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Empathy enhancement through VR: A practice-led design study

Xina Jiang [a], Wen Zhou [a], Jicheng Sun [b], Shihong Chen [c,*], Anthony Fung [d]

[a] Beijing Normal University, 19 Xinjiekouwai St., Beijing, 100875, China
[b] Stevens Institute of Technology, 1 Castle Point Terrace, Hoboken, NJ 07030, USA
[c] Beijing Union University, 197 Beitucheng West St., Beijing, 100191, China
[d] The Chinese University of Hong Kong, Shatin, New Territories, Hong Kong SAR, China

A R T I C L E I N F O

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A B S T R A C T

Virtual reality (VR) has been widely acknowledged as a highly effective medium for augmenting empathy, enabling individuals to better comprehend and resonate with the emotions and lived experiences of others. Despite its acknowledged potential, the field lacks clear design guidelines and a systematic framework for creating VR environments for empathy training. In this article, we present a practice-led research project in which we triangulated design research using a paired sample *t*-test to evaluate and optimize the design guidelines of the empathy-training VR design (EVRD) framework. We evaluated the impact of a VR experience, designed based on the EVRD framework, on emotional, cognitive, and behavioral empathy among Chinese higher education students (n=84). A comprehensive assessment approach, including the Interpersonal Reactivity Index, interviews, system log analysis, and monitoring of donation activities was utilized, to measure changes in empathy before and after the VR intervention. The results validated the EVRD framework and demonstrated that it is a practical and systematic tool for designing a VR that training empathy. The findings of this study provide design insights with regard to (1) the process of VR empathy and (2) how to design "doomed-to-fail" interactions to promote cognitive empathy in VR.

1. Introduction

The 3D reconstruction (Sra et al., 2016) and embodied experiences (Shin, 2018a) provided by VR technology ensure a sense of presence (Slater et al., 1994), creating a feeling of "being there" in the virtual environment (Wiederhold et al., 2010). Considering empathy is highly related with situational factors and of contextual-dependent (Sulzer et al., 2016), VR is widely recognized as an 'empathy machine', with the potential to foster empathy and related behaviours among its audience (Han et al., 2022; Hassan, 2020). Numerous studies have demonstrated that VR can enhance empathy in individuals and serve as an environment for social-emotional learning (SEL), consequently leading to increased prosocial behaviours towards strangers (Banakou et al., 2016; Chirico et al., 2017; Kim et al., 2022). Given this context, it is crucial to explore the extent to which VR, as an emerging technological medium, can contribute to the social and emotional development of individuals. However, despite the high social demand for VR for training empathy (Christofi et al., 2022), there is a lack of clear design principles to guide the development of such virtual environments, let alone a systematic design framework.

To address this research gap regarding how to design a VR for empathy training, this study adopts the practice-led research (PLR) methodology (Mäkelä, 2007) in a three-step process: proposing initial design guidelines, developing an artefact based on the guidelines, and using the artefact as an intervention material to validate the guidelines. This paper is organized into four main sections: (1) The theoretical framework section provides an overview of existing research on empathy, explores the role of VR in promoting empathy, examines

* Corresponding author.
E-mail address: ydlhy8797800@126.com (S. Chen).

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current practices and research on empathic VR design, and identifies the research gap. (2) The methods section outlines the PLR methodology employed in the study, detailing the research processes involved. This includes the design phase, which involves clarifying the design guidelines through the presentation of the VR artefact, *synaptic retrogenesis.*[1] Additionally, the experimental phase entails using *synaptic retrogenesis* as the intervention material for pre- and post-test experiments. (3) The findings section presents the effectiveness of the design guidelines by analyzing participants' changes in the three dimensions of empathy (emotional, cognitive, and behavioural) before and after the intervention. Furthermore, valuable design insights are extracted from users' feedback, including dynamic process of VR empathy, creating relatable main character, arranging help-seeking episodes, and doom-to-fail interaction. (4) The conclusion and discussion section discuss the Empathy Training VR Design (EVRD) framework, reflects on the limitations of this study, and suggests avenues for future improvement.

2. Theoretical review

2.1. Empathy

Empathy is widely acknowledged as the capacity to comprehend and share others' feelings (Wispé, 1986). It involves the ability to put oneself in another person's shoes, thereby facilitating a deep connection with others in terms of perspective, emotions, and experiences. Empathy exhibits a strong correlation with prosocial behaviour (Eisenberg et al., 1996; Kaukiainen et al., 1999). Put simply, individuals who lack empathy struggle to understand the world from others' perspectives or to resonate with their emotions, which may result in apathy and aggression (Leppin et al., 2014; Mayer et al., 2018).

Early treatments of empathy deficits, such as lobotomies, electroshock therapy, and pharmacotherapy, have shown limited efficacy (Felthous, 2015; Tew et al., 2012), leading to a shift towards psychotherapy (Chialant et al., 2016). Research suggests that empathy is a dynamic process heavily influenced by situational factors, thus making it highly context-dependent (Sulzer et al., 2016). Consequently, interventions often involving stimuli like photographs, video clips, and role-playing(Gagen et al., 2017; Koblar et al., 2018; Shea and Barney, 2015) to help individuals imagine the feelings of others or put themselves in others' situations (Decety and Moriguchi, 2007). Therapies like dance/movement therapy (DMT) (McGarry and Russo, 2011) and Motivational Interviewing (MI) (Romero-Martínez et al., 2019) have been explored . DMT relies on kinesthetic empathy, involving individuals perceiving and experiencing the actions and emotional states of others through imitation and synchronized movement (McGarry and Russo, 2011). This bodily level of empathy allows individuals to understand and empathize with the emotional states of others by feeling their movements through their own bodies (Berrol, 2006), essentially mirroring themselves in others (Behrends et al., 2012). MI involves therapists demonstrating emotional empathy, aiding individuals in learning to feel and understand others' emotions similarly (Romero-Martínez et al., 2019). In summary, interventions and treatments in the medical field emphasize two main aspects: (1) situational representation and (2) perceptual-cognitive sharing. VR's ability to provide reality-reconstruction (Nagao et al., 2019) and presence (Biocca and Levy, 2013) gives it an advantage over existing methods such as pictures, comics, videos, and role-playing in situational representation. As for perceptual-cognitive sharing, while comparative studies with DMT and MI are lacking, empirical research has validated the effectiveness of VR in perceptual sharing (Romeas et al., 2019), particularly due to its ability to provide first-person embodied experiences (Pan and Hamilton, 2018).

The psychological process of empathy can be categorized into three schools of thought. First, scholars represented by Lipps view empathy as solely an emotional affect (Wispé, 1986), a non-cognitive phenomenon experienced through passive intuition (Aaltola, 2013). However, proponents such as Kohler, Mead, and Piaget—represented by Tichener—argue that empathy focuses on comprehending others' emotions rather than simply sharing emotional states. The third perspective posits that empathy encompasses both emotional and cognitive elements (Basto-Pereira et al., 2020; Decety and Jackson, 2006; Lieberman, 2007). For example, Feshbach and Kuchenbecker (1974) suggest that empathy comprises two cognitive components—the ability to recognize and label others' emotional states, and the ability to adopt their perspectives—and one affective component involving emotional responsiveness. Davis (2018) proposes that empathy encompasses empathic concern, perspective-taking, identification with fictional characters, and empathic distress. This study aligns with the perspective that both emotion and cognition are important. Moreover, recognising behaviour as a significant indicator of empathy (Harmsen, 2019; Peterson, 2014), and the increasing inclusion of behaviour in empathy research (Christov-Moore et al., 2014; Lewis et al., 2008; Smith, 2006), the interactive nature of VR enables the investigation of empathic behaviour. Thus, in addition to emotion and cognition, this study also explores behaviour.

2.2. VR empathy

The neural mechanism of the empathic process can be divided into several stages that succeed each other (Fan and Han, 2008); thus, it becomes evident that the empathic process is dynamic and is referred to as the temporal dynamics of the empathic neural mechanism. This study also embraces the dynamic nature of empathy, as depicted in Fig. 1. Drawing from previous research, we aim to conceptualise the users' VR empathy experience in three steps:

(1). Placing in a specific context involves creating a spatio-temporal framework in which participants immerse themselves in others' situations, thereby generating a sense of reality within an artificial environment. This facilitates environmental empathy, where players feel that the time and space they are immersed in is genuine (Herrera et al., 2018; Riva et al., 2016).

(2). Sharing affect and taking perspective involves providing information and stories about others through various entities, guiding participants to adopt the specific perspective of another (Jeannerod, 1999). This stimulates participants' cognitive and emotional systems to understand others. Participants assess the validity of their empathic connection with another, thereby leading to the emergence of reactive emotions and motivating corresponding behaviours, whether implicitly or explicitly (Yu, G. et al., 2012).

(3). Implementing interactions involves establishing interactive relationships between participants and others in the VR environment (Goubert et al., 2005; Hilborn et al., 2013). In summary, the three aspects crucial to VR empathy are experiencing a specific spatio-temporal context, which includes information and stories of others, and establishing a connection between the participant and the other through interactive experiences in VR. This proposed VR empathy

[1] "*Synaptic retrogenesis*" refers to the degenerative process observed in Alzheimer's disease where there is a reversal of synaptic development, similar to the developmental process seen in early infancy, but occurring in a degenerative context. It involves the breakdown and loss of synaptic connections in the brain, leading to cognitive decline and memory loss characteristic of the disease (Wasling et al., 2009). The term "synaptic retrogenesis" encapsulates the hallmark characteristics of Alzheimer's disease, namely synaptic dysfunction and degeneration, leading to cognitive decline and memory loss. This process forms the core experience of our virtual reality (VR) artifact, where we aim to immerse participants in the cognitive challenges faced by individuals with Alzheimer's. By using this term as our artifact's title, we aim to convey Alzheimer's underlying pathology and its impact on cognition, promoting understanding among participants.

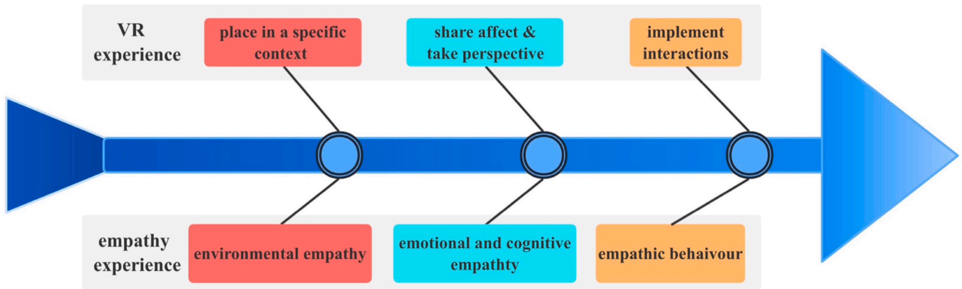

Fig. 1. The anticipated VR empathy process in three steps: (1) placing in a specific context to facilitate environmental empathy, (2) sharing affect and taking perspective to stimulate cognitive and emotional systems, and (3) implementing interactions to establish interactive relationships between participants and others in the VR environment.

process serves as inspiration for subsequent design analysis and artwork development and is validated through user feedback.

2.3. Role of VR in empathy

Based on the aforementioned VR empathy process, the role of VR in empathy training can be categorized into three key aspects.

(1). Realistic immersion. VR's immersive nature enables users to experience specific time and space from the perspective of others (Herrera et al., 2018), thereby enabling them to engage in authentic domain activities (Brown and Cairns, 2004). VR serves as a cognitive tool or mind tool, facilitating context-dependent, situated, and enculturating learning experiences by immersing learners in authentic settings, thereby promoting empathetic understanding (Kasperski and Hemi, 2022).
(2). Customized simulation. VR's 3D models can accurately represent the scale and material of physical objects, thereby meeting personalized needs (Yung and Khoo-Lattimore, 2019). Designers can guide users' visual attention by strategically distributing entities and incorporating narrative cues (Itti et al., 1998; Jeremy, 2015), thereby enabling embodied experiences that allow users to empathize by 'stepping into the shoes' of others (Shin, 2018).
(3). Real-time interactivity. VR provides a safe environment for participants to practice and explore without real-world consequences (Rovira et al., 2009), thereby allowing users to explore the world more 'recklessly' (Knowles et al., 2014). Users can interact with virtual entities and receive immediate feedback based on their actions. These interactive experiences, compared to abstract concepts, establish stronger connections with concrete experiences. Engaging in concrete experiences enables individuals to critically reflect and validate their empathetic understanding through repeated interactions, gradually constructing empathy for others (Kolb, 1984).

2.4. Empathic VR design

Various approaches to have been proposed to create "empathy machines," including intergroup contact (Tassinari et al., 2022), perspective-taking task (Ho and Ng, 2022; Herrera et al., 2018), embodiment experience (Rosenberg et al., 2013), high levels of presence (Slater and Sanchez-Vives, 2016), and meaningful interactions (Piumsomboon et al., 2017). However, these studies primarily focus on empirically investigating the natural properties of VR and their effects on empathy (Huang et al., 2024; Schutte and Stilinović, 2017; Ventura et al., 2020), rather than exploring how to design VR elements specifically to enhance empathy. Nonetheless, the VR elements proposed in these studies which have shown a positive correlation with enhancing empathy, provide inspiration for the current study.

Additionally, some researches present guidelines for creating empathy in VR experience. Riva et al. (2019) proposed a framework that emphasizes the experiential, narrative, and social aspects of VR, including simulation, augmentation, and interaction. Gaggioli (2015) presented a VR experience design framework that enhance the sense of presence by focusing on character attachment, emotional engagement, and sensory immersion, leading to a better understanding of others' perspectives and empathy. Promoting embodiment through improved immersion, presence, and interactivity has also been highlighted as a means to foster empathy and perspective-taking (Bertrand et al., 2018). However, it's worth noting that most of these studies are limited to specific issues within narrow fields (Hu and Lai, 2022), such as nursing practice (Dean et al., 2020), human-centered design (X. Hu et al., 2021; Neubauer et al., 2017), reducing racial discrimination (Banakou et al., 2016), and experiencing the lives of special groups to encourage inclusivity, such as homelessness (Herrera et al., 2018), autism (Weinel et al., 2018), the dementia disorder (Wijma et al., 2018), refugees (Durnell, 2018), and blindness (Ghali et al., 2012).

In these studies, empathy functions as a design strategy aimed at tackling specific issues rather than serving as the primary design objective. These studies belong to the realm of social science, addressing particular types of issues, rather than design-centric studies that focused solely to empathy. Therefore, while these design principles provide direction for VR projects addressing specific social issues, they might not be directly applicable to projects aimed solely at enhancing empathy.

Only a very few design studies treat empathy as the primary research goal, one of which discussed only scenic design and lacked analysis of other important VR design elements such as characters, storytelling, and interaction (Dozio et al., 2022); another study focused on children aged 6–9 years, likely due to the challenges of conducting VR research with children as subjects, including potential fatigue, eye strain, and discomfort (Benelli et al., 2023), this study only conducted a few pilot studies without systematically validating the effects, which limits the empirical evidence supporting the design theory (Muravevskaia and Gardner-McCune, 2023). To address the above research gap mentioned above, the current study aims to make empathy as the design goal and target young people, attempting to propose design guidelines for VR elements that enhance users' empathy.

In terms of methods, some studies focus solely on theoretical analyses without providing empirical evidence for efficacy (Bertrand et al., 2018; Martingano, Hererra, and Konrath, 2021), thus limiting the support for design theories. Another approach involves using already published finished VR artefacts for experimental and comparative studies, which summarize design principles (Slater and Sanchez-Vives, 2016; Tassinari et al., 2022). However, these design principles may lack practical application as they do not originate from practice-based research. Demonstrating the feasibility of guiding design practice through proposed principles requires successful self-design, which means design based on the principles proposed (Mäkelä, 2007). Additionally, only when the artefacts, self-designed based on these principles, are employed as experimental materials and validated for effectiveness the proposed design principles be deemed valid (Anzai and Simon, 1979). To address the aforementioned research gaps, this study adopts the Practice-led Research (PLR) methodology (Cross, 1982) which involves a three-step process of "proposing design principles + developing the game + examining its effects."

3. Methods

3.1. Application of PLR method in study

Design practice plays a central role in this project and requires the expertise of experienced designers and knowledge of empathy. Given the central question of PLR, which explores how design practices interact with the research field and generate new insights (Smith, 2009), PLR's concept of "designedly ways of knowing" is well suited to guide this study. Conducting PLR research within the 'empathy machine for individuals' project consists of the following steps:

(1). Proposing preliminary empathy VR design guidelines.

The 'empathy machine design' project is supported by a diverse range of specialists, including a psychology researcher from the State Laboratory of Cognitive Neuroscience and Learning, a VR designer from Tencent's Timi Studio, and a VR developer from EPIC GAMES. The team initially analysed the mechanism of empathy (see Section 2.1) and VR elements related to empathy to establish the relationship between the design goal (empathy) and design contents (VR) and then proposed the design guidelines of these VR elements (see Section 3.2).

(2). Developing an artefact based on the guidelines proposed in the first step.

In addition to the three aforementioned specialists, this project recruited and trained five students to design and develop the VR artefact. A psychologist was involved in the design process to ensure the professionalism of the artefact. With guidance from two experienced VR mentors, three students were responsible for modelling, materials, lighting, and character animation, while another two students focused on interaction development. Another 12 students were invited to join the participatory design process as pilot users.

(3). Evaluating the effectiveness of the artefact in fostering empathy.

This experiment was conducted at the Creative Media Research Centre at Beijing Normal University, which is equipped with a VR lab. We sent a notice through the Beijing University Consortium to recruit subjects and then filled in an online questionnaire as a filter—204 people filled in the form and 95 people participated in the experiment. Empathy was measured across three dimensions: emotional, cognitive, and behavioural (Section 3.3). Pre- and post-study, respondents were required to fill in a questionnaire, participate in a donation activity, and measure their emotional and cognitive responses and behavioural responses to the designed VR experience, respectively.

(4). Building the design model.

The experimental results were used to validate the effectiveness of the VR artefact and, consequently, the design guidelines (Section 4.1). Additionally, design insights were extracted from user feedback to optimise the design guidelines. Thus, a systematic design framework was developed based on the experimental results and design practice insights, as detailed in Section 5.

3.2. Design guidelines and synaptic retrogenesis

In this 'knowing through making' study, it is the practice itself and the resulting artefact that embody the knowledge that holds operational significance for the practice (Candy et al., 2006). In other words, the artwork VR experience system "*Synaptic retrogenesis*" incorporating visual, auditory, and haptic feedback through controllers, and the process of creating it include design guidelines that offer practical guidance for empathy-training VR design. Therefore, in this section, the design guidelines will be unveiled through the process of the design practice and the interpretation of the artefact. In addition, it is worthy to emphasize that this section contains the review of artefacts to better explain the design principles, which is known as "textual analysis".

The design practice and the artefact of this study are illustrated in the following manner: First, we select a topic for the design practice. We found that China had an estimated 15.07 million Alzheimer's patients over the age of 60 in 2021 (China Alzheimer's disease patient, 2023). With the aging population becoming an increasingly pressing issue each year, this has become a significant social problem that cannot be overlooked. Currently, there is no medical cure or reversal for Alzheimer's disease. Studies call for increasing empathy for Alzheimer's dementia patients (Campbell et al., 2021; Dadds, 2008; Dyer et al., 2018; Kroma and Lachman, 2018). Therefore, it is crucial to foster empathy among the general public towards this group. Hence, the team chose 'Alzheimer's' as the topic of the artefact, with the aim of enabling the general population to empathize with individuals affected by Alzheimer's through a VR experience, ultimately promoting acceptance of this special group. In order to mimic the world of Alzheimer's patients, we consulted experts, reviewed literature, interviewed their children, observed the environment of home care in China, and then processed the aesthetics in order to create the artwork. As shown in Fig. 2, the 360-degree panoramic VR space was expanded into a flat layout, with several key experience points clearly labelled. The entire experience unfolds within the living room of an elderly individual, where players traverse through 6 stages of Alzheimer's progression, as illustrated in the figure. At each stage, players assume the role of the elderly individual and engage in activities such as getting up from the sofa, viewing family photos, watching television, sitting by the fireplace, and listening to the radio. Starting from the second stage, as the condition worsens, the individual's auditory and visual processing abilities gradually decline. Consequently, television images, and radio music become increasingly unclear, prompting players to adjust the television and radio settings. However, as cognitive abilities deteriorate, completing these tasks becomes progressively challenging, eventually becoming impossible.

Following the three steps of VR empathy mentioned in Section 2.2 (specific context, affect sharing and perspective taking, and implementing interaction), the corresponding VR elements (space, entities, and interaction) were identified and analysed to derive the design guidelines for these elements, as shown in Table 1.

3.2.1. VR space—realistic restoration

Realistic restoration is the guiding design principle of VR space, with the aim of squarely reproducing the specific spatiotemporal context for users. Since the level of contextual realism influences the occurrence and intensity of empathetic responses (Fan and Han, 2008), participants should be immersed in the most realistic situation depicting the lives of individuals with Alzheimer's, thereby evoking a sense of 'stepping into the world of Alzheimer's'. The restoration of the temporal scene encompasses two aspects. First, the static aspects involve the 3D reconstruction of the virtual space, striving for a remarkably close resemblance to the real world. For example, the opening scene of the VR game 'Half Life: Alyx' (2020, developed by Valve) exemplifies this by meticulously restoring real-world buildings, ruins, and intricate dirt details. This level of fidelity enables players to swiftly visually perceive the environment, thereby fostering a profound sense of immersion within the scene. Second, the dynamic aspects pertain to the environment's adherence to the physical laws governing the real world. An illustration of this can be found in the VR animated short film 'Age of Sail' (2018, developed by Google), which narrates the story of an elderly

Fig. 2. The flat layout showcases the 360-degree panoramic experience space and depicts the progression through six stages of development. Five key experience points (without sequential order) are labelled in the layout.

Table 1
Key Idea of Preliminary Design Guidelines.

VR empathy steps	VR elements	Guidelines
specific context	Space	realistic restoration achieved through static and dynamic restoration
affect sharing and perspective taking	entities	narrative-driven arrangement by employing spatial distribution and attention guidance
implementing interaction	interaction	simulate natural human behaviour utilizing action, haptic, auditory, and eye-movement interactions

sailor rediscovering his zest for life after rescuing a young girl. The production team conducted a simulation experiment based on the principles of fluid dynamics to authentically portray the old sailor being engulfed by colossal waves and facing perilous situations. In the viewing process, the audience is provided an immersive experience that mirrors the tension and fear felt by the old sailor.

We aim to create a VR space that appears realistic to users by adhering to the design guidelines mentioned above. Considering the fact that a majority of Alzheimer's patients in China receive home care (Jia et al., 2020), this project focuses on recreating indoor living spaces as the primary setting, as depicted in Fig. 3. Every object within the scene has been meticulously modelled in 3D to maintain accurate scale, while natural lighting and colour rendering are built in to precisely reproduce a real-life living room environment. Furthermore, all objects within the room undergo dynamic changes in accordance with the laws of the physical world. For example, the fireplace incorporates a simulated fire effect that closely resembles the burning of realistic flames. Moreover, raindrops falling on the glass and cascading down are accurately simulated using physical principles. Overall, the combination of static restoration and dynamic simulation work in harmony to create a highly immersive and true-to-life virtual environment.

3.2.2. *Entities—storytelling*

The second aspect of VR empathy involves affect-sharing and perspective-taking through the information and story conveyed by the entities within the virtual environment. Therefore, it is important to carefully consider how these entities—including characters, scenes, and

Fig. 3. The space design of *synaptic retrogenesis*.

props—are arranged. One option worth considering is a narrative-driven arrangement. Narrative-driven VR projects such as ‘Clouds Over Sidra’ (2015, directed by Gabo Arora et al) (Weinel et al., 2018) and ‘Notes on Blindness’ (2019, developed by Novelab of Atlas V) (Brylla, 2017) have demonstrated that stories with strong emotional resonance can effectively engage users and cultivate empathy (Herrera et al., 2018). However, due to the immersive nature of VR technology, which breaks the ‘fourth wall’ in theatre, television, and film, where the content of the artwork remains separate from the audience (Teske and Horstman, 2012), VR instead places the audience within the work itself, observing it from a first-person perspective. This spatial distribution of content and guiding the audience’s attention in VR differ from the established conventions of art creation, thereby presenting new challenges to overcome.

Spatial distribution. The approach to spatial distribution in VR is heavily influenced by the movement of the point of view (POV). There are three main types of POV movement. First, fixed POV involves a relatively stationary VR camera, creating a spatial perception similar to traditional theatre where the audience does not need to move significantly. For example, in the interactive VR film ‘The Line’ (2020, developed by ARVORE), all the content is placed on one side of the camera, thereby allowing the audience to follow the plot by simply moving their eyes. Second, tracked POV typically positions the camera in the centre of a channel-like space, thereby requiring the audience to shift their attention between narrative elements on both sides of the space to collect all the story-related information. In the VR short film ‘Help’ (2015, developed by Google), two groups of characters—monsters and humans—are positioned at opposite ends of a train, with the camera placed in the centre. The audience can only observe one direction at any given moment, thereby intensifying the sense of urgency in the plot as they gauge the distance between the monster and the humans. Third, free-moving POV allows the camera to be placed in the centre of the space, thereby granting the audience the freedom to explore the surrounding elements. This is the most flexible approach to POV movement in VR. Typically, this approach requires equal importance and attention to be given to all the surrounding elements, thereby resulting in a richer and more immersive virtual space. For instance, the Cirque du Soleil VR video ‘Dreams of “O”’ (2017, directed by François Blouin et al.) utilizes a free-moving POV, where the audience is surrounded by four groups of characters in the centre of the space. Although the viewpoint can be freely selected in a 360-degree range, only a portion of the content is visible within the field of view, thereby requiring the audience to shift their view to observe the full content. Thus, it is evident that different storytelling requirements dictate the choice of POV, which subsequently affects the spatial distribution of content. The use of cues or attention guidance also plays a crucial role in directing users to follow the narrative thread.

Attention guidance. There are five primary methods of directing attention in a VR panoramic space. First, the contrast of light and colour is utilised to emphasise the key content. For example, in the VR experience ‘Back to the Moon’ (2018, Google), as depicted in Fig. 4a, multiple characters simultaneously exist in the scene. To quickly draw the audience’s attention to the protagonist and their location, a spotlight effect is employed, creating a contrast with the surrounding shadowy light. Second, motion guidance capitalises on the human sensitivity towards moving objects. In the VR short film ‘Shennong: Taste of Illusion’ (2018, Pinta Studios) (the inventor of agriculture and medicine in Eastern legends), as depicted in Fig. 4b, the audience’s gaze follows Shennong’s back-and-forth movements, thereby guiding their focus towards the story of Shennong tasting various herbs. Third, the line of sight of the character directs the audience’s attention, thereby indicating the next location of the story or displaying the interrelationship between the characters. In the example of ‘Help’, as shown in the bottom right of Fig. 4a, the characters nervously gaze towards the other side of the train, directing the audience’s attention to the opposing viewpoint of the characters, which is behind the audience, where the monster is about to appear. Fourth, restricting the field of view enables the defocusing of unimportant scene content or obscuring certain information and guiding the viewers’ sight accordingly. In the VR live-action film ‘My Brother’s Keeper’ (2017, Perception[2]), as depicted in Fig. 4a, white fog is employed to limit the view. Lastly, sound guidance utilizes audio cues to aid visual orientation, leveraging panoramic sound technology for guiding sight in the VR space. Once again, in the case of ‘Help’, as depicted in Fig. 4a, the sound of a train window suddenly breaking redirects the viewer’s line of sight towards the opposite direction of the human characters, thereby setting the stage for the appearance of the monster. In conclusion, similar to the classical audiovisual language serving the story narrative, the visual elements in the VR space also follows the guideline of serving the storytelling.

Applying the aforementioned guidelines to the creation of *synaptic retrogenesis*, the following approaches were employed: First, the storytelling demand was defined. Participants experience the gradual deterioration of everything that constituted their sense of self—including memory, behaviour, and cognition—through the perspective of the protagonist. The journey unfolds in six stages, depicting the struggle to retain their consciousness but ultimately being left with only fragmented pieces or even ‘snow noise’. Second, the spatial distribution was based on the story demands. Considering that the appearance of entities such as photos, TVs, phonographs, bookshelves, etc., does not significantly impact storytelling, a free-moving POV was selected to provide players maximum freedom to explore and create a sense of living in their own home. However, this approach has the potential downside of players becoming too engrossed in exploration and detaching from the main story. To counter this, multiple sight guides were implemented, as illustrated in Fig. 5. The image and sound of the TV, the flickering flame of the firewood, and the sound of splintering were strategically utilised to direct the player’s attention towards important empathic elements from the outset. Changes in sound and movement allowed players to make judgments regarding the protagonist’s illness status. Furthermore, as the level progresses, the photos of family members displayed on the wall gradually becoming indistinguishable, thereby simulating the patient’s diminishing vision and cognition.

3.2.3. Interaction—natural simulation

The third aspect of VR empathy involves interaction behaviour. When it comes to interaction logic, VR differs from personal computers. The interaction logic of PCs relies on moving and clicking the mouse and typing on the keyboard to input commands, which is a learned behaviour rather than an innate ability. However, one of the greatest advantages of VR technology is that it reverses this logic by adapting computers to human behaviour. Utilizing this advantage, interactions can be designed for users based on how human senses naturally work. Therefore, the fundamental principle of VR interaction design is natural simulation. This implies that the users operate within a virtual environment that closely resembles the real world and the VR system provides real-time feedback, mimicking how the objective world responds to human behaviour. A few common methods of VR interaction include action interaction, haptic interaction, auditory interaction, and eye-movement interaction, which are analysed below.

Action interaction. Owing to the rapid development of VR technology, 6DOF VR devices ensure the complexity, real-time responsiveness, and accuracy of users’ actions, greatly enhancing the integration of real-world actions and the virtual environment. For example, in ‘The Line’, the first VR experience with fully integrated hand-tracking function, participants can directly use their hands to operate buttons and springs on the miniature stage, as depicted in the top half of Fig. 6a. Without the need for a controller, users’ hand movements in the real world perfectly mirror their actions in a virtual environment. This immersive interaction allows users to believe they are the ones controlling a miniature stage. Body movements are also cleverly incorporated into the experience.

Haptic interaction. Vibrational feedback is a well-established form of haptic interaction, typically achieved through VR controllers. In the classic VR game ‘Vader Immortal Episode II’ (2019, ILMxLAB), as

Fig. 4a. 'Back to the Moon' footage screenshots.

Fig. 4b. 'Lie Shan Shi' footage screenshots.

Fig. 5. Attention guidance in *synaptic retrogenesis*.

depicted in Fig. 6b, c, the gameplay involves using the 'Force' to manipulate objects through space. To enhance the player's experience of using the 'Force', the game incorporates simulated sensation of objects floating and provides rumbles and vibrates feedback when the player picks up objects.

Auditory interaction. The sound field in VR provides true spatial,

Fig. 6a. 'The Line' screenshots.

Fig. 6b. The 'Force' gameplay screenshot of the game 'Vader Immortal Episode II'.

stereo-localized sound that closely resembles the original sound environment. It dynamically changes according to the audience's head movements, thereby creating an immersive audio experience (Bala et al., 2019).

Eye-movement interaction. Eye movement-based interaction is facilitated through eye tracking technology, which records real-time information regarding the audience's eye movements (Tanriverdi and Jacob, 2000). This enables contactless interaction development. For example, in the animation 'Piggy' (2018, Google), the film incorporates eye tracking, thereby triggering different animation effects based on where the audience is looking. Additionally, regardless of where the audience moves within the space, the character Piggy always maintains eye contact with the viewer, thereby creating a constant sense of connection and fostering a more intimate relationship.

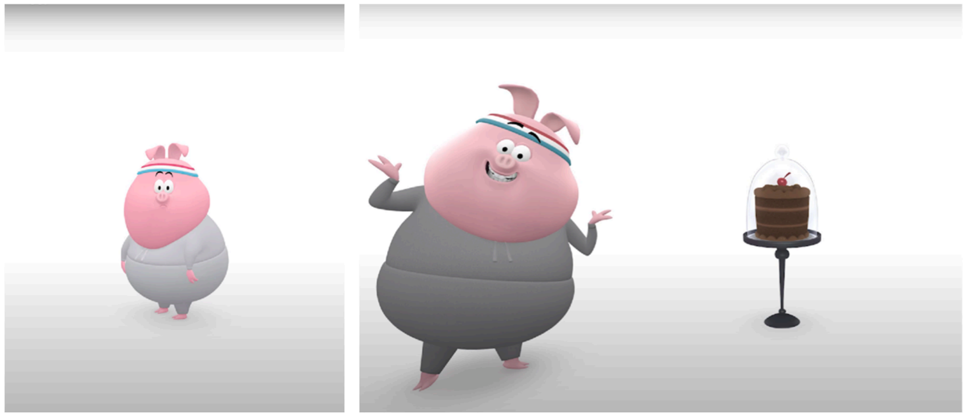

Fig. 6c. 'Piggy' footage screenshots.

Based on the principle of natural simulation, we selected sensory interaction methods that closely resemble real-life experience. Once the audience has perceived the virtual environment through audiovisual cues, they are encouraged to verify the reality of the environment through their actions. *Synaptic retrogenesis* runs on the HTC VIVE Cosmos headset device, thereby ensuring 6DOF movement.[2] Most objects within the scene can be interacted with by participants. As the level progress, the patient's condition worsens and the precision of object interaction decreases. This deliberate setting aims to enhance the realism of the patients' living conditions, thereby evoking stronger empathy in participants and a desire to provide more assistance. Spatial audio is employed to recreate the sound field, thereby aiding the audience in better perceiving the spatial layout of the environment. Furthermore, eye tracking technology is utilised to monitor the user's eye movements in real time. When the player gazes at the fireplace for an extended period, the firelight gradually intensifies, thereby creating the warm and immersive experience of being surrounded by the gentle glow of the firelight.

3.3. *Effectiveness evaluation*

In order to evaluate the effectiveness of *synaptic retrogenesis* in enhancing empathy among participants, an experiment was conducted from March 2023 to April 2023. We formulated the following hypothesis to guide our investigation:

H: There is a significant increment in terms of users' emotional empathy, cognitive empathy, and empathic behaviour after VR.

Fig. 7 provides an overview of the entire experimental study, consisting of three parts: (1) Hypothesis, which posits the VR experience can enhance participants' emotional empathy, cognitive empathy, and empathic behavior; (2) Measures, including four aspects of the IRI scale, interview data, log data, and simulated donation, detailed in Section 3.3.3; and (3) Procedure, comprising 8 steps, outlined in Section 3.3.2. It's worth noting that the connections between these three parts are represented by colors. For instance, the relationship between hypothesis and measures is depicted by color; the emotional empathy hypothesis is represented in blue, and the measures involving the IRI scale, interview, and log data are indicated by blue bars underneath. Similarly, the connection between measures and procedure is shown by color; the IRI scale in measures is depicted in magenta, and its corresponding step in the procedure is marked with magenta as well. This visual representation helps readers grasp the relationships between different parts more intuitively, allowing for a comprehensive understanding of the empirical study as a whole, serving as a navigational aid.

3.3.1. *Experiment contexts and participants*

The experiment took place at Beijing Normal University and involved students from four universities: Beijing University of Posts and Telecommunications (a technical university), Capital Normal University (a humanities university), Beijing Normal University (a comprehensive university), and Communication University of China (an arts university). While 95 students initially participated in the experiment, 3 were unable to complete the entire experiment, and 8 participants had close relatives with Alzheimer's disease, which did not meet the requirements for homogeneity testing. Consequently, valid data was obtained from 84 participants, including 45 male and 39 female students, with an average age of 22.6 years, ranging from 18 to 35 years, as presented in Table 2.

The study protocol was approved by the Institutional Review Board (IRB) at Beijing Normal University. All participants provided written informed consent prior to their participation in the study. The consent form outlined the purpose of the study, the procedures involved, potential risks and benefits, confidentiality measures, and the participants' rights. Additionally, participants were provided with information sheets detailing the study's objectives and procedures, allowing them to make informed decisions about their involvement.

3.3.2. *Experiment design*

The paired sample *t*-test was employed to examine the changes in emotional empathy, cognitive empathy, and empathic behaviour among participants before and after the VR experience. The formal experiment spanned eight days and involved eight steps:

(1). Simulation task of donation: Participants engaged in a task that simulated the act of donation.
(2). Pre-interview: Prior to the VR experience, we conducted interviews to gauge the participants' empathy towards the Alzheimer's group. We also administered a homogeneity test to exclude heavy VR users or individuals with family members affected by Alzheimer's disease.
(3). The Interpersonal Reactivity Index (IRI) scale: Participants completed the IRI scale, which measures empathy.
(4). Training: Since the majority (78.8%) of the subjects had no prior VR experience, we provided instructions on how to wear and interact with VR devices, along with information regarding possible physiological discomfort;

[2] The running file and demo video of *synaptic retrogenesis* can be accessed through the following link: https://pan.baidu.com/s/1dTrODKLmAshG2OQN5ydNng?pwd=0gcs. To download the files, you will need to enter the extraction code: 0gcs. The work is compatible with the Win10 operating system and requires a VR headset, specifically the HTC VIVE Cosmos. This is a beta version; the final version is currently unavailable due to confidentiality requirements.

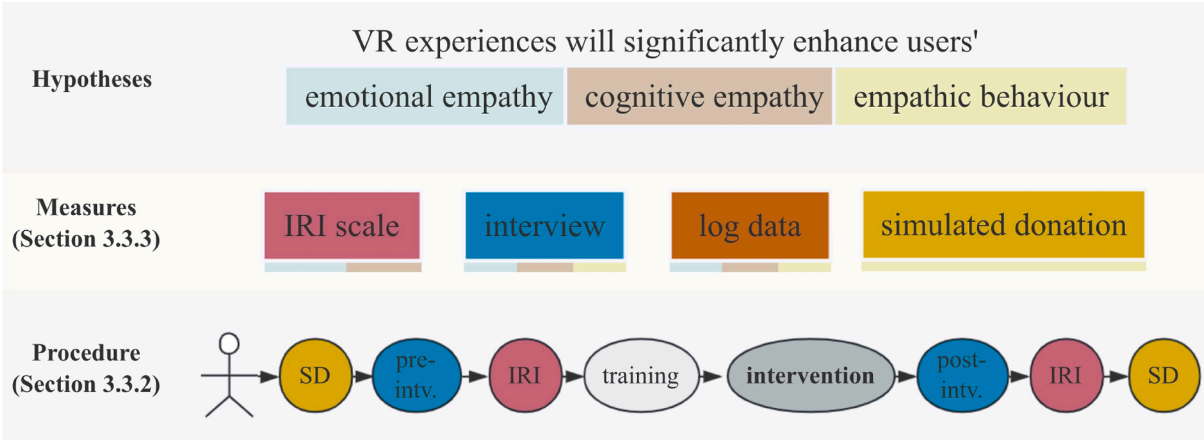

Fig. 7. Overview of the experimental study.

Table 2
Participants.

Age	N	Fictional names
Freshman	11	Ajiu, Hanru, Meng, Xiaobo, Mingjin, Chenmi, Jiaojiao, Yujie, Aolei, Jiayu, Siyu
Sophomore	14	Xianping, Qinbo, Zuqiang, Dianna, Yanhan, Wenqian, Zhurui, Lilu, Caicheng, Dongna, Juanjuan, Dongzhu, Shule, Shumin
Junior	18	Wenju, Chenxi, Yishui, Chenyin, Yinghe, Yumeng, Yujie, Yuyan, Zifeng, Wujing, Baolin, Yunshu, Xuanxin, Haonan, Yulin, Chenyu, Xinrui, Keyue
Senior	9	Mingzhi, Yunpeng, Zicun, Yuyang, Dafu, Zijian, Suqiao, Guangzhen, Xiaoyu
Graduate student	19	Yifu, Yun, Zhiman, Liuyan, Yikai, Zhiyun, Ruizhe, Lulu, Lizheng, Baoli, Danping, Xuehui, Mingxin, Tianlin, Shu, Qiang, Yaoye, Ziqi, DongYan
PhD Candidate	13	Chenhu, Dongmei, YangGang, Fukai, Leng, Yangrui, Mingsheng, Qianyun, Yiqiao, Sibo, LingLing, Lunchen, Ningbin

(5). Intervention: Participants underwent the VR experience of *synaptic retrogenesis*. First, the experimenter provided an overview of the Alzheimer's disease patient group and the symptom changes at each stage. During the experience, participants were allowed to explore freely within a safe area, with no timers set for each stage. Experimenters monitored participants' exploration to ensure they fully experienced each of the five key experience points (as shown in Fig. 2) before transitioning to the next stage.
(6). Post-interview: Following the VR experience, we conducted interviews to collect participants' feedback and reflections.
(7). IRI scale: Participants once again completed the IRI scale to assess any changes in their empathy levels.
(8). Simulated donation: The final step of the experiment involved another simulated donation task.

3.3.3. *Measures*

We collected and analysed multiple data, including the IRI scale and interview to assess emotional and cognitive empathy. For empathic behaviour, we used a simulated donation. as it is a form of prosocial behaviour (Taute and McQuitty, 2004). Additionally, log data was collected as auxiliary information to illustrate specific aspects of the participants' experience. The correspondence between the measures and their respective contents is provided in Table 3.

Table 3
Assessment Content and Measures.

Assessment content	Measures
Emotional empathy	IRI scale, interview, log data
Cognitive empathy	IRI scale, interview, log data
Empathic behaviour	interview, simulated donation, log data

IRI scale. The IRI scale is a widely used empathy scale (Fultz and Bernieri, 2022). It consists of 28 questions and is divided into 4 components: empathic concern, personal distress, perspective-taking, and fantasy (Davis, M. H., 1983). The perspective-taking items were used to measure cognitive empathy, while empathic concern and personal distress assessed emotional empathy. Each item was rated on a 5-point Likert scale, ranging from 0 = "Strongly disagree" to 4 = "Strongly agree".

Interview. Since the scale alone cannot provide insights into the causes of empathy change, a semi-structured interview was conducted before and after the intervention. The interview[3] focused on two main aspects: capturing participants' detailed experiences in cognitive, emotional, and behavioural aspects, thereby aiming to explore the underlying causes of empathic change; second, collecting participants' evaluations of the artefact, particularly related to the design guidelines, to further enhance the user-centred design. All interviews were digitally recorded, transcribed, and manually proofread. The transcripts were shared with participants for verification. In the qualitative analysis process, five researchers were involved. Initially, two research assistants transcribed the audio interviews into text format. Subsequently, the remaining three researchers each reviewed one-third of the interview transcripts, conducted initial discussions, and outlined the main themes. Following this, one researcher read through the entire set of transcripts, organized the data, and performed the coding. The coding process involved two rounds using NVivo (version 11) followed the 'Gioia method' (Gioia et al., 2013). In the first round, words and phrases in the transcript were coded; in the second round, the codes were assigned to themes and dimensions (Sotiriadou et al., 2014).

Simulated donation. Before and after the intervention, a simulated donation task was implemented along the path that the subjects passed through, as depicted in Fig. 8 a. To minimize ethical influences on the subjects' donation behaviour, the donation location was secluded, away from the crowd, and unstaffed. Throughout the process, the subject's behaviour was covertly recorded by a camera positioned for surveillance. The donation counter provided information on Alzheimer's, featuring a poster and a donation web app QR code with a sharing function. When the subject clicked the donation button, as depicted in Fig. 8 b, a pop-up window stated 'This is a simulation. Thank you for your participation. Please share this poster to raise Alzheimer's

[3] Find the interview guide in Appendices.

Fig. 8. The donation counter. a) The unstaffed donation counter recorded by a secluded camera. b) The poster with the donation QR code and the pop-up window.

awareness among more people'. In this setup, the subjects had the opportunity to engage in four specific behaviours: viewing the poster, flipping through the materials, swiping the QR code to donate, and sharing the poster with their friends. Inspired by the researcher's graded evaluation of performance (Dagiene and Stupurienė, 2016), we designed a 5-point scale to quantitatively assess empathic behaviours:

0. points: Ignoring the poster
1. point: Noticing the poster
2. points: Reading the materials
3. points: Scanning the QR code to donate
4. points: Sharing the web app on social networking sites (SNS)

System log. In additional to the aforementioned measures, we utilized the VR system log to capture process data for each user through the system backend. The system log recorded various types of information, including the duration of each user's experience, the points of interaction at each stage, and a complete screen recording of the entire experience process. It is important to note that log data served as supplementary information and was used as auxiliary data when necessary, thereby complementing the other three types of data mentioned earlier.

4. Findings

This section is divided into two parts. First, we present the results of the *t*-test data analysis from three perspectives: emotional, cognitive, and behavioural. These results validate the previously proposed hypothesis. Second, we delve deeper into the experimental data to extract design insights that may deviate from the initial design guidelines. This exploration aims to identify areas for further optimisation and iteration of the design guidelines, thereby enhancing their effectiveness and relevance.

4.1. Results

4.1.1. Emotional and cognitive empathy

To assess the changes in empathy between the pre-test and post-test, we conducted a paired *t*-test on the average scores of emotional empathy and cognitive empathy. The results, presented in Table 4, indicate significant improvements in both dimensions, with emotional empathy showing a stronger effect size, as reflected by a larger Cohen's d value and the differences in post-test and pre-test scores.

Table 4
Paired sample *t*-test results of emotional and cognitive empathy. The maximum score of both is 35.

	Pre, in M (SD)	Post, in M (SD)	Post-Pre, in M (SD)	T	Cohen's d	Sig.
Emotional	19.75 (3.774)	22.289 (3.871)	2.539 (3.1)	7.41**	0.819	<0.001
Cognitive	23.579 (3.977)	25.763 (5.251)	2.105 (4.188)	4.55**	0.503	0.003

Emotional empathy. The findings from interviews reveal consistent improvements in the participants' emotional and cognitive empathy. Through axial coding, various perspectives emerged in the emotional, cognitive, and behavioural dimensions. Table 5 presents the frequency of codes, thereby indicating a significant increase in empathy across all three dimensions after experiencing the VR environment. Furthermore, a notable increase in the number of references related to emotional empathy suggests that the subjects may have formed profound emotional connections with the empathic entities in some manner. Fig. 9.

The interview on emotional empathy focused on two aspects: affect sharing (Shdo et al., 2018) from the participants' own perspective and from the perspective of the Alzheimer's patient. The findings indicate significant enhancements in both aspects. Participants revealed an improved ability to sense affect signals from others after the VR experience. For expamle, Lilu expressed in the pre-interview:

> *I think they must be anxious and then nervous and overwhelmed.*

But expressed in the post:

> *I tried to bring myself into the experience just now, and I just thought if it was me who was slowly feeling these changes, I would feel especially miserable. I especially need companionship, just can't put me here alone I feel so alone, so desperate, so helpless, and so helpless. I think especially for me this is an unimaginable, especially horrible, especially suffocating and desperate thing, such a colorless world will make people lose the courage to continue to live. (interview with Lilu at Beijing, March 12, 2023)*

It is clear that compared to the few words in the pre-test, the post-test is more descriptive of the participant's feelings. Moreover, participants were able to quickly empathise with the emotional experiences of others, i.e., "step into the shoes of the Alzheimer's elder", in the case of

Table 5
Frequency of nodes captured in NVivo.

Node	Frequency of pre-interview		Frequency of post-interview	
	Interviewees	Mentions	Interviewees	Mentions
Emotional empathy	73	114	84	415
Self-angle Affect Subjective	61	71	12	15
Objective	6	8	82	192
Other-angle Affect	15	19	76	224
Cognitive empathy	84	533	84	663
Perceptual understanding	84	342	84	458
Conceptual understanding	84	195	83	208
Empathic behaviour	72	122	76	152
Low effort	59	85	61	49
High effort	34	45	69	98

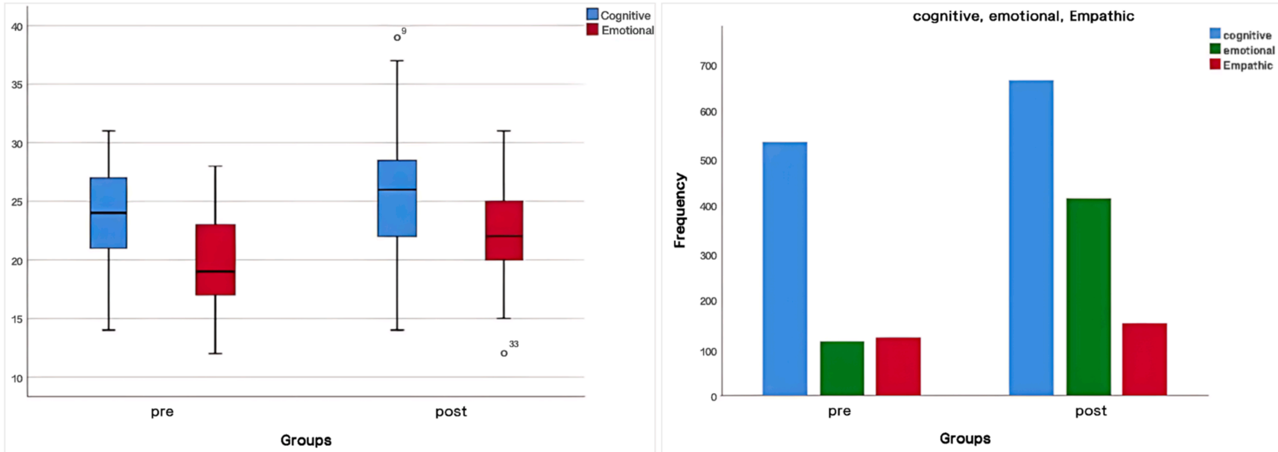

Fig. 9. The boxplots of Table 4 and the bar chart of Table 5.

Haonan, he expressed in the pre-interview:

> *They will repeat the events of long ago, the recent events or people do not remember, so they may be more lonely, probably so, in fact, I cannot say too much.*

But expressed in the post:

> *I will bring into the situation, I think first of all to recognize their state to express a sense of empathy that they are really not easy, and then I can appreciate their inner thoughts, that is, when your world from familiar to strange, and then from colorful to nothing. Such a state of mind, like they have no way to control, has been living in such a state of words, is very afraid of discouragement to the end. I can appreciate that they are really helpless in such a life in reality. As the elderly themselves, they are really in the midst of such a very sad change in the world, I think they are in a very difficult torment. (interview with Haonan at Beijing, March 9, 2023)*

In the post-test, respondents in general indicated that they felt the inner dilemma of the Alzheimer's patient through contextualization as opposed to the more hesitant guess in the pre-test.

In addition, the interviews also revealed a shift in expression from subjective to objective descriptions of affects. The post-interviews contained more objective and detailed accounts (Mentions = 192) than the pre-interviews (Mentions = 8), thereby suggesting that VR provided participants with authentic sensory affect experiences.

Cognitive empathy. The interview on cognitive empathy mainly revealed two dimensions of perspective-taking (Marvin et al., 1976). First, participants demonstrated perceptual perspective-taking by understanding the lived experience of Alzheimer's patients and describing their specific symptoms based on visual, auditory, and haptic information from the VR artefact. Visual descriptions were particularly prominent, thereby indicating an increased awareness of visual degradation caused by Alzheimer's. Participants also gained insight into the decline in sound resolution. For example, Yumeng expressed:

> *I just look at that image, slowly from color into a blur and then into black and white, and finally almost no more. I really did not know that Alzheimer's disease is so serious for color, including visual degradation, in fact, it is still rather shocking...... they cannot live as before, including the resolution of sound, I heard the sound seems to be relatively clear from the beginning, from the TV, the back has been difficult to distinguish the sound of these specific content. (interview with Yumeng at Beijing, March 23, 2023)*

Clearly, this participant was concerned with the patient's visual deterioration from colour to blurry to black and white.

Second, participants engaged in conceptual perspective-taking by comprehending the psychological experience of Alzheimer's, including thoughts and attitudes. One of the participants even criticised the romanticized portrayal of the disease in literature and art, expressing a deeper understanding of the challenges faced by Alzheimer's patients. They empathized with the feelings of worthlessness and the societal misunderstandings associated with the disease. For example:

> *I had read an article on Alzheimer's film research, and some literature and art works including it romanticize it, for example, when people get old, they only remember my old partner so romantically, and I wanted to criticize this artistic expression. The real situation I would feel better to just die. Especially as the elderly, they will often feel that they have little value, have this disease will also be a lot of people misunderstanding, blame, even their closest people will be involuntarily because of the long-term consumption of antipathy, I think it is really worth sympathy... (interview with Yifu at Beijing, March 12, 2023)*

Moreover, participants also recognized the need for acceptance and understanding, acknowledging that individuals with Alzheimer's cannot be expected to conform to societal norms. For example:

> *I might understand better why they act in a way that seems strange to others, and then I might understand better why they act in a way that is different from the way we see the world, and we can't ask them to overcome their condition and behave like a normal person. (Interview with Ziqi at Beijing, March 10, 2023)*

This participant expressed the importance of understanding and tolerance for people with Alzheimer's disease and indicated that this understanding helps to reduce expectations and pressures on patients in order to better support them in living with their disease.

4.1.2. Empathic behaviour

Through a paired sample analysis, a comparison of subjects' behaviour performance before and after the VR experience revealed a significant increase in empathic behaviour. The mean score after the VR experience (M = 2.75, SD = 2.649) was significantly higher than the score before the VR experience (M = 1.15, SD = 1.401), with significance close to 0 (95% confidence interval). This finding rejects the hypothesis that there was no difference between pre- and post-observations, thereby indicating that the empathic behaviour performance improved after the VR experience.

The interviews on empathic behaviours revealed an overall increase in motivation for empathic behaviours, which were further divided into low-effort and high-effort behaviours. Interestingly, low-effort behaviours—such as understanding, tolerance, and concern for family and friends decreased (from 85 in the pre-interview to 61 in the post-interview)—while high-effort behaviours such as learning about Alzheimer's, establishing a public service organization, and participating in volunteer activities increased (from 45 in the pre-interview to 98 in the post-interview). For instance, Zhiman expressed a shift in perspective from simply helping a lost elderly person (pre-interview) to developing a deeper understanding of the disease and considering participation in public welfare activities (post-interview). This suggests that the VR experience influenced participants' motivation for prosocial behaviour, shifting from a negative to a positive outlook.

The experimental results presented above clearly reveal that the intervention enhances participants' empathy across the three dimensions and further provide evidence supporting the validity of the initial design guidelines proposed in Section 3.2.

In addition, we conducted a test for equality of means to ascertain if there were any pre-existing differences across groups, which could influence our subsequent analysis. Subsequently, due to the unequal variances identified, we opted for the Tamhane post hoc test to compare the means between groups following an ANOVA. Our findings indicated a significant correlation between the emotional score of the Interpersonal Reactivity Index (IRI) and donation behavior, $F\ (1156) = 7.84$, $p < 0.05$), suggesting that individuals with higher emotional empathy were more inclined to donate. In contrast, we did not observe a significant correlation between the cognitive score of the IRI and donation behavior, $F\ (1156) = 2.38$, $P=0.125$.

4.2. Design insights

4.2.1. Dynamic process of VR empathy

Utilising the grounded theory method, we explored the interconnections among the nodes mentioned earlier; this is depicted in Fig. 10. This flowchart partially aligns with the VR empathy steps outlined in Fig. 1. While lacking neural data support, it effectively captures the VR empathy process, as it is substantiated by first-hand interview data from 84 participants immediately after their VR empathy experience. Based on this process, we construct a design framework.

We delineated four phases of VR empathy:

(1) Presence and environmental empathy. We found that almost all participants (73 people) expressed that VR provided them with a realistic scenario that enabled them to face or imagine the Alzheimer's condition. The immersive environment enhanced their sense of presence and environmental empathy (Han et al., 2022). For example, participants mentioned:

I feel that at the beginning it is a very cozy environment, the living room has a fireplace, there is some music, and then there are some books and so on, I feel that I am in a very warm and elegant environment… (interview with Ziqi at Beijing, March 12, 2023) In retrospect, I feel like I'm in a room, but it seems to be an enclosed space, and then… (interview with Ziqi at Beijing, March 12, 2023)

(2) Affect sharing and personal distress. Once users have immersed themselves in the virtual world, they tend to shift their focus towards the entities within the environment, such as characters, props, and scenes. They also become more engaged with the story and gather information about the protagonist, including individuals like Zhiman, Danping, Shu, and others (a total of 69 people). This immersive experience allows them to truly "step into the shoes of the protagonist" and fully embody the character, triggering a cognitive and emotional response that leads to the sharing of the protagonist's emotions (Goldman, 1993; Nichols et al., 1996). They felt personal distress, experiencing tension, discomfort, and negative emotions, as mentioned by Haonan and Yumeng in the section of 4.1.1, they felt "miserable", "so alone, so desperate, so helpless", "horrible", "suffocating and desperate",

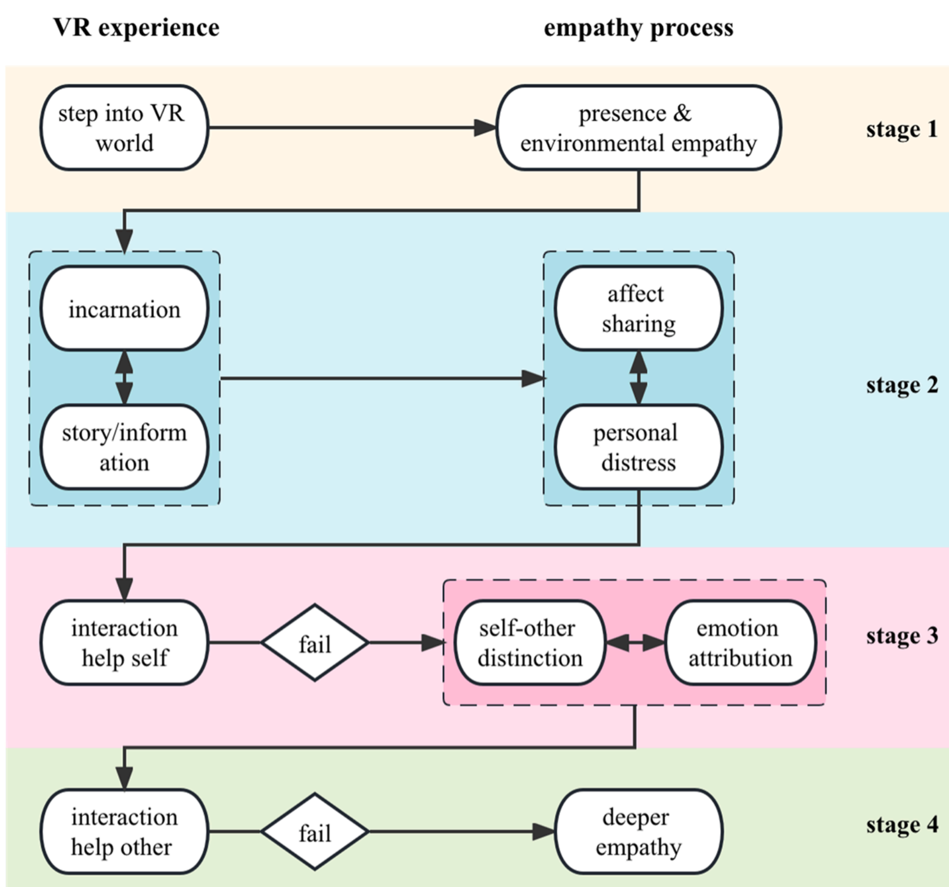

Fig. 10. The dynamic process of VR empathy.

"very afraid of discouragement" and so on. These emotional responses reflect the development of personal distress in participants, which motivates them to respond by trying to help and comfort the protagonist. In other words, the personal distress experienced by participants serves as a driving force that compels them to take action and provide assistance.

(3) Self-other distinction and emotion attribution. During interviews, many participants reported taking action in the third stage of the experience, such as attempting to improve the protagonist's condition through various means, such as wiping the lens (52 people), adjusting the television (57 people) and the phonograph (43 people), and so on. However, their endeavours were thwarted by the pre-determined interaction rules that enforced the worsening of the protagonist's state. At this juncture, participants recognized a distinction between themselves and the character, attributing their own fear and helplessness to the character—for example, the respondents' choice of words changed from 'I, we' to 's/he, they.' In one case, she said in the second stage:

If I ever get to this day, I might as well die.

Then, in the third stage, she said:

When I saw such a change in him, I felt very distressed and would want to help him… (interview with Yujie at Beijing, March 22, 2023)

In this manner, individuals achieve the self-other distinction (Decety and Lamm, 2006) and emotion attribution (Schulte-Rüther et al., 2008). This shift in perspective, moving from a focus on oneself to considering others, plays a pivotal role in development of empathy (Decety and Jackson, 2006). Empathy research emphasizes the importance of individuals being able to differentiate between their own experiences and those of others by effectively managing their emotions and cognition (Zahn-Waxler et al., 1992). From the perspective of fostering a harmonious society, the optimal response to the distress of others is not merely to share their distress, but to actively assist them in finding solutions and alleviating their suffering. This corresponds to the fourth stage of empathy development.

(4). Prosocial behaviour and deeper empathy. Once participants were able to distinguish between themselves and others, their focus shifted from self-help to helping others (51 people), thereby demonstrating prosocial behaviour (Carlo et al., 1992; Eisenberg et al., 2006). However, their attempts to assist others were unsuccessful due to the predetermined interaction rules. This led participants to develop a stronger sense of powerlessness, realizing that Alzheimer's symptoms were irreversible. Consequently, they felt a deeper empathy for the Alzheimer's group and had an active desire to do whatever they could to support them. As discussed in Section 4.1, participants transitioned from low-effort to high-effort behavioural motivation. This finding aligns with a previous study that indicates that when individuals perceive pain resulting from ineffective treatment, they view it as meaningless and more difficult to endure, whereas pain accompanied by effective treatment is considered valuable and should be tolerated (Lamm et al., 2007).

For the aforementioned four stages, although a few respondents only mentioned two to three stages, 45.2% (n = 38) still expressed all four stages completely. For example, Yifu expressed:

[stage 1] The whole experience began with sitting on the living room sofa ...... [stage 2] the state deteriorated, the face of loved ones began to become blurred, as well as the color of objects, sound and other aspects of the deterioration of such a state ...... I felt a very strong discomfort ...... [stage 3] beyond their own knowledge of the disease, and feel very uncomfortable ...... is a feeling that your life is not over, but your good life is over ... ...he is very desperate, on time he can not do anything ...... [stage 4] may be more concerned about this group, and more for them feel heartbroken and pitiful ...... to participate in this kind of similar volunteer activities, I may want to help them, and then to accompany them, and then may also be timely to pay attention to their own elders around such

The respondent's description of the phased experience is summarized as follows: (1) feeling the overall environment atmosphere, (2) gradually perceiving the deterioration of the Alzheimer's patient's state and the development of feelings of discomfort from the perspective of the incarnation, (3) a strong sense of despair and helplessness that caused the participant to peel away from the role, and (4) generating the behavioural will to further help the group and suggesting some high-effort behaviour options to help.

And Keyue recalled:

[stage 1] The very beginning is in the patient's home, there is a still relatively warm, decorated okay home, the most impressive is the family photos ...... [stage 2] in fact, the very beginning on the ordinary people, the life may be a little expectation, and then I think to the second session, things become blurred, is a little powerless, but for people like me near-sighted It may be acceptable, because I at least know what is in front of me. At the third stage, I felt that if I had not reached a certain level of emotional processing ability, I would have been unable to accept it at the third stage, because I felt that it was overturning my worldview, that it was different from my previous perception of the world, that it was very stressful, that I would be uncomfortable, and that there was inevitable pessimism, that my world had fallen into this state. And then it becomes black and white, and in the fourth and fifth stage, I feel that everything around me is squeezing, and I am very anxious, and then I am very disappointed, and the people I relied on before, my children, my friends, or if my parents, the people I can rely on are gone, and I can't see, and I can't hear, and I am very negative, and then I feel that life is just like this. I may not even very much want to live in this world, although it sounds well and good negative ...... [stage 3] I think is that I can understand their logic better, that is why it would be is that kind of loved ones in front of comfort themselves, and then the patient still ask who you are, what you are doing, I know why he would say such things, as well as that very just There is mentioned that the ability to take care of themselves is reduced, so it leads to the chaos of their family environment ...... [stage 4]I think our popularization of Alzheimer should be down to the details, and I hope that we can understand the process of the onset of the disease as you just let me mention, so from then on we have a deeper understanding of this group. Then I think the main purpose is to inform their families when they find themselves with similar symptoms, so that they can be psychologically prepared for prevention. Then I think what I can do at this time is to slowly and patiently explain to him what will happen in the future, but we will always be by your side, and don't be afraid in that environment, we are still supporting you and accompanying you, we will always love you. Just like this, down to the details, just now (before the VR experience) is only a macro, but now after the experience will know how to do it in detail. In addition, I would not have paid attention to this kind of public welfare event, but because I have just experienced it, I understand more practically that they need help, so I will be more inclined to join some volunteer groups.

This respondent also described the experience in four phases: (1) described the environment in its entirety and in detail, (2) described personal feelings in relation to the phases of the illness, (3) shifted from a role identity to a bystander's perspective to understand the problems that the patient faced, and (4) suggested specific plans for help such as science, public service, and volunteering activities.

With regard to the outcome, we discovered two reasons why VR can be considered the 'empathy machine'. First, the concept of incarnation/agent distinguishes empathy for Alzheimer's from empathy for a simple injury like cutting a finger. Since no normal person has experienced Alzheimer's before, it is impossible to understand their feelings through extracting memories. Viewing actual Alzheimer's patients or related images offers a third-person perspective without providing an avatar or agency, unlike VR. VR allows participants to embody an Alzheimer's patient and experience their pain from a first-person perspective, thereby facilitating somatic empathy. Second, withdrawal from the agent promotes self–other discrimination and a shift from affective/emotional responses to cognitive/rational ones. It also encourages a transition from self-help to helping others, thereby fostering prosocial behaviour motivation (Bertrand et al., 2018). These findings have significant implications for empathic VR design. Designers need to explore methods for achieving positive embodiment/incarnation or 'active agent' (Shin, 2018b) (i.e., 'not the mere sense of ownership of another body and passive perspective-taking of another individual' (Barbot and Kaufman, 2020)) through storytelling design (as mentioned in Section 3.2.2) and agent withdrawal through interaction design (as discussed in Section 3.2.3). The design guidelines for these elements is further optimised by incorporating user feedback, as discussed later in Sections 4.2.2 and 4.2.3.

4.2.2. Storytelling-related design findings

In addition to the discussion on spatial distribution and attention guidance to support storytelling in Section 3.2 section, other design guidelines are further refined based on user feedback and analysis of experimental data.

First, it is important to create a main character in the story that resonates with the target group. Considering the lack of social institutional support for Alzheimer's in China and the fact that Alzheimer's patients are usually cared for at home, the protagonist of *synaptic retrogenesis* was portrayed as an elderly person living at home. Numerous participants described the character as 'reminding me of the elderly who live at home' or 'the elderly who sit in wheelchairs downstairs in our community during the day and sunbathe'. This approach is more likely to trigger ingroup empathy, as previous research suggests that humans tend to identify with and support members of their own group (Cikara et al., 2014). This opinion was also supported by a counterexample from Tianlin, a student from a poverty-stricken area in the western region. Tianlin mentioned, "Although the old man in VR is sick, he is happier than all the elderly people in my hometown village. He has a clean houses and music. I envy him and I feel he is quite happy. There is no need to sympathy". The case involving Tianlin also highlights the importance of ingroup dynamics in empathy.

The second finding pertains to the arrangement of help-seeking episodes in the story. We analysed the duration of participants' experiences using log data and examined its correlation with empathy scale scores. It was found that the total duration of the experience was positively correlated with empathy scores ($r = 0.337$, $p < 0.01$). Furthermore, the amount of time participants spent in the VR experience after the Stage 3, where the protagonist's condition significantly deteriorated, showed a strong positive correlation with empathy scores ($r = 0.765$, $p < 0.01$). This result indicates that the level of empathy is influenced by the intensity of others' need for help. This aligns with a study suggesting that individuals have stronger empathetic reactions and intentions to help when the need for help from others is pronounced (Sierksma et al., 2014).

4.2.3. Interaction-related design findings

In addition to the natural simulation mentioned in Section 3.2.3, the feedback from participants also offered valuable insights regarding the design principle of interaction, specifically emphasizing the importance of timing the interactions at key story points. In *synaptic retrogenesis*, we incorporated interactions during the transition between each stage. For example, participants were required to gaze at the campfire for more than three seconds to trigger a scene switch to the next stage. This design choice significantly enhanced participants' sense of control within the VR space and increased their overall engagement (as reported by 41 participants). As Dafu aptly expressed, 'It makes me feel like I'm actively driving the progression of the world itself, and the sense of engagement is particularly powerful'. Furthermore, another noteworthy finding emerged from the analysis of the log data: the number of user interactions demonstrated a significant correlation with the score at the donation site ($r = 0.907$, $p < 0.01$). This suggests that the more attempts participants made to help within the VR, the more likely it is to translate into prosocial behaviour in the real world.

5. Conclusion and discussion

5.1. EVRD framework

The experimental results provided empirical evidence that supported the efficacy of the VR artefact created using the design guidelines outlined in Section 3.2 for enhancing participant empathy. Moreover, through extensive analysis of the interview and log data, we were able to extract additional design insights. By combining these insights, we formulated the EVRD framework, as depicted in Fig. 11.

Here, we would like to discuss the distinctive features of the EVRD framework—that is, what goes beyond past researches or the 'doomed-to-fail' interactions. Prior studies have suggested that VR excels in enhancing emotional empathy but falls short in promoting cognitive empathy (Martingano et al., 2021). The reason for this is that, based on a dual process model of empathy (Álvarez-Castillo et al., 2018; Yu and Chou, 2018), unlike emotional empathy, cognitive empathy requires deliberate engagement in mentalising efforts to be evoked. However, due to the realistic and explicit nature of VR experiences, it leaves little room for imagination, thereby depriving participants of the opportunity to mentally practice what it feels like to be in unfamiliar environments and perspectives. In essence, VR enable individuals to personally feel what others are experiencing rather than merely think from others' perspectives. Consequently, VR primarily improves emotional empathy while neglecting cognitive empathy.

In contrast, the findings of this study reveal that doomed-to-fail interactions have two significant effects on cognitive empathy. First, these interactions enable users to differentiate themselves from the elderly Alzheimer's patient, as they realize that the person struggling to see clearly is not themselves but an elderly individual with Alzheimer's, thereby achieving self–other distinction. Second, these interactions evoke a sense of regret in players regarding their unsuccessful attempts to assist the elderly Alzheimer's patient in the VR environment. This sense of regret subsequently translates into prosocial behaviour and motivation when users transition from the VR environment to reality. In summary, VR artefacts developed based on the EVRD framework have the potential to enhance both emotional and cognitive empathy as well as stimulate empathic behaviour. It is important to note that, alongside interactions, storytelling also plays a crucial role (e.g., ingroup character or help-seeking episodes); this is an area where art and design disciplines hold an advantage over psychology and medicine in the realm of VR empathy. While science emphasises objectivity, art emphasises subjective creation grounded in respect for objectivity, thereby asserting that 'art is superior to life and reality' (Chernyshevsky, 1953).

5.2. Limitations and future directions

This study was conducted at multiple universities in Beijing, China. There is certainly the issue of generalizability to other social groups and other social contexts. It should be noted that there's no need to screen participants for their empathy levels because this study involves a comparison of pre- and post-test results. Even if some participants have exceptionally high or low empathy levels, as long as their post-test scores improve compared to their pre-test scores, it still indicates the effectiveness of the VR experience system. We've excluded participants with specific associations with Alzheimer's disease who could potentially influence empathy outcomes, as mentioned. Additionally, consciously excluding participants based on extreme empathy levels could actually limit the study's generalizability.

Of course, studying the effects of VR experiences on different

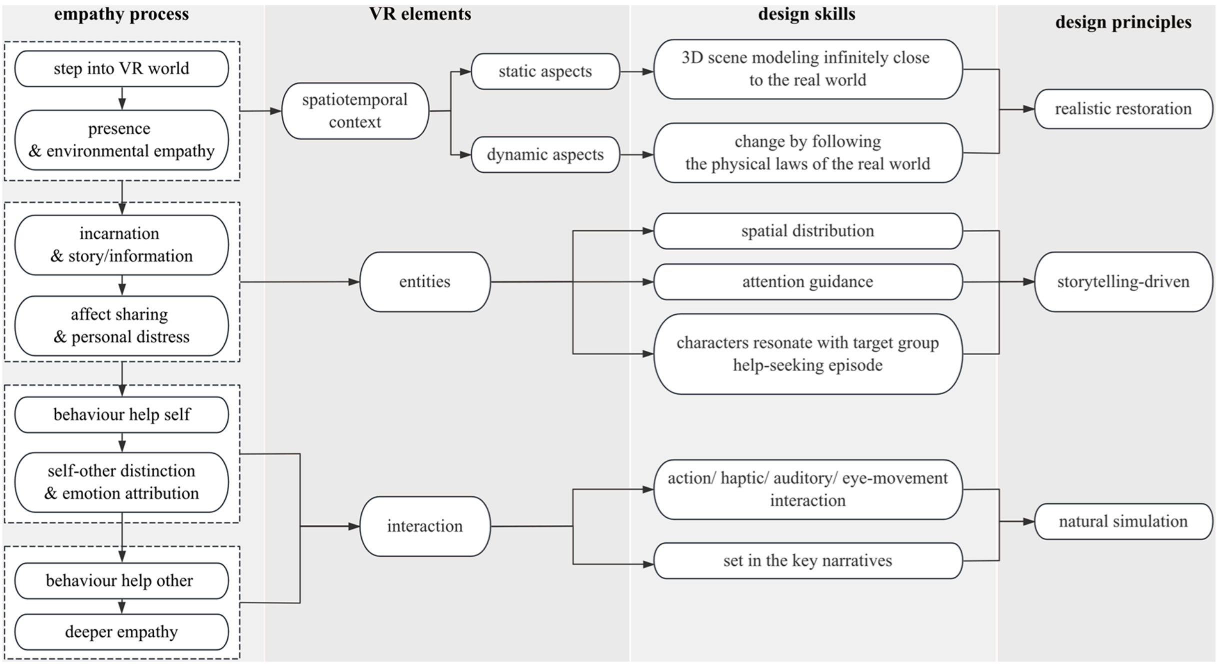

Fig. 11. Empathic VR design (EVRD) framework. It consists of four aspects. The first aspect are the four components of the *dynamic process of VR empathy* discussed previously: presence and environmental empathy, affect sharing and personal distress, self-other distinction and emotion attribution, and prosocial behavior and deeper empathy. This aspect also entails "*what participants have to do*." This part lists specific activities that need to be designed to achieve the empathy objectives of each component, including stepping into VR world, incarnation, self-help behavior, and aiding other. The second aspect are the VR elements. The framework maps three key VR elements—spatiotemporal context, entities, and interaction—to what participants have to do and thus indirectly to the VR empathy components. To aid in designing these VR elements specifically within the context of VR empathy, *design skills* are present and distilled into three *design principles*.

empathy level groups holds significance, especially for those with low empathy, such as abusers who negatively impact society. In this regard, the medical community has conducted numerous studies and proposed various treatment approaches as mentioned in Section 2.1. Hence, it could be worthwhile to explore whether the VR experience systems designed based on the EVRD framework can enhance the empathy of individuals with empathy deficits.

The effectiveness of the design framework relies on a comparing the effects before and after of the intervention experiment. However, the testing phase of this study utilized a paired test with pre- and post-assessment, which was unable to isolate the role of immersion inherent in VR hardware on empathy. As a next step, we plan to export a 3D PC version of "Synaptic Retrogenesis" and conduct controlled experiments. Additionally, we will aim to delve deeper into understanding the extent to which each principle of the EVRD framework, as well as their interactions, influence participants' which aspect of empathy. To address this matter, we intend to design separate contexts, entities, and interactions, resulting in 6 versions of each, and then conduct a 6 × 3 (emotional, cognitive, and behavioral) experiment. By doing so, we hope to uncover which design principle(s) impact participants' emotional empathy, cognitive empathy, or empathic behavior. Moreover, we aim to extract the weights associated with each influence, ultimately leading to the development of a more systematic design model.

In terms of the design of the experimental material, particularly the "Synaptic Retrogenesis" VR artefact, there is still room for improvement, especially in the aspect of tactile design. Currently, we utilize controller vibrations to remind players that the controller functions as a knob and can be rotated to adjust the clarity of the television and record player. However, controller vibration only represents a basic form of tactile perception and cannot fully simulate human sensation. The ideal approach would involve using tactile feedback sensors to simulate forces, allowing users to perceive the shape or dynamic changes of objects and thus simulate the tactile sensation of interacting with objects, as exemplified by Meta's tactile gloves. Future work could explore various technologies, such as using physical shape displacement to render the shape of virtual objects, with the aim of creating a more realistic physical interaction experience and eliciting deeper empathic effects.

Additionally, a notable limitation of the current study is the lack of long-term follow-up to assess the persistence of empathy training effects induced by the VR experience. Future research should consider conducting longitudinal studies to investigate the lasting impact of VR-mediated empathy training. Furthermore, exploring the relationship between sustained empathy levels and various factors such as participant demographics, frequency of VR exposure, and real-world behavior changes would provide valuable insights into the effectiveness of VR interventions in fostering empathy over time.

5.3. Conclusion

High-resolution monitors, stereoscopic lenses, and multi-sensory devices synchronize each other to create the immersive nature of VR, thereby offering participants the illusion of a 'first-hand experience' and, hence, earning the moniker of the 'empathy machine'. To a certain extent, VR and the brain share a common mechanism known as embodied simulation (Riva et al., 2019). According to neuroscience, the brain creates an embodied simulation of the body and the physical environment to enhance adaption to the surroundings (Massetti et al., 2017). VR systems function in a similar manner and create a representational system for participants that includes the virtual agent/incarnation and the context elements surrounding the agent (Hein and Singer, 2008). It is worth noting that various social cognitive processes, including empathy, primarily occur within specific social contexts (Baez et al., 2013; Kennedy and Adolphs, 2012). Surprisingly, there has been limited research on designing such a context-dependent machine, let alone proposing a comprehensive design framework. Therefore, this study seeks to address this gap by proposing a more systematic EVRD framework.

The development of this framework involves three key steps: (1) collaborative analysis between psychology researchers and VR designers to establish initial empathic VR design guidelines, and (2) the strict adherence to these guidelines during the creation of the VR artefact *synaptic retrogenesis*, which serves as an intervention material to ensure the experimental data accurately reflect the validity of the guidelines. Additionally, (3) through the analysis of experimental data, particularly the exploration of user feedback, the general process of VR empathy was uncovered. This, in turn, enabled the optimisation and iteration of the design guidelines, thereby ensuring that the design theory becomes a tailored solution for the specific problem at hand.

In conclusion, this practice-led study contributes to the design of empathic VR in terms of two aspects: (1) it will help to generate knowledge regarding the design process itself (Mäkelä, 2007), as exemplified by the inherent EVR framework developed during the creation of *synaptic retrogenesis*, and (2) it will produce tangible products closely intertwined with the source of knowledge (Cross, 1982), as indicated by the interpretation of *synaptic retrogenesis* that reveals the knowledge embedded within its design process. These contributions can be seen as valuable insights into the question of 'how to design an empathy machine' and serve as a reference for future empathic machine design practice. In terms of methodology, this study exemplifies a typical interdisciplinary collaborative design approach: combining practice-led research methodology of design (referred to as designerly ways of knowing) (Cross, 1982) with the experimental method of cognitive psychology aims to craft out the subjective aesthetic experience and objective enhancement of empathy in VR artefacts. Lastly, this study also pioneers a methodological innovation for the design of empathic VR by bridging the realms of subjective aesthetics and objective psychological effects.

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Xina Jiang: Writing – original draft, Data curation, Conceptualization. **Wen Zhou:** Investigation, Formal analysis. **Jicheng Sun:** Writing – review & editing, Software, Resources. **Shihong Chen:** Writing – review & editing, Project administration, Methodology. **Anthony Fung:** Writing – review & editing, Supervision, Resources, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ijhcs.2024.103397.

Data availability

Data will be made available on request.

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Xina Jiang is Assistant Professor in the Faculty of Digital Media at Beijing Normal University. Her research and teaching focuses on serious game, interactive design, and game user research.

Wen Zhou is a professor in the Faculty of Digital Media at Beijing Normal University. She specializes in the realms of digital art, virtual reality imaging, and the animation industry.

Jicheng Sun is a current graduate student at Stevens Institute of Technology. His research interests lie in the development of software systems and data analysis.

Shihong Chen is Professor of Network and New Media in the College of Applied Arts and Sciences of Beijing Union University. Her current research interests are computer applications, computer education and digital media technology.

Anthony Fung is Professor in the School of Journalism and Communication at the Chinese University of Hong Kong and Professor in the School of Arts and Communication at Beijing Normal University. His research interests include game studies, popular culture, and digital media studies.