Self-Illusion: A Study on Cognition of Role-Playing in Immersive Virtual Environments

Sheng Li, *Member, IEEE,* Xiang Gu, Kangrui Yi, Yanlin Yang, Guoping Wang, Dinesh Manocha, *Fellow, IEEE*

Abstract—We present the design and results of an experiment investigating the occurrence of *self-illusion* and its contribution to realistic behavior consistent with a virtual role in virtual environments. Self-illusion is a generalized illusion about one's self in cognition, eliciting a sense of being associated with a role in a virtual world, despite sure knowledge that this role is not the actual self in the real world. We validate and measure self-illusion through an experiment where each participant occupies a *non-human perspective* and plays a *non-human role* using this role's behavior patterns. 77 participants were enrolled for the user study according to the priori power analysis. In the mixed-design experiment with different levels of manipulations, we asked the participants to play a cat (a non-human role) within an immersive VE and captured their different kinds of responses, finding that the participants with higher self-illusion can connect themselves to the virtual role more easily. Based on statistical analysis of questionnaires and behavior data, there is some evidence that self-illusion can be considered a novel psychological component of presence because it is dissociated from Sense of Embodiment (SoE), plausibility illusion (Psi), and place illusion (PI). Moreover, self-illusion has the potential to be an effective evaluation metric for user experience in a virtual reality system for certain applications.

Index Terms—Presence, Self-Illusion, Plausibility Illusion, Place Illusion, Sense of Embodiment, Virtual Body Ownership, Non-Human Role, Dissociation, Virtual Reality.

1 Introduction

PRESENCE in virtual environments (VEs) is a fundamental issue in the field of virtual reality (VR) [1], [2]. By interacting with the VE, the user can experience various aspects of the virtual reality setting. Basically, users perceive the virtual world and respond to stimuli and events that occur within that world. This response can be corporeal, physiological, or cognitive, even if corresponding events do not happen in the physical world [3]. Within the literature of presence [4], a key problem is measuring and manipulating the realism or coherence of immersive VEs [5]. In this regard, two orthogonal components have been found to contribute to realistic behavior in VEs: *place illusion* (PI) and *plausibility illusion* (Psi) [6]. PI is an illusion related to how the user perceives place. This illusion is constrained by the sensorimotor contingencies (SCs) supported in a system [7]. The level of PI is governed by the degree of immersion [8], [9]. Psi is "the illusion that what is apparently happening is really happening (even though you know for sure that it is not)." It describes a correlation between individual perceptions and virtual events [6].

Both PI and Psi can cause users' physiological and psychological arousal [10], [11]. Generally, a realistic VE will evoke a physiological response similar to the one that would occur in the corresponding physical world. The environments where the user has a virtual self-representation (generally using a 3D anthropomorphic avatar) [12] can elicit more generalizable responses to the stimuli because the virtual world is considered a replica of a game or of real life. Therefore, users may expect an experience equivalent to one in the real world and want a seamless integration of VR experiences and the physical world. Beyond that, however, is the question of whether a totally new experience can still be achieved with realistic responses when role-playing. In other words, a user behaves in a virtual role that is different from the user's self in the physical world. The question becomes: What is the cognition about one's self when one is involved in role-playing in VEs? Is there any illusion about the self that is different from the component proposed by presence? In other words, do humans perceive themselves as themselves or as their role in VEs?

Self-concept: In this paper, we mainly address the illusion of self-concept in the context of presence. Self-concept [13] is "the individual's belief about himself/herself, including the person's attributes and who and what the self is." The illusion of self-concept is not inherent to real lives because few psychologically normal people would experience self-confusion in the physical world, but this may not be the case in VEs. This illusion may occur in virtual reality because of its potential to "engender a high sense of physical presence" [14]. Specifically, we propose that there may be an illusion of self-concept, which we call *self-illusion*, in VEs. As a high-level cognitive component of immersive VEs, self-illusion may emerge when a user plays a virtual role, especially when this role in the VE has different physical and social characteristics (e.g., identity, behavior pattern, abilities, values, goals, functions, etc.) from the user himself/herself. Once the self-illusion is revealed and can be captured, we can modulate the VR system to have positive effects on human beings. Therefore, it is worth developing

- *Sheng Li is the corresponding author.*
- *Sheng Li, Xiang Gu, Kangrui Yi, Yanlin Yang, Guoping Wang are at Peking University, China.*
  E-mail: {lisheng | xgu | yikangrui | yangyl | wgp}@pku.edu.cn.
- *Dinesh Manocha is at University of Maryland, College Park, USA.*
  E-mail: dm@cs.umd.edu.

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Fig. 1: Snapshots: A participant involved in experimental scenarios. He interacts with the immersive virtual environments (VEs) from a non-human perspective (a cat, in our research) and acts with a cat's behavior patterns using data gloves. Based on the experiment, we find a measurable existence of self-illusion.

methods for validating and measuring this illusion.

Although sense of embodiment (SoE) [15] and self-presence [1] both address the connection between virtual self-representation and one's actual self, they are fundamentally different from self-illusion. Sense of embodiment is a body-level illusion and describes the sensation of owning, controlling, and being inside the virtual body [15]. Although self-presence, one sub-category of presence [2], [12], describes ways of connecting between the virtual self-representation and the actual self, it basically emphasizes a virtual self-representation's ability to express the identity of the self with some characteristics that are inherent in the real world [12]. In contrast, an illusion of self-concept is not inherently based in the physical world and may have distinct differences from the actual self, as mentioned above. Such an illusion of self-concept may occur when users role-play in an immersive VE. On the one hand, users may still perceive themselves as they are in the physical world (i.e. having a strong sense of one's actual self); on the other hand, users may immerse themselves in the virtual environments, thinking that the role they play in that world is the actual self. The key question revolves around how users identify themselves with the virtual role when playing that role in immersive VEs.

Main Results: As discussed above, we hypothesize that there is an illusion of self-concept in a VE, which we call *self-illusion* (*SI*). The definition of self-illusion is *the generalized illusion of being in a role despite sure, cognitive knowledge that one is not that role*. If this illusion does exist as a psychological state, it can be used to describe one's cognition of the self in a VE. The measurement of self-illusion can indicate whether a player perceives himself/herself as and behaves as a virtual role in the immersive VE or as the actual self and, in either case, to what extent.

We present an experimental approach to validate the occurrence of self-illusion and provide subsequent evaluation. Our approach is devised based on a non-human perspective (a cat role) using the first-person view in the experiment, i.e., all the experimental aspects are performed from the cat's view. This cat role is used to make the occurrence of self-illusion evident, and it can be captured easily according to the experiment design. Users play cats and interact with the VEs as cats to obtain a different cognition about the self, as shown in Fig. 2.

Overall, our contributions include:

- We present that self-illusion, an illusion of self-concept that may occur while an individual plays a role in the VEs, can be considered a component of presence. Generally, the higher the self-illusion, the more the users can devote themselves to the virtual role and obtain more realistic behavior consistent with that role.
- By introducing a novel non-human role and view, we devise a mixed-design experiment with different levels of manipulation to explore the mechanism involved in human self-illusion. Specifically, the individual can experience immersive VEs from a cat's view and behave in the cat's pattern within the VEs.
- Through user studies, we validate the existence of self-illusion with measurement, which also shows its differences from existing components in presence. The behavior data shows that self-illusion influences the experience in a VE.

To the best of our knowledge, this is the first systematic evaluation of self-illusion in the field of virtual reality. Given its dissociation from PI, Psi, and SoE, self-illusion can be considered a new psychological element, and it has the potential to be used as a novel metric to measure the realism of response in the VEs for certain applications.

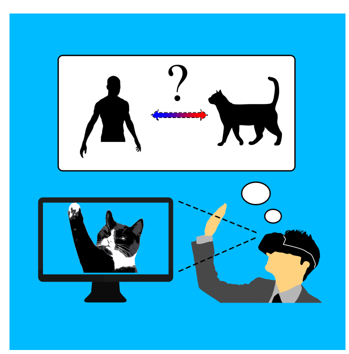


Fig. 2: The user plays the role of a cat from the perspective of a cat and acts with a cat's behavior while interacting with VEs. We use this experiment to determine whether a user perceives and responds to the VE as himself or as the role that he plays.

2 Related Work

In this section, we give an overview of the most important concepts related to presence and survey prior works on the components of experience in VR along with the methods for measurement and relevant technology.

2.1 Self-Illusion, Self-Presence, and Sense of Embodiment

Since self-illusion (SI) is a newly-introduced concept, we first clarify its essential difference from other semantically similar terminologies.

Self-illusion is an illusion at the cognitive level about self-concept [13] that may occur when users role-play in VR. Specifically, self-illusion indicates the extent to which a role in virtual self-representation becomes part of a player's self-concept. If higher levels of self-illusion occur, users may experience another self with characteristics, abilities, values, goals, etc. that are totally different from their own. Note that this should not be confused with the term "self illusion" presented in [16], which only refers to the illusion of identity created through social interaction in psychology. Self-illusion, however, focuses on presence when role-playing in VR applications.

Sense of embodiment (SoE) [15], associated with realistic responses, emerges when users process the physical properties of the avatar as the properties of their own biological bodies. SoE includes three components: sense of self-location, sense of agency (SoA) [17], and sense of virtual body ownership (VBO) [15], [18]. Among these components, VBO seems to be connected with self-illusion. However, VBO indicates low-level human sensation and perception of the virtual body in a VE [15], while self-illusion indicates cognition of the self between the virtual role and one's actual self. The difference between SoE and SI is obvious through a comparison of items used to measure VBO such as "I felt as if the body I saw in the virtual mirror might be my body" [19], items used to measure self-concept such as "I cry easily" in the questionnaire titled "*The Way I Feel About Myself*" [20], and items such as "making friends easily with boys" in the questionnaire titled "*Self-Concept Inventory*" [21].

Self-presence [1] is another term related to the link between the true self and virtual self-representation. According to [12], self-presence describes "how people connect to their virtual self-representations on three distinct levels of self (body, emotion, identity)." As a low-level indicator of perception, *body-level* self-presence emphasizes the controllability of an avatar in the virtual world, i.e. it indicates whether this self-representation can be controlled as easily as their own body. With high *emotion-level* self-presence, avatars can yield emotional responses from users.

Identity-level self-presence [22] is defined as "the extent to which some aspect of a self-representation is related to some aspect of personal identity" [12], which seems to be closely related to self-illusion at the psychological level, but they are essentially different. The cause of identity-level self-presence is the complexity and fluidity of self-concept, which means that people can choose from numerous "possible selves" [23], [24]. Fortunately, mediated environments like VR enable players to "choose from numerous possible selves" [12], which is not easily attainable in their daily lives.

Self-presence vs. Self-illusion: Self-presence basically emphasizes the extent to which an avatar can express the identity of the self with some characteristics that are *inherent* to one's actual self in the real world. In contrast, self-illusion refers to how much a virtual role is integrated into the identity of the self and becomes a part of one's self in the real world. From the self-illusion in immersive VEs, people may acquire some characteristics that they themselves *do not* have in the real world and may even gain cognition different from those experienced by their identities in the real world. Self-illusion also emphasizes the effect of one's self-cognition alteration, meaning that one would act like the role without extra instruction.

Overall, self-presence represents "the extent to which some aspect of a person's self is relevant during media use" [12], i.e., self-presence arises when some certain characteristic of self-representation is consistent with the user's own self. Therefore, when facing a role *irrelevant* to one's self (i.e. totally different attributes from one's self), the presence experienced by the user cannot be explained by self-presence. On the contrary, we emphasize that these different attributes from a role can apply to the user and take effect, thus resulting in a new experience. This type of presence can be explained by self-illusion.

2.2 PI and Psi

Two main components in presence are PI and Psi, as proposed by Mel Slater [6]. There are many ways to enhance PI, including providing a wider field of view [25]. This is based on the assumption that perception represents existence (what is perceived is actually there) [7]. The term PI is generally used to indicate the illusion of being there. As the key to control the PI, immersion can be objectively measured and altered by changing the "inclusive, extensive, surrounding, and vivid illusion of VE to a participant" [26]. Physiological changes of a user in interactive design can indicate the extent of immersion via the Libet clock experiment [27]. The degree of immersion will increase as the range of objects with which participants are allowed to interact expands in the VE [28]. Immersion can be readily controlled with feedback from the VR experience in terms of realism by the user.

Plausibility illusion (Psi) refers to the illusion that the scenario being depicted actually occurs [6]. Psi provides correlations between external events and the users' own sensations. A realistic virtual environment can evoke physiological responses similar to those evoked by the corresponding real world, and the sense of presence increases with the degree of similarity. Both PI and Psi are subjective internal sensations, and they may vary due to individual differences. Furthermore, the coherence of PI and Psi provides us with a way to objectively control and test the sense of presence in the virtual systems [29].

Measuring PI and Psi is important in evaluating the experience of a VR system. Psi is determined by the extent to which the system can produce events that directly relate to the user and the overall credibility of the scenario being depicted compared to expectations [6]. Skarbez et al. [30]

studied the important factors of Psi and explored "consistency" in the VEs. Consistency is a factor that measures the realism of events created by the VEs. Rovira et al. [31] proposed three essential elements for designing realistic Psi events. A VE depicting a string quartet performance was used to address the factors that influence Psi through the Markov transition matrix [32]. Similar methods can also be used to identify an equivalent class of "PI extent" or "Psi extent" to reflect the users' sensations [25]. As a special case, Psi can also be achieved in the absence of PI. An interesting and well-known problem is the "book problem" [33], which deals with the immersion that can be achieved through a narrative.

2.3 Measurement and Technology

The experience in a VR is complex and multidimensional, generally requiring specific evaluation methods to measure or validate the existence of these presence-related elements. To measure the SoE on the level of its sub-components, indirect measures can be outlined from a higher-level perspective concerning SoE's potential psychological, emotional, and behavioral consequences, i.e. SoA [15]. Jeunet et al. presented two components and provided methods for manipulating and measuring SoA [34]. A body transfer illusion refers to the conversion of body ownership to an avatar that is played in a first-person view [35]. A Proteus effect was defined to explore the impact of visual self-representation (avatar) on behavior in VEs [36]. An EEG-based experiment was conducted to evaluate how the rendering style of the users' hands affects behavioral and cognitive responses [37].

As a key element of SoE, virtual body ownership (VBO) characterizes the cognition of body ownership in a VR experience and is based on the "Rubber Hand Illusion (RHI)" experiment [38], which revealed the RHI illusion [39], [40]. An experiment was conducted to study the stages of transition between the real world and the virtual one when this illusion is produced [41]. Many other works in VR address this component from different perspectives [42], [43]. A universal questionnaire measuring the illusion of VBO [19] and a neuroscientific model explaining the underlying perceptual and cognitive mechanisms that enable illusions in VR have recently been proposed [44]. Other studies associated with avatars include the personalized avatar and its impact on VBO and presence [45], the possible impact of an avatar's body part visibility on a player's experience and performance [46], and a virtual body-swap illusion [47]. In addition to embodying and controlling a normal human representation with multi-sensory integration, embodiment of an artificial entity (limb or body) is also modulated by various physical and spatial features of the entity [48]. Recent research on this issue considered users' novel ability to "take on" non-human representation as their own. These interesting body-related experiences for owning and controlling an extended humanoid avatar with an artificial entity include experiences of a set of virtual wings [49], a third arm [50], [51], [52], and a sixth finger [53].

Presence from the VEs may influence the user's psychology significantly. Advanced therapy based on VR technology has shown its effectiveness for people with physical and psychological disabilities, e.g., anxiety, fear, or stress [54]. There are many other psychological effects of immersive VR technologies. These are collectively referred to as virtual reality-induced side effects [55] and often focus on a general feeling of malaise or motion sickness experienced by users [56]. A virtual animal laboratory has been proposed in comparative psychology to explore these feelings [57]. However, the measurement and analysis of the nature of presence in VR at the psychological level is not fully understood [15]. A new understanding of one's self in immersive VEs may help improve the application of psychological therapy.

3 Experiment Design

In this paper, we explore the correlations between the self as experienced in a role and the actual self. We devised an experiment in which a user played a novel role with many interactions to validate the existence of self-illusion in immersive VEs. Our experiment design and procedure conform to the policy of the ethics committee at our university.

3.1 Role Selection

As analyzed in Sect. 1, the obvious difference between a role's self-concept and a user's original self-concept in the physical world tends to promote the illusion of self-concept, where a role generally relates to some typical behavior patterns, abilities, characteristics, beliefs, etc. [58]. Additionally, an avatar can embody this role in the VE and may provide a user with a visual self-representation [59], but it is not compulsory in the experiment of this study. Because our study is partly based on behavioral monitoring when the user interacts with the VE, the role's behavior pattern should be clearly and visibly distinct from the person's normal behavior pattern. To make self-illusion manifest, we devised an interesting non-human role (a *cat*) for the users to play instead of a human role or any traditional role from commercial games. The rationale for choosing a cat as the role is given below, according to the principles of psychological experimentation.

First, there should be a universal prototype with well-known attributes, especially behavior patterns corresponding to this role. In other words, the role should not be created or imagined by experimenters, e.g., a monster, a ghost, an alien, etc. Otherwise, it would be likely that the users would find it difficult to familiarize themselves with the role and then voluntarily act as the role in a short time frame. More importantly, these strange roles do not have generally agreed-upon behavior patterns.

Second, while many common roles in commercial games (killers, heroes/heroines, etc.) or those based on professional characters (doctors, lawyers, teachers, etc.) have specific behavior patterns, these roles' behavior patterns are very close to normal human behavior patterns, i.e. not visually distinguishable. Therefore, we discarded human-related roles or other traditional roles from commercial games (API of these commercial games is also not readily available). We then turned to a novel non-human role, i.e. an animal role [60], to lend a different perspective for our study.

Third, users should have relatively similar levels of familiarity with the nature of this animal role to avoid significant deviation between individuals [61]. Furthermore, the typical pattern of the animal role's behavior should be technically imitable when using the immersive VR apparatus to play, and the behavior must be consistent with the user's prior knowledge [31]. This prevented us from choosing animals like snakes or frogs, which might require movements that conflict with the human body's motion. Specifically, a user's action in the VE should imitate the bodily form using prior knowledge about this kind of species (driven by our sense of proprioception and balance).

Finally, domesticated animals (such as cats or dogs) present as the best candidates. They both have universally-known behavior patterns, neutral impacts on human beings, similar levels of familiarity for participants (better than bonobos, gorillas, monkeys, etc.), and easily imitable non-human behavior patterns. Previous research has shown that humans can get used to non-human virtual bodies quickly [62]. In a university-based survey, we found that almost everyone is familiar with the behavior patterns of cats and has had harmonious contact with cats in campus life. In addition, cats had not been aggressive toward students, while dogs had exhibited occasional aggression. Some students even reported strong fear of dogs in an early inquiry.

Based on the aforementioned analyses, we finally chose a cat as the role in this study. All the participants had similar levels of knowledge about and familiarity with cats, but they had not had the opportunity to play a cat before. The final experimental results also confirmed the rationality of this role design because the behavior patterns between humans and cats were significantly different, meaning that the users' behavior could be clearly observed and recorded as evidence to support our argument.

3.2 Apparatus and System

Apparatuses used in the experiment are listed below.

- HTC Vive (immersive VR headset with wireless suite).

- Noitom Hi5 VR Glove (motion capture, all fingers exposed, without any digital force/haptics feedback).

Each user tried on the HMD and data gloves during the experiment. The data gloves were used for hand motion tracking and gesture tracking, and they left the user's fingers exposed. The user could therefore touch the physical world to receive direct haptic feedback.

We developed a cat simulation system (detailed in Sect. 3.5) for our experiments, which was implemented based on the Unity3D platform. Specifically, we developed a method for converting human motion to the corresponding cat motion for user interaction. After completely matching the user's eyes with a cat's avatar, the poses of the cat's limbs were estimated using the inverse kinematic method from the motion of the head (using an HMD) and claws (using data gloves), where we made the cat's fore-limbs fit the user's hands; then its hind limbs were located on the ground as far away as possible. Fig. 1 shows the experimental scenarios where the user plays our system using VR Gloves to act as a cat.

3.3 Design

We hypothesized that self-illusion would enable players to experience another self and behave as that role.

3.3.1 DVs and IVs

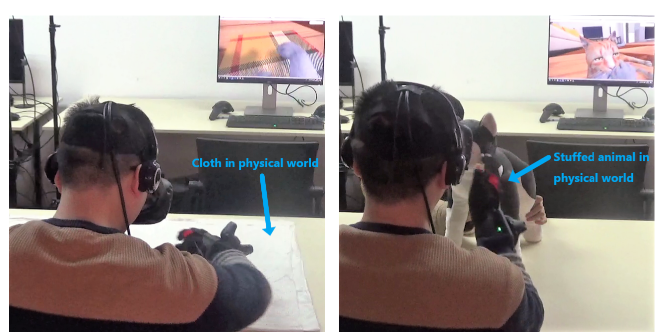
Psi has been widely proven to influence behavior in VEs. We hypothesize that self-illusion may also affect the user's behavior in the virtual world, and the behavior can be used as the measure of presence. To validate the existence of self-illusion and investigate the differences between Psi and SI, we therefore devised two dependent variables (DVs): participants' actual degrees of plausibility illusion and their degrees of hypothesized self-illusion. A 7-point Likert questionnaire (Table 2) was designed to measure the participants' *Psi, PI, SoE, and self-illusion*. Each participant's behavior during the experiment was also recorded for analysis. We then designed two independent variables (IVs): manipulation of plausibility and manipulation of self-illusion. Different levels of manipulations in our experiment are shown below.

Manipulation of Psi (MoP) was expected to bring different levels of plausibility illusion by varying the quality of the scenario and providing different levels of fidelity of physical perception and feedback, as analyzed in [30].

- Level 0 (MoP-0): The scenes in the VE were rendered with lower realism (Fig. 5(a) left); no perceptually consistent interaction and no high-fidelity feedback when the user interacts with the virtual world by scratching fingers in Stage 3 (Sect. 3.5).
- Level 1 (MoP-1): In contrast, the scenes were rendered with higher realism (Fig. 5(a) right); perceptually consistent interaction with the virtual world to get high-fidelity feedback when scratching fingers in Stage 3 (Sect. 3.5) in the VE, as shown in Fig. 3(a).

Manipulation of self-illusion (MoS) was expected to bring different levels of hypothesized self-illusion by enacting different levels of self-conversion to the role on identity recognition and by providing event consistency/inconsistency with the assigned tasks.

- Level 0 (MoS-0): No avatar; the assigned tasks were inconsistent with the events shown in the tutorial stage.
- Level 1 (MoS-1): Personalized avatar with many options available where the whole body could be observed in the VE; the assigned tasks were consistent with the events shown in the tutorial.



(a) Interaction with real cloth (b) Interaction with a cat-form toy

Fig. 3: Using physical proxy objects when role-playing in the experiment. (a) only for MoP-1 during Stage 3, (b) for all participants during Stage 5.

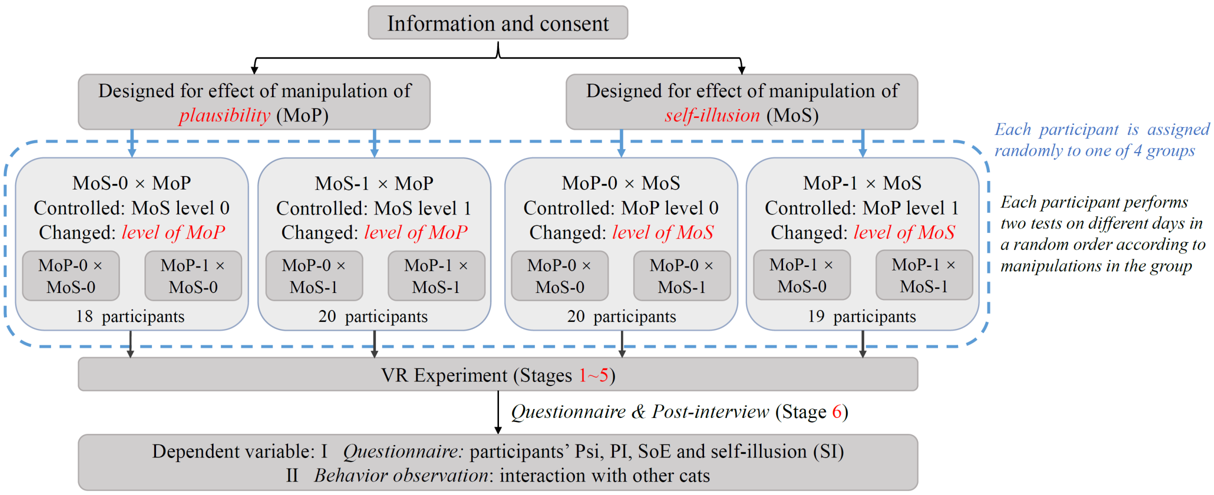


Fig. 4: Participants being assigned to one of four groups in our mixed-design experiment.

3.3.2 *Mixed Design*

Considering that individual differences would bias the results based on the questionnaire survey, within-group design could be used to mitigate these effects. However, this would cause a total of 4 different tests associated with corresponding manipulations including MoP-0×MoS-0, MoP-0×MoS-1, MoP-1×MoS-0, and MoP-1×MoS-1, where "×" denotes the combination of two manipulations. If a participant experiences the experiment multiple times, the *practice effect* might occur. In other words, experience of repeated and similar content might cause excessive familiarity and even boredom, leading to reaction bias.

To avoid this effect, a **mixed-design** experiment was introduced with only 2 tests for each participant. For this mixed design, we created 4 groups: MoS-0×MoP, MoS-1×MoP, MoP-0×MoS, and MoP-1×MoS. The former two groups were designed to examine the effect of MoP because each group experienced within-group changes of MoP, and the latter two were designed to examine the effect of MoS. Accordingly, *two* separate *repeated measures analyses of variance* (repeated measures ANOVAs) were conducted to the former two and the latter two groups. No data is reused.

As shown in Fig. 4, each group is a combination of a fixed level of manipulation with a changing level of another manipulation, so two combinations of manipulations are contained in each group based on the one that changes. For example, group MoS-0(fixed)×MoP(changing) includes two combinations of manipulations: MoS-0×MoP-0 and MoS-0×MoP-1, others ditto. As a result, each participant being assigned into one of 4 groups randomly completes two tests (corresponding to two combinations of manipulations within a group) in a random order. Based on this design, participants in the group MoS-0×MoP share the within-group factor: MoP. When compared with the participants in MoS-1×MoP, they share the between-group factor: MoS.

3.4 Participants

To make the experiment reliable, we conducted a *priori power analysis* to estimate the sample size for each ANOVA. We assumed an α-error of 0.05 and a β-error of 0.05. To effectively detect the effect of MoS and MoP (effect size = 0.30), we needed 40 subjects per ANOVA, i.e. around 80 subjects for the whole experiment.

Finally, we recruited 77 participants (36 male, 41 female, ages $18-28$, including 46 undergraduates and 31 graduate students) according to the above power analysis. Each participant was randomly assigned into one of 4 groups: MoS-0×MoP (18 participants), MoS-1×MoP (20 participants), MoP-0×MoS (20 participants), and MoP-1×MoS (19 participants), as shown in Fig. 4. Each participant reported normal or corrected-to-normal vision and the headset lens was calibrated for each user before he/she took part in our experiments. None of the participants had prior knowledge of our experiment. We also collected demographic data from these participants, including gender and age. In addition, video game experience and familiarity with cats were also collected using a 7-point Likert scale. People afraid of cats or having special emotion towards them were not recruited to avoid reaction bias caused by their emotional arousal. Before starting the experiment, *each participant was informed in advance that they would play a cat role in the experiment*, each participant was trained on how to interact with the VEs smoothly when using an HMD, and the data gloves were calibrated for the individual. In addition, each participant was in a peaceful state without severe emotional fluctuations.

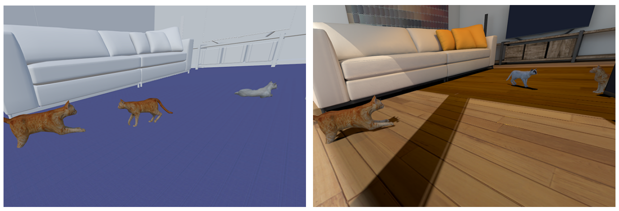
3.5 Procedure

In our experiment, each participant performed two tests corresponding to two combinations of manipulations within a group, and there was a recovery interval of more than 24-hours between the two tests. For instance, a participant assigned to a group associated with the combination of manipulations MoP-0×MoS performed one test MoP-0×MoS-0 and another test MoP-0×MoS-1 in a random order. Two experimenters participated in the whole process of the experiment.

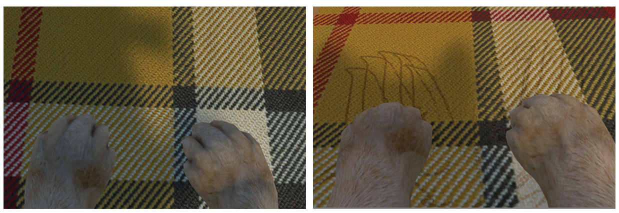
The entire test includes *six* stages (**Stages 1∼6**), in which Stage 5 examines the participant's response and behavior in a VE after different levels of self-conversion have been gradually introduced from Stage 1 to 4, as described below. The main differences between levels of manipulation in these

TABLE 1: Comparison between different levels of MoP and MoS

#Stage	Event & Appearance	Manipulation	Level 0	Level 1
1∼5	Virtual scenario	MoP	Lower realistic rendering	Higher realistic rendering
2	Avatar	MoS	No avatar & Cannot see one self	Personalized avatar & Can see one self's avatar
3	Interaction with tangible proxy through fingers	MoP	No scratch appeared in VE & Haptic perception not correspond to VR	Scratch appeared in VE & Haptic perception corresponds to VR
4	Task-oriented playing	MoS	Consistent with tutorial in video	Inconsistent with tutorial



(a) Rendering: Left (MoP-0); Right (MoP-1)



(b) Scratch interaction: Left (MoP-0); Right (MoP-1)

Fig. 5: MoP-0 vs. MoP-1. (a) shows the scenario rendered with different realism; (b) shows the scenario in Stage 3 in the first-person view when the user scratches in the VE.

stages are summarized in Table 1. When immersed in the VE, participants associated with MoP-0 were provided with lower realistic renderings throughout the procedure (Stage 1∼5), as shown in Fig. 5(a) left; participants associated with MoP-1 were provided with relatively higher realistic renderings, as shown in Fig. 5(a) right.

To begin the test, the experimenters provided each participant with the following instructions:

This test consists of two parts. The first part is a VR exploration with some tasks. You should wear both a wireless HMD and a pair of data gloves to interact with the virtual world. We hope you devote yourself to the game as deeply as possible and imagine that you have become the role you'll be playing, i.e. a cat. During the test, please follow the guidance using the tips on the screen in each stage to perform some designed tasks. This part will not terminate until you have finished all the tasks. During the test, you should remain seated in a chair next to a table. You can perform any action with the upper body, including the head, hands, limbs, and upper torso, except getting up. The second part is a survey without any VR devices equipped.

Stage 1: Watching tutorial video. A video consisting of several live-action clips about cats' common behaviors was given to all participants. In the video, three types of scenarios detailing cat behavior were demonstrated: catching mice, playing with a cat teaser, and pulling tissue.

This stage made participants aware of the behavior patterns involved in the cat role. It was expected to establish the participants' schema towards the cat role and allow them to form a more intuitive understanding of the role they will play in the following stages.

Fig. 6: Diverse avatars of cats provided for participants associated with MoS-1 to choose in VE.

Stage 2: Identity recognition stage. Different levels of MoS were assigned with different setups. Various cat appearances were provided for those participants associated with MoS-1 (Fig. 6), and they could select their favorite as the avatar by watching themselves in a mirror with a self-performance show. These participants could get enhanced recognition of their cat identity in this VE.

In contrast, no avatar was provided to participants associated with manipulation MoS-0, and there was also no mirror available for self-viewing; the participants could only observe the surroundings in the VE during this stage. Since no information was relevant to the cat role, this might even weaken their recognition of their identity as a cat. This step lasted for several minutes.

Through this stage, the degree of cognition of one's self as a cat in the VE would be differentiated in different setups. We expected that the participants associated with MoS-1 would experience a higher degree of self-conversion to the role.

Stage 3: Physical perception stage. The participants touched and felt the physical proxy using their fingers (exposed from data gloves) as the cat's claws to scratch a virtual cloth in the VE. Different physical proxy objects were provided according to different levels of MoP.

For participants in a test associated with MoP-1, a piece of cloth coincident with that in the virtual world was provided to produce more consistent haptic perception and response (Fig. 3 left). In addition, corresponding scratch marks appeared on the virtual cloth when fingers touched the cloth in the real world (Fig. 5(b) right). However, participants associated with MoP-0 could only touch and feel the desk (poor proxy), which was inconsistent with the expected sensation when they were scratching a piece of virtual cloth (inconsistent response). In addition, no virtual scratch marks appeared in the VE (Fig. 5(b) left).

Since the proxy fidelity affects performance of interaction [63], the fidelity of feedback obtained with different levels of MoP was quite different. We expected that, with the high-fidelity feedback from the experience of a VE, participants associated with MoP-1 would obtain higher Psi.

Stage 4: Task-oriented playing stage. In this stage, two sets of games (each including three specific mini-games) were provided for the participants associated with different levels of MoS. Participants associated with MoS-1 were assigned specific tasks, including 3 mini-games: catching mice, playing with a cat teaser, and pulling tissue, as shown in Fig. 7. This set of games was consistent with the events shown in Stage 1. In contrast, another set of games (including catching bugs, playing with a wool ball, and playing with a slipper, as shown in Fig. 8) assigned to participants associated with MoS-0 was irrelevant to the events shown in the tutorial. To enhance the participants' motivation to play, a score was also shown during playing.

Since mini-games for the participants associated with MoS-1 (MoS-1×MoP-0 & MoS-1×MoP-1) correspond to the events shown in the tutorial video in Stage 1, we expected these participants to introduce stronger self-conversion to the role, thereby leading to higher self-illusion. For those associated with MoS-0 (i.e. MoS-0×MoP-0 & MoS-0×MoP-1), the inconsistency might weaken self-conversion.

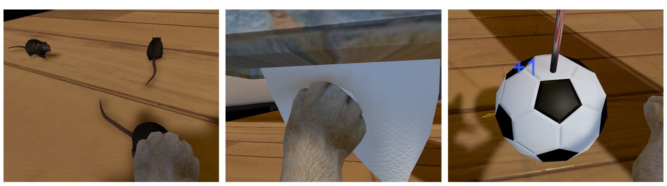


Fig. 7: Mini-games for participants associated with MoS-1 include catching mice, pulling tissue, and playing with a cat teaser. All scenarios had been shown in the tutorial video.

Fig. 8: Mini-games for participants associated with MoS-0 include catching bugs, playing with a wool ball, and playing with a slipper. None scenario had been shown in tutorial video.

Stage 5: Interaction with other cats. In this stage, all the participants were examined using the same scenario with the same setup, regardless of the associated manipulation. In the VE, two cute cats in the field of view greeted each other, then one approached the participant in his cat role; this cat sat in front of the participant, as shown in Fig. 9. The participant can do any spontaneous action to this cat in this stage, without any instruction. Specifically, if the participant made contact with the virtual cat, a physical tangible proxy (a cat-form plush toy as the embodiment to virtual cat) was provided to evoke a realistic perception with consistent haptic response [64], [65], as shown in Fig. 3(b).

This procedure aimed to discover the cognitive inclination between the participant's self and the cat, which are the same species in the virtual world but different species in the real world, through the participant's response to the virtual cats. One experimenter drove the physical proxy to play in accordance with the actions shown in the VE, and another experimenter observed and recorded the participants' responses and their physical behaviors in the real world.

Fig. 9: Participant interacting with other virtual cats.

Stage 6: Questionnaire and post-interview. Each participant took off the VR apparatus and completed the questionnaire shown in Table 2. In addition to measuring SoE, PI, and Psi, we devised questions measuring self-illusion for the first time. Considering that the elements concerning self-concept generally include physical characteristics, identity, typical behavior, ability, belief, values, goals, etc. [13], [58]), we designed three questions focused on acquisition of behavior patterns Q(7), subjective evaluation (whether one is more inclined to see oneself as the original self or the role played) Q(8), and spontaneous behavioral intent Q(9). Other attributes like ability, values, goals, etc. were not applicable to a cat role, so we ignored them in this study. Then, experimenters conducted a post-interview. During the interview, experimenters confirmed with the participants that the records of their actions were accurate and investigated the intent behind them.

After at least 24 hours (for psychological recovery), each participant returned and performed the second test (i.e. another combination of manipulations), which repeated the procedures from Stage 1 to Stage 6 but with different manipulations, as illustrated in Fig. 4.

4 Results

During the experiment, we collected two kinds of data: participants' scores on the questionnaire in two tests and their behavior data. All the questionnaire statistics were analyzed using repeated measures ANOVA, as discussed in Sect. 3.3. For participants' actions and implied intent, we used descriptive statistics and a chi-squared test to detect the differences between the performances of participants under different conditions. We also conducted a demographics analysis. We present our results and evaluate them on five distinct components below.

4.1 Analysis of Questionnaire

The reliability of the entire questionnaire is sufficiently high (*Cronbach's* α = 0.774). This conclusion also applies to the sub-scale consisting of the three items (Q(7)∼Q(9)) assessing self-illusion (*Cronbach's* α = 0.782).

TABLE 2: Questionnaire for assessing participants' SoE, PI, Psi, SI.

Category	Question
Sense of Embodiment [1]	To what extent do you feel the virtual hand is your hand? ... (1)
	To what extent do you feel the virtual hand moves just like you want it to, as if it is obeying your will? ... (2)
Place illusion	To what extent do you feel present in the VE right now? ... (3)
Plausibility illusion [2]	To what extent do you think this scene is realistic and credible? ... (4)
	How do you evaluate the interaction with the living things (cat, mice, bugs, etc.) in the VE? ... (5)
	How do you evaluate the interaction with the non-living things (wool ball, cat teaser, tissue, etc.) in the VE? (6)
Self-illusion	To what extent do you think you acquire the behavior pattern of the cat you acted? ... (7)
	To what extent do you feel you really come to be a cat? ... (8)
	To what extent will you behave like a cat rather than human? ... (9)

[1] Q(1)Q(2) are from the questionnaire in [45]; [2] Q(4)Q(5)Q(6) are from the questionnaire in [30].

TABLE 3: PCA of questionnaire (absolute value of correlation coefficients $< .3$ excluded)

Component	Factor 1	Factor 2
Q(1)	.480	.486
Q(2)	.696	
Q(3)	.608	
Q(4)	.680	
Q(5)	.603	
Q(6)	.625	
Q(7)		.826
Q(8)		.764
Q(9)		.842
Variance Explained Init. (%)	36.340	16.549
Variance Explained Rot. (%)	26.754	26.135

To identify the underlying structure of our questionnaire, we conducted *exploratory principal component analysis* (PCA) on questionnaire scores, as shown in Table 3. Two factors, accounting for 52.889% of the variance, were extracted. Q(2)∼Q(6) belong to the first factor (accounting for 26.754% of the variance); Q(1) and Q(7)∼Q(9) belong to the second factor (accounting for 26.135% of the variance).

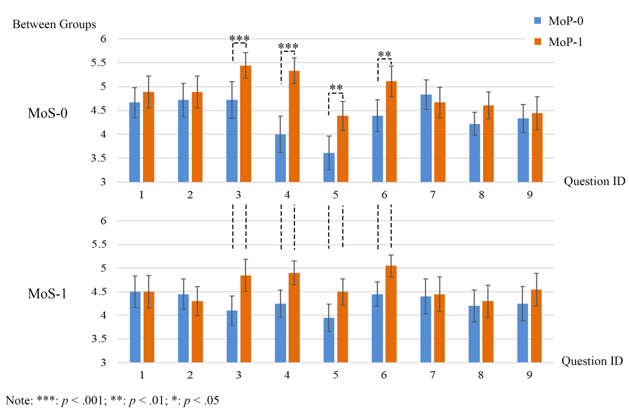


Fig. 10: MoS-0×MoP & MoS-1×MoP grading on the questionnaire, presenting mean value and standard error of each item. MoP successfully changed participants' grades on Q(3)∼Q(6), regardless of different levels of self-illusion.

4.2 Effect of MoP

There are two groups that experienced a change in MoP (MoS-0×MoP & MoS-1×MoP). In this section, we choose these two groups to do repeated measures ANOVA with the within-group factor MoP and the between-group factor MoS.

The results of ANOVA (see Table 4) show that, among all nine items, no significant interactions are found between MoS and MoP. Furthermore, no significant effects of MoS (the between-group factor) are found. MoP has a significant effect on Q(3) ($F(1, 36) = 14.976$, $p < .001$, *partial* $\eta^2 = .294$), Q(4) ($F(1, 36) = 23.724$, $p < .001$, *partial* $\eta^2 = .397$), Q(5) ($F(1, 36) = 14.295$, $p = .001$, *partial* $\eta^2 = .284$), and Q(6) ($F(1, 36) = 8.234$, $p = .007$, *partial* $\eta^2 = .186$). This indicates that, from MoP-0 to MoP-1, Psi increases regardless of self-illusion. The effect of MoP on Psi tends to be identical for different levels of MoS.

MoP can neither change the participant's self-illusion nor the components of SoE, which ensures the success of our design on this manipulation of MoP.

4.3 Effect of MoS

Similarly, there are two other groups that experienced a change in MoS (MoP-0×MoS & MoP-1×MoS). In this section, we choose these two groups to do repeated measures ANOVA with the within-group factor MoS and the between-group factor MoP.

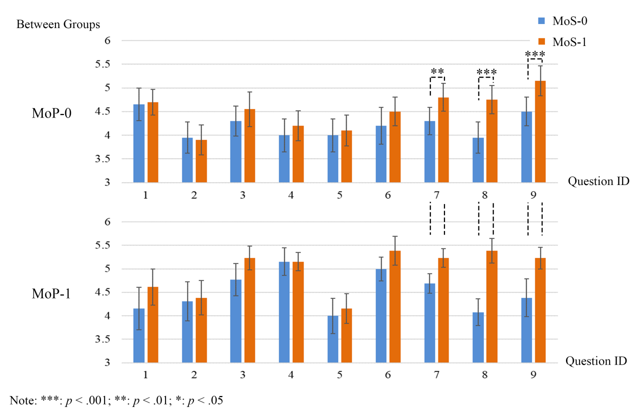


Fig. 11: MoP-0×MoS & MoP-1×MoS grading on the questionnaire, presenting mean value and standard error of each item. MoS successfully changed participants' grades on Q(7)∼Q(9), regardless of different levels of Psi.

The results of ANOVA (see Table 5) show that, among all nine items, no significant interactions are found between

TABLE 4: p-value in ANOVA for groups: MoS-0×MoP & MoS-1×MoP

p-value	Q(1)	Q(2)	Q(3)	Q(4)	Q(5)	Q(6)	Q(7)	Q(8)	Q(9)
Main effect (MoP)	.399	.959	<.001	<.001	.001	.007	.712	.063	.214
Interaction effect (MoS×MoP)	.399	.330	.942	.102	.521	.792	.493	.264	.564

TABLE 5: p-value in ANOVA for groups: MoP-0×MoS & MoP-1×MoS

p-value	Q(1)	Q(2)	Q(3)	Q(4)	Q(5)	Q(6)	Q(7)	Q(8)	Q(9)
Main effect (MoS)	.285	.922	.152	.413	.711	.250	.001	<.001	<.001
Interaction effect (MoS×MoP)	.436	.922	.866	.799	.711	.940	.760	.884	.953

MoS and MoP. Also, no significant effects of MoP (the between-group factor) are found. MoS has a significant effect on Q(7) ($F(1, 37)$ = 12.942, p = .001, *partial* η^2 = .259), Q(8) ($F(1, 37)$ = 32.703, $p <$ .001, *partial* η^2 = .469), and Q(9) ($F(1, 37)$ = 16.932, $p <$ .001, *partial* η^2 = .314), which means that, from MoS-0 to MoS-1, self-illusion increased regardless of plausibility. MoS does not significantly influence other items, and therefore our design of MoS is reasonable.

4.4 Behavior Data Analysis

From the experiment record in Stage 5 (Sect. 3.5), two experimenters organized the actual behaviors and the behavioral intent of the participants; no disagreement was raised in this classification. It must be emphasized that no instruction is given to the participants during Stage 5, and all the behaviors performed are based on participants' own intent. In all, these behaviors and behavioral intent can be divided into five categories:

a. Aggressive behavior. Beating the cat, slapping its face, or spanking it;

b. Petting behavior. Touching and feeling the cat gently on its head, back, or chin using the participant's hands (claws in VR);

c. Behaviors showing intimacy. Licking the cat's fur, rubbing another cat with corresponding body parts (head against head, back against back, etc.), or drilling into the cat's forelimbs;

d. Mimicking behavior. Simulating the behavior of the cat in front of the participant, including behaviors such as licking himself (claws) or greeting the other as a cat in the VE;

e. Purposeless behavior. Motionlessly watching, looking around aimlessly, no reaction to the cat, etc.

We classified a, b, and e into the *incoherent response* (IR) group, which means these actions are more consistent with a human's behavior than a cat's inherent behavior pattern. Behaviors that are inconsistent with a cat's pattern represent a lower self-conversion to the cat role. In contrast, c and d should be put into another category called the *coherent response* (CR) group, where participants act as if they are the cats themselves, indicating that they feel like cats. These behaviors are considered to be consistent with the cat's inherent behavior pattern. In this paper, *coherent* means that the user follows the role's inherent attributes naturally in the VE (e.g. behavior pattern, response, perception). Note that coherent response here should not be confused with the same term used in [66], which refers to the characterization of a system that leads to Psi.

TABLE 6: Participants' behavior statistics in Stage 5 (some participants show multiple behaviors). Compared with other participants, those associated with MoS-1 tend to act more like the role they played.

	a	*b*	*c*	*d*	*e*	*IR*	*CR*
MoP-0 × MoS-0	9	19	3	1	7	35	4
MoP-1 × MoS-0	3	25	4	2	3	31	6
MoP-0 × MoS-1	3	17	12	9	0	20	21
MoP-1 × MoS-1	1	10	18	9	3	14	27

Table 6 shows the statistics of all participants' behaviors with respect to the virtual cats under different manipulation conditions in Stage 5. We perform a *chi-squared test* on the data in the *coherent response* (CR) and *incoherent response* (IR) columns. This test examines whether the likelihood of two types of behavior among the four groups is identical or not. The result demonstrates that participants in different groups behave significantly differently, with $Pearson$ $\chi^2(3) = 37.139$, $p <$ .001. From the crosstab, participants who experience MoS-1 tend to act like cats while participants who experience MoS-0 tend to act in accordance with a human model.

Remarkably, some participants behaved like a cat and kept scratching the table unintentionally without any instruction from the experimenter, even during the questionnaire stage (not in the VE). This indicates that changes in a participant's behavior pattern are the result of self-conversion rather than merely following the instructions.

4.5 Demographics Analysis

In the post-interview, we find that game experience seems to affect participants' grading. A participant with more game experience may think of "playing" as a simulation of a role rather than as being a cat himself/herself. As a result, they may behave like cats even with a lower level of self-conversion. Moreover, this kind of participant always has strong desire on the rendering quality of the scenario in the VE. For these reasons, we choose *game experience* as a demographic variable that may influence our measurement.

To measure this potential effect caused by our manipulation, we divide all the participants into two groups: *Game Experts* and *Game Amateurs*. We label the participants with a score of 5 and above in a 7-point Likert scale (39 participants, around 51%) on "Game Experience" as *Game Experts* and the others as *Game Amateurs* (38 participants, around 49%). Then we perform the independent t-test to detect the difference between these two groups.

The result shows that game experts grade Q(4) significantly higher (in the first test, M_{expert} = 4.67, $M_{amateur}$ = 4.05, p = .065; in the second test, M_{expert} = 5.21, $M_{amateur}$ = 4.63, p = .037). No significant results can be found among the other 8 items, which implies that, from the perspective of the $mean$ value, participants' game experience does not affect their grading on other items, including the items designed for evaluation of self-illusion. This also demonstrates the reliability of our design.

In addition, we conducted the independent t-test to detect the difference between male and female participants to see whether gender can affect self-illusion when embodied in a cat's body. The result shows that female participants graded Q(5) (M_{male} = 3.92, M_{female} = 4.54, p = .030) and Q(6) (M_{male} = 4.67, M_{female} = 5.24, p = .040) higher in the second test, i.e., females rated the interaction with living and non-living things (Q(5) and Q(6)) in the VE higher than male participants. More research should be conducted to investigate the causal relationship between these factors. Gender differences did not appear in the items (i.e. Q(7)-Q(9)) we designed to measure self-illusion. No other significant results can be found.

5 Discussion

The following discussions on the existence and measurability of self-illusion are based on the above results and analyses and highlight self-illusion's dissociation from other components involved in presence.

5.1 Existence and Effect of Self-Illusion

From the experimental results in Sect. 4.3 and Sect. 4.4, we can see that the participants achieve new experiences with realistic responses using a cat role in the virtual world, where the role is different from the self in the physical world. Within a VE, the cognition about one's self may change from one's actual self to the role and follow some of the role's attributes. This phenomenon is the occurrence of the hypothesized self-illusion, i.e. the idea that humans can, to some extent, perceive themselves as the role in the VE instead of retaining a full sense of their actual selves.

In the experiment, we change the self-concept of the participants through MoS. As a result, when provided with avatar personalization and tasks that match the tutorial video, participants tend to better recognize themselves as cats. According to the ANOVA result from different levels of manipulation between MoS-0 and MoS-1 (Sect. 4.3), participants who experienced MoS-1 reported learning the behavior patterns of the cat better, saying they "behave like a cat rather than a human" and even feel themselves "to be a cat." This is exact evidence of this illusion of self-concept, i.e., self-illusion exists and may occur when role-playing in VEs.

PI and Psi also contribute to realistic behaviors in the VE. With high-level PI and high-level Psi, individuals feel that they are in a virtual scene where everything that happens around them is real and that they can interact well with the VE [6]. In contrast, self-illusion emphasizes the cognitive inclination of self-concept. Participants with high-level SI will commit themselves to the role they play in the virtual scene and act while spontaneously using the coherent patterns rather than passively following the game instructions. Specific to the experiment, more participants with high levels of SI chose to interact with the cat friendly in a cat's way as if they were the members of a cat family (Sect. 4.4) and reported the reason for their behavior as "as a member of cat, I behave in that way naturally." However, participants who experienced low-level MoS-0 tended to choose exploratory activities such as petting the cat (i.e. treating it as a pet) or hitting it (i.e. treating it as a plaything) to try to see what would happen next, which can be considered the typical schema of humans. While both PI and Psi bring realistic behavior, SI makes the participants connect themselves to the virtual role in the immersive VEs, producing behavior that we called *coherent* behavior as defined in Sect. 4.4.

TABLE 7: External representations of different illusions taking *Counter-Strike* as an example.

Illusion	What a player can experience in the game
Self-illusion	Accepting new assignment (terrorists/counter-terrorists), physical characteristics (well-trained, strong), belief (violence is the only way to solve any problem) no matter what he is in the real life [58]. Thinking this role is right himself.
Sense of embodiment	Feeling that he owns the body and employs every part of the body. Feeling that he can use the gun by his virtual hand as easy as his own hand [15].
Self-presence	Feeling that the specific role matches him in some aspect, such as the belief or job [12].

The existence of self-illusion can be embodied in other applications, and we provide external representations of different illusions using a game *Counter-Strike* as an example, as shown in Table 7. This game is often criticized for making adolescents aggressive [67]; our study on SI may give insight into what elements in this kind of game should be blamed, controlled, and adjusted to reduce the violence guidance. As shown in Table 7, while identity-level self-presence happens because mediated environments provide players a platform to choose the specific aspect of the self they want to show, self-illusion may occur when the role imposes some trait on players. Thus, for the games where violent scenarios are frequently exposed, it is worth developing techniques to control the level of SI obtained to keep adolescents from being negatively guided and seduced by these games. From another perspective, obtaining high-level self-illusion from role-playing and attributes conversion may also cause a short-term residual effect in changing a user's emotions. Through long-term role-playing practice, this effect may persist and then solidify, until the attribute becomes a part of the user. In other words, a user's personality traits could be converted under tailored manipulation of the way that self-illusion is modulated in VR, e.g., the coward may become brave, the violent may become peaceful, and vice versa. Therefore, fully exploiting and utilizing this feature of SI may also bring positive changes to people's negative emotions and personalities.

5.2 Measurability of Self-Illusion

As shown in Table 3, the exploratory factor analysis shows Q(1) *"To what extent do you feel the virtual hand is your hand?"* and Q(7)∼Q(9) belong to the same factor. Q(1) is used to measure participants' sense of embodiment [45] and Q(7)∼Q(9) are designed to measure participants' self-illusion. Looking into the rationales of these four questions, we find that they focus on separate aspects: subjective virtual body ownership, acquisition of knowledge on behavior patterns, subjective evaluation on role cognition, and spontaneous behavioral intention (whether one acts like the original self or the role they play), respectively.

Q(1) focuses on the measure of VBO in SoE. From our point of view, acceptance of the virtual role's body should be the first step of self-conversion. From our PCA analysis in Table 3, this item places almost the same load on the two factors, which indicates that VBO has the potential to be a bridge between SoE and self-illusion. However, this item does not differ significantly (p = .071) under different levels of MoS in our experiment, possibly because Q(1) only emphasizes the ownership of a "hand." In fact, all participants can effectively feel their "hands" even if they experience MoS-0 and know nothing about their own avatars.

Q(7) emphasizes the acquisition of knowledge about the given behavior pattern. Obviously, sufficient acquisition of knowledge should be the basis for self-conversion. In our experiments, if the user does not experience the same events as shown in the tutorial (associated with MoS-0), the acquisition of knowledge may be insufficient to effect self-conversion. Although it is not directly related to the result of self-conversion, this item still reflects self-illusion to some extent. In our experiment, participants who experienced MoS-1 reported better acquisition of the cat's behavior pattern than those associated with MoS-0 (p = .001, *partial* η^2 = .259, see Sect. 4.3).

Q(8) and Q(9) focus on participants' subjective feelings after the test. It is clear that Q(8) measures self-illusion directly and explicitly. Participants who experienced MoS-1 felt that they really became a cat more than those who experienced MoS-0 ($p < .001$, *partial* η^2 = .469, see Sect. 4.3). Q(9) is proposed under the consideration that the spontaneous behavior may reflect the *implicit* cognition on self-concept. In the experiment, participants who experienced MoS-1 show stronger willingness to behave like a cat ($p < .001$, *partial* η^2 = .314, see Sect. 4.3). The behavior data analysis, which shows that participants who experienced MoS-1 really tend to act like cats, also validates our assumption.

On the whole, we believe that all three of our questions can be used to measure self-illusion objectively. One may ask whether it is circular logic to propose both the concept of SI and the measurements for SI. This is not the case because we design the experiment and questionnaire independently. The role-play experiment is designed with the motivation discussed in Sect. 3.1 and Sect. 3.3, while the questionnaire is derived from the definition of self-concept. The manipulation of self-illusion (Sect. 3.3) is not determined by the specific items in our questionnaire, i.e., it has nothing to do with the questionnaire.

5.3 Double Dissociation from Psi

From the results demonstrated in Fig. 11 regarding changing MoS, we find that MoS does not significantly affect players' evaluation of items emphasizing Psi. Similarly, MoP does not affect SI significantly from Fig. 10. In all, one manipulation (MoP) affects the Psi but not the self-illusion, while the other manipulation (MoS) affects the self-illusion but not the Psi. Therefore, we can safely conclude that there is a *double dissociation* [68] between self-illusion and Psi.

5.4 Single Dissociation from SoE and PI

From Fig. 10 and Fig. 11, we can see that both SoE and PI remain almost unchanged under different conditions; in other words, neither MoS nor MoP change SoE or PI significantly. Given that there is one manipulation (MoS) that can change self-illusion but not one that changes SoE or PI, we can conclude that self-illusion is single dissociated from PI and SoE.

As mentioned in Sect. 5.2, VBO may be the foundation of obtaining self-illusion. Although self-illusion can be altered without changing VBO in our experiment, it may be difficult to modify the level of VBO (e.g., visible v.s invisible avatar) while leaving self-illusion untouched. Further research is necessary to check whether self-illusion is double dissociated or just single dissociated from SoE.

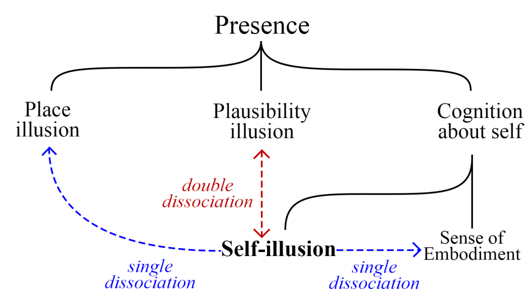


Fig. 12: Relationship between self-illusion and other elements about perception or cognition within the scope of a VR experience.

Our research extends the scope of the illusion of cognition about the self by suggesting that there exists a higher level of illusion about cognition than SoE, i.e. self-illusion. Given that SI is dissociated from other important components in presence, as shown in Fig. 12, it can be considered a new element involved in presence in VR. It remains a question whether self-illusion has a stronger dissociation from Pi and SoE or not. On one hand, there is a possible prior relationship between them since a vivid avatar may help participants connect themselves to the role. On the other hand, many VR systems and games only using plain representation for the controllers or abstract hands can still achieve a high degree of presence. Our future work will focus on in-depth exploration of the relationship between SoE and SI.

Considering self-illusion's effect on contributing coherent responses in VEs, we propose that, in addition to Pi and Psi, self-illusion has the potential to be a new metric for presence in VEs. Generally, the higher the self-illusion, the more the users can connect themselves to the virtual roles, and high levels of presence can be obtained through a VR system. In addition, the quality of a VR system can be assessed using SI as a metric.

5.5 Factors Affecting Self-Illusion

When manipulating MoS, we try to vary the level of self-illusion based on two factors: whether or not we provide a personalized avatar for self-observing and whether or not the mini-games are consistent with the tutorial. Specifically, avatar personalization in front of the mirror allows participants to enhance their recognition of a role's identity through strengthened stimuli. Those mini-games consistent with the tutorials are designed to give the participants a better understanding of the behavioral patterns of the role they play. From Fig. 11, we are sure that these two factors in the manipulations jointly affect SI. However, the quantitative evaluation of their individual effect needs further investigation. Other factors that can affect the SI should also be carefully considered. They will be considered in our future work to deepen understanding of this illusion.

From the post-interview, we expected that experienced game players would follow the cat's behavior patterns more easily, thus affecting the behavioral intention in SI. Research has also shown that difference in game experience can affect players' evaluations of the VR system [69]. However, from demographics statistics (Sect. 4.5), although *game experts* grade higher on Q(4), i.e. the rendering quality and credibility, game experience does not affect any other item significantly. In future between-group experiments, we would better control the game experience among the participants or seek other measurement methods.

6 Conclusion, Limitation, and Future Work

In this paper, we made attempts on exploring the experience of immersive VR from the perspective of self-cognition. We evaluate self-illusion, which is an illusion of self-concept that may occur when playing a role in VEs. Through an experiment in which participants interact with VEs from a non-human perspective using cats' behavior patterns, our study validates the occurrence of self-illusion during immersive VR experiences. High-level self-illusion of a user generally contributes to more commitment to the virtual role and leads to more coherent responses within a VE. Based on our research, a VR system could enhance users' presence by facilitating more coherent responses in the VEs, altering the self-illusion by manipulating relevant factors. More research on how to enhance or control the level of self-illusion in VR applications is necessary in the future, especially for therapy applications, which must be carefully designed to avoid ethical problems.

Our approach has some limitations because the cognition of self is affected by so many objective and subjective factors. In our experiment, we mainly used questionnaires and qualitative behavior data measurements. Although we chose a mixed design and set two levels to reduce the measuring error, this type of self-report approach may still bring bias. Also, due to the restrictions of the cat role, such elements as belief, ability, and value have not been taken into consideration in the questionnaire. We should broaden the questionnaire to address relevant issues since they are also significant elements of self-concept. A clear baseline for each question should be established to help compare between different VR applications. In addition, measurements of physiological indicators such as the activation states of brain regions related to selfhood should be taken into consideration. Specifically, we can employ an electroencephalogram (EEG) to obtain corresponding biological signals to analyze self-illusion and other relevant indicators. Research has shown that realism and virtual character's appearance could induce different emotional [70] and behavioral [69] reactions; it is worth investigating the correlations between the emotional states, appearances, and behaviors that may contribute to self-illusion.

Intuitively, in a low-Psi environment where the participants have poor interactions with the environment, they may feel that events in the environment are unrealistic, which hinders self-conversion. However, this is not the case in our experiments. Noticing that Psi and self-illusion are continuous psychological variables rather than binary variables, it would be worth pursuing an experiment with a larger range of manipulations on Psi and self-illusion in the future to determine the extent of these variables in a VE.

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Sheng Li is currently an Associate Professor of the School of Electronics Engineering and Computer Sciences, Peking University. He works as a member of the Graphics & Interactive Technology Lab. and has published over 30 refereed papers in prestigious journals and conferences, including ACM TOG, IEEE TVCG, CGF, etc. His research interests include virtual reality and augmented reality, rendering, physical simulation and interaction. He is a member of ACM and IEEE.

Xiang Gu is a Ph.D. candidate at Graphics & Interactive Technology Lab., School of Electronics Engineering and Computer Science, Peking University. His research interests include virtual reality and augmented reality and its psychological mechanism.

Kangrui Yi is currently a Master candidate at Graphics & Interactive Technology Lab., Peking University. His research interests include real-time rendering and virtual reality technology.

Yanlin Yang graduated from Peking University and obtained Bachelor degree in 2019. He was an intern at Graphics & Interactive Technology Lab. His research interests include virtual reality technology and game.

Guoping Wang is currently a professor in Peking University, where he is also the director of Graphics & Interactive Technology Laboratory. He achieved the National Science Fund for Distinguished Young Scholars in 2009. His research interests include Virtual Reality, Computer Graphics, Human-Computer Interaction, and Multimedia.

Dinesh Manocha is Paul Chrisman-Iribe Chair in Computer Science & ECE at University of Maryland, College Park. His research interests include virtual environments, physically-based modeling, and robotics. His group has developed a number of software packages that are standard and licensed to 60+ commercial vendors. He has published more than 550 papers & supervised 38 PhD dissertations. He is a Fellow of AAAI, AAAS, ACM, and IEEE, member of ACM SIGGRAPH Academy, and Pioneer of Solid Modeling Association.