particularly

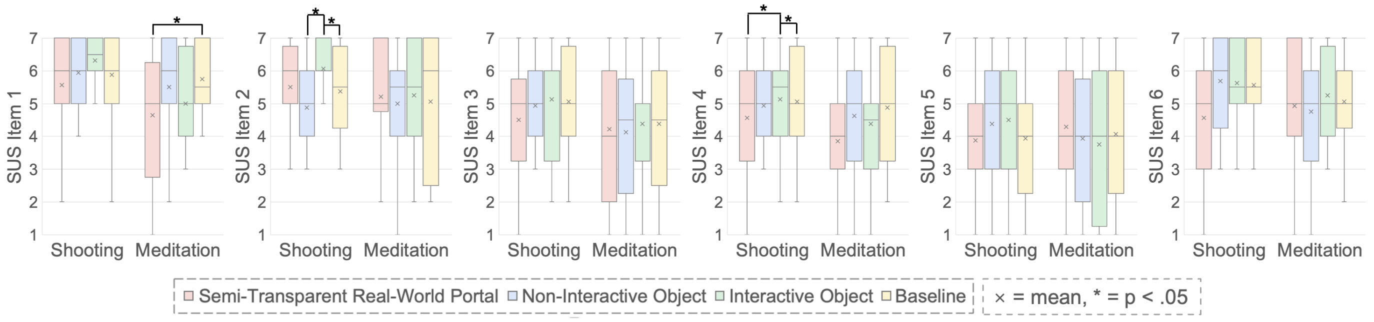

Fig. 8: Result of Slater-Usoh-Steed (SUS) Questionnaire Items.

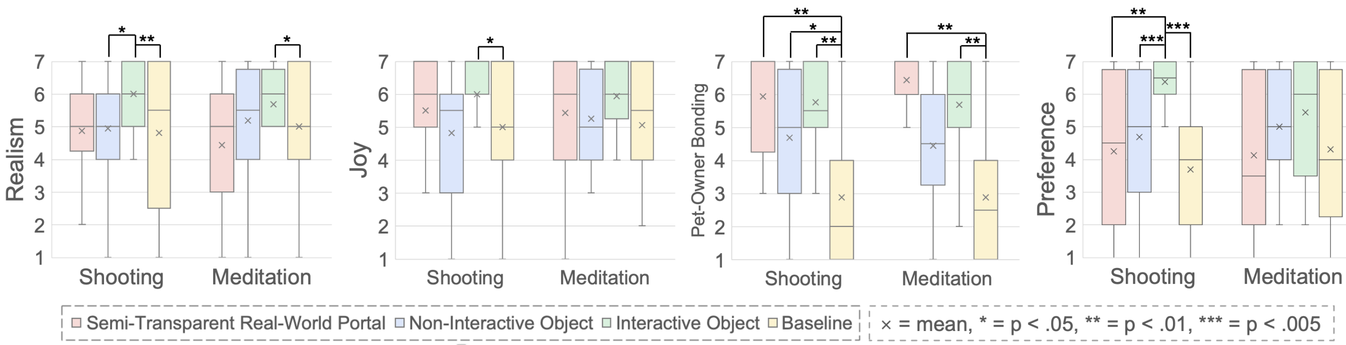

Fig. 9: From left to right: Result of ***Realism***, ***Joy***, ***Pet-Owner Bonding*** and ***Preference*** in VR shooting and meditation with four conditions.

in terms of enhancing human-animal bonds. Oxley et al. [37] have demonstrated that virtual environments hold potential to enrich human-animal interactions. It offers valuable insights into mutual engagement that can be applied to real-world pet activities in VR. The intent behind integrating pets into VR extends beyond the mere mitigation of disruptions. As Dao et al. [6] suggests, one should not view pets' activities as *Bad Breakdowns* within VR experiences. Instead, we leverage the advantages of VR technology, viewing these interactions as opportunities to design more engaging and enhanced VR experiences. Echoing this, Fang et al. [7] highlighted how environmental elements can lead to more interactive VR experiences.

While a primary objective remains the prevention of physical collisions or inadvertent harm to pets, our approach has inadvertently enriched the pet-owner interaction within the VR space. For instance, we noted that when pets were visible in the VR environment, owners often expressed feeling more at ease and reassured while engaged in gaming activities. This is in line with findings by Golbeck et al. [11] and Shih et al. [41], who noted the positive emotional impact of pet visibility on users in remote or digital environments. Owners reported feeling comforted by knowing their pets were beside them, which indicates potential mutual awareness between pets and their owners. Such multual awareness could further strengthening their bond [22]. This unintentional outcome underscores the importance and depth of the human-pet bond, which thrives on mutual awareness and engagement. By allowing users to remain cognizant of their pets in a virtual setting, we subtly reinforce this bond, suggesting that technology can indeed complement and amplify traditional pet-human interactions.

6.2 Balancing Act: Emotion vs. Efficiency

The challenge of integrating pets into VR brings to the fore a nuanced balancing act between emotional comfort and gameplay efficiency. On one hand, the very essence of VR is to immerse users in an uninterrupted virtual environment [44], allowing for seamless interaction and navigation. From this perspective, any non-gameplay element, such as the semi-transparent portal showing pets, could be deemed a distraction, potentially compromising the efficiency in VR.

However, the varied feedback from our participants suggests a more complex dynamic at play. Our techniques, especially the semi-transparent portal method, brought about polarizing feedback. For many, the emotional assurance derived from knowing their pet's precise location, as facilitated by the semi-transparent portal, outweighed any disruptions to gameplay. Comments like *"I felt more at ease knowing exactly where my dog was"* reveal an emotional anchor that some users found indispensable. In contrast, sentiments such as *"The portal kept drawing my attention away from the game"* underscore the delicate balance that designers must strike.

The key takeaway here is that the notion of "efficiency" in VR is subjective. While some prioritize uninterrupted gameplay, others value a holistic experience where they can be immersed without any real-world anxieties. This aligns with the research conducted by Kudo et al. [24] and Wu et al. [55], who investigated the comparison of different methods for providing informal awareness cues to headset users about bystanders. They argue that it is essential to focus on the effectiveness of these notifications while mitigating their negative impact on immersion. The challenge lies in devising VR integration techniques that cater to this spectrum of user preferences, ensuring both gameplay efficiency and emotional connection.

6.3 Potential Driving Factors for Pet-Owner Interaction in VR

The user and the pet behaviors in VR could be driven by multiple factors, including emotions, habitual behaviors, and the human desire for connectedness.

Emotional Security and Awareness: Previous studies such as [26, 27, 34] underscored the emotional connection between virtual pets and users. In our study, a prominent sentiment that emerged was the emotional comfort derived from knowing the activities of their pet in the real world while being in VR. The semi-transparent portal method, even with its potential to distract, seemed to cater to this need, emphasizing the depth of the human-pet bond and the innate desire for mutual awareness.

Curiosity and Engagement: The virtual reality environment is not a solo experience for the users, especially when they are accompanied by their pets. From the pet's perspective, the owner's actions, movements, and reactions while engaged in VR are a deviation from their usual behavior, sparking curiosity. For instance, a user trying to dodge an oncoming virtual obstacle or reaching out to grab a virtual object may seem like an invitation to play or to pay attention to the pet. These acts of virtual engagement, though routine in the VR realm, can be perceived as direct interactions or calls for engagement by the pets. In multiple instances during our experiments, dogs exhibited playful responses or expressions of concern when their owners were actively involved in VR tasks. A participant's sudden movement in a shooting game might be interpreted by a dog as a playful gesture, leading the pet to engage, thinking it's playtime. On the user's side, the result from our research found that the unexpected yet delightful interruptions by their pets in the virtual space often led to moments of enhanced emotional connection. This was particularly evident in the meditation game. When pets made their presence felt during these sessions, participants would occasionally drift away from their meditative state to interact with their pets. For some, the calming ambiance of the meditation game combined with their pet's presence created a unique blend of virtual and real-world serenity. For others, what began as a virtual meditation session evolved into an impromptu play or bonding session with their pet, blurring the lines between the virtual and real worlds. Such unplanned interactions underscore the intricate nature of human-pet dynamics. Even within a highly immersive digital environment, spontaneous and genuine reactions of pets can deeply influence user experience and sentiment.

Habitual Behavior Influences: Pets, based on their temperaments and past experiences with their owners using VR, reacted differently. In the pilot study and subsequent user studies, varied reactions were observed. Some pets responded by barking or howling, indicating possible discomfort or confusion, while others distanced themselves or even pounced on their owners, perhaps as a playful or inquisitive reaction to the unfamiliar gear. However, for pets accustomed to their owners frequently engaging with VR or working from home, these distractions subsided.

6.4 Limitation & Future Work

While our research contributed to the integration of distractions from pets within the VR space, several limitations need to be acknowledged and addressed in the future work:

Scope of Pet Types: Our study primarily focused on dogs, given their active nature and potential to interfere with VR users. While cats were considered in the pilot study, other pets like birds, reptiles, or smaller mammals were not explored. Different pets have varied temperaments and behaviors that might influence VR experiences differently. To this end, we plan to thoroughly study the behaviors of different pets and their integration in VR, to construct a comprehensive framework for human-pet VR interaction.

Variability in Pet Behavior: Pets, especially dogs, have a wide range of temperaments, sizes, and behaviors. While our study incorporated a diverse set of pet-owner pairs, it's possible that certain unique or rare behaviors were not captured. The habitual behavior of pets, influenced by past experiences with their owners using VR, also could introduce variances in our results. Pets' reactions to their owners using VR can change over time based on their past experiences. For instance, a pet who has frequently observed its owner using VR might become more accustomed to the situation and exhibit a different behavior compared to a pet encountering VR for the first time. Some pets, after multiple exposures, might learn to stay quiet and passive, while others might continue to react with curiosity or concern.

Tracking Pets' Experience: While we utilized trackers in our study to monitor the activity of pets, these trackers might not be suitable for all types or sizes of pets. For instance, smaller pets or those with unique shapes or features might find it challenging to wear, or their movement might be hindered by the tracker. Additionally, we did not measure the physiological indicators of pets, which could offer valuable insights into understanding a pet's reactions during VR experiences. In future research, we plan to develop and test more pet-friendly and comfortable trackers and, combined with physiological metrics, provide a more holistic view of pet-owner interactions in VR.

Application Selection: Our study utilized two VR applications: a shooting game and a meditation activity. While these were chosen to represent the VR scenarios involving different levels of body actions, they might not encompass the full spectrum of VR experiences. The reactions of pets and their owners could differ in other types of games or applications. As the next follow-up study, we aim to investigate the pet integration in other types of VR activities, such as working, remote collaboration, and so on.

Mediated Interactions: Beyond the existing human-human or human-machine interaction paradigms in VR, our study hope to gain a broader understanding of mediated interactions, especially with the inclusion of pets. This raises intriguing questions about the depth, authenticity, and nuances of such interactions involving non-human living entities in digital spaces. Future research could explore how digital mediation might shape or be shaped by our pre-existing bonds with pets. There's potential to delve into how VR can facilitate new forms of communication and interaction between humans and pets, enriching the human-pet relationship.

Broader Societal Implications: Our study also touches on the societal and ethical implications of blurring lines between physical and virtual realms. The way we represent, acknowledge, and interact with living entities in virtual settings can influence our perceptions and behaviors in the physical world. This invites a broader discussion on the evolving nature of reality, mediated experiences, and the dynamic interplay between technology, humans, and animals. Future investigations could examine the societal impacts of VR integrations, such as changing perceptions of animal rights or ethical considerations in digitally mediated environments.

7 Conclusion

Throughout this research, we embarked on an exploration into this nuanced relationship between VR users and their pets, emphasizing the challenges and opportunities of integrating such dynamic distractions into VR environments. Our overarching goal was to harness the presence of immediate surroundings, especially pets, to enhance the immersive experience in VR. We proposed three distinct integration techniques: the semi-transparent real-world portal, non-interactive object representation in VR, and interactive object representation in VR. Our user study showed that compared to the baseline condition without any pet-integration technique, the approach of integrating the pet as interactive objects in VR yielded significantly higher participant ratings in perceived realism, joy, and connection with their pets. As we move forward, we are keen on expanding our techniques to accommodate a diverse range of VR scenarios and exploring ways to integrate other non-human living objects, ensuring that the boundaries between the real and virtual continue to blur constructively.

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