BRIDGING DESIGNER-USER GAP WITH A VIRTUAL REALITY-BASED EMPATHIC DESIGN APPROACH: CONTEXTUAL INFORMATION DETAILS

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ABSTRACT

Without shared experiences, empathy gaps between designers and users are difficult to bridge. Advancing Virtual Reality (VR) has shed new light on this regard by enabling designers to simulate and experience their users' living scenarios in a virtual environment (VE). However, implementing VR-based empathetic design approach requires dealing with critical design questions, such as: (1) whether VR operators can develop empathy for unfamiliar user groups solely based on objective experience and (2) whether VR operators can utilize task-irrelevant contextual information in the VEs. To explore these issues, we designed an experiment based on two VEs with varying levels of detail that simulated the scenes viewed by people with red-green color vision deficiency (CVD). Participants were randomly assigned to either detail-rich or detail-simple VEs to complete neutral item-searching tasks. Results indicate that objective and neutral experience alone cannot elicit empathy towards users, and VR operating designers will utilize task-irrelevant contextual information.

Keywords: Virtual reality, Empathy, User centred design, Design methods, Experience design

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1 INTRODUCTION

One of the long-persisting challenges faced by designers has been how to accurately interpret the needs and concerns expressed by users. Human brain functions as a complex black box system, whose internal mechanisms are concealed and can only be inferred based on its inputs and outputs. Thus, all inquiry-based user research methods are inherently prone to the subjective biases of both users and designers. Historically, designers attempted to bridge this gap by empathizing with their target users to the greatest extent possible, with the intention of being able to interpret their needs with their contexts (Koskinen, 2003; Leonard et al., 1997). However, for a long time, the accuracy of this strategy has been questioned, as it is inherently subject to error due to designers' subjectivity. Therefore, designers are in urgent need of a research approach that enables them to understand and empathize with the users in a reliable way.

Attempting to address this concern, prior research proposed a Virtual Reality-based empathic design approach that intends to use Virtual Reality (VR) as an "empathy machine". This tool has the potential to enable users perceive the world from their own perspective (Hu et al., 2021a). The rationale behind this approach was that first-person immersive VR experiences can effectively elicit human empathy for unfamiliar groups (Herrera et al., 2018) and can reduce misunderstandings and related stereotypes (Yee and Bailenson, 2006). In this way, by developing and immersing designers in a virtual environment (VE) that accurately reflects a target user's living scenario, it would be possible to experience the world of the users and gain critical insights to produce more effective design solutions.

However, important questions such as the extent to which the design of VE should resemble the users' surroundings must be deal with before this promising approach could be implemented in real design contexts, but selecting the important elements is susceptible to subjectivity. Moreover, how to successfully direct the attention of designers in VE without imposing substantial biases or omitting key elements of the environment is a crucial design challenge. Besides, empathy is a multifaceted mental mechanism that involves different mental functions and perspective-taking strategies. How the different types of empathy will influence the empathic design approach remains uncertain. Furthermore, the extent that the elicited empathy can be applied to user-centred design is another open question of the empathic approach.

This study explores whether exposure to a VR scenario that resembles a physical context of a less familiar user group will help designers to better identify the needs and concerns of those users. Specifically, we created two VEs at varying levels of detail that imitate the scenes viewed by individuals with red-green colour vision deficiency (CVD). A reason since the study focuses on the perspective of individuals with CVD is because it is rare for non-CVD to truly empathize with CVD experiences unless they have personally experienced them.

2 BACKGOUND

2.1 Empathy

Empathy is a complex mental mechanism used to describe a wide spectrum of phenomena related to the generation of responses to observed emotions (Bošnjaković and Radionov, 2018; Yagil, 2015). Humans elicit affective empathy (I feel what you feel) and cognitive empathy (I understand what you feel), based on the involved brain functions in the activity. The former usually relies on humans' automatic emotional functions, while the latter requires deliberate perspective-taking (Eres, 2016; Shamay-Tsoory et al., 2009). In turns of perspective-taking, humans may adopt an imagine-self or imagine-other strategy, which respectively triggers self-related knowledge and evokes altruistic motivation and behaviours (Batson et al., 1997; Davis et al., 1996; Hu et al., 2021a).

2.2 Virtual reality

Virtual reality (VR) technologies can assist in the removal of mental obstacles by directly addressing underlying mental mechanisms (Hu et al., 2021b). VR tools have been given big hopes for becoming the "ultimate empathy machine" (Martingano et al., 2021) due to its capacity to produce highly immersive and interactive experiences. Indeed, with every detail under complete control, it is possible to develop a virtual environment (VE) that can reliably reflect a real-world living scenario of the target users by tuning the sensory inputs inside the virtual world. Hence, by replicating the scenarios

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experienced by the target users and immersing the designers in those environments, it is expected that the designers will develop perspectives similar to the users. Sharing similar experiences may be the easiest way to establish empathy between users and designers (Hu and Georgiev, 2020).

2.3 Virtual reality and empathy

While studies across disciplines have reported enhanced empathy levels with VR, more detailed mechanisms are yet to be explored. For example, it still remains unclear whether all subtypes of empathy are evoked by VR experiences. Earlier studies suggested that VR experiences influence operators' knowledge states (Yee and Bailenson, 2006), as well attitudes and behaviours (Herrera et al., 2018) towards the empathized group. However, recent research on this topic has yielded mixed findings. A meta-analysis by Ventura et al. (2020) found that VR experiences have positive effects on enhancing empathy by providing a sense of presence and embodiment, while Martingano et al. (2021) reported that VR experience only elicits affective empathy but not cognitive empathy. Moreover, Villalba et al. (2021) highlighted that VR could increase engagement, empathic concern, and perspective-taking more effectively than traditional methods, whereas Martingano et al. (2021) reported that VR could arouse compassionate feelings but not encourage users to imagine other people's perspectives.

The lack of consensus about the impact of virtual reality on empathy is likely attributable to how the interaction in virtual environments is designed. A guided interaction with a clear storyline, a free exploration of the environment, and a task-oriented interaction will undoubtedly have different effects on empathy. Young et al. (Young et al., 2021) found that empathic contents, narrative, and interaction are much more crucial for providing quality immersive empathy-building experiences than technical factors such as presence, audio, and video. In other words, how the attention of VR operators is directed within the VE may have an impact on whether or not they can effectively develop empathy. However, more implementation details are yet to be investigated.

2.4 VR-based empathic design

How to effectively guide VR operators to experience virtual scenarios and facilitate quality empathic experience is especially important to the VR-based empathic design approach, which will enable designers to develop more user-friendly systems, interfaces, or products. In this context, establishing empathy is simply a beginning, as the ultimate goal is to be able to better understand the users' needs and then applied the gained knowledge to successful designs. Thus, when developing the VR experience using an empathetic design approach, it is essential to consider how the simulated user scenarios should be introduced to the VR operating designers. It is crucial to establish a balance between inspiring empathy with a compelling narrative and avoid the induction of subjective biases. For example, what the ideal fidelity of the simulated VEs should be, how can designers ensure that the scenarios included in the VEs sufficiently resemble the living scenario of the users, and how to avoid distorting the VE experience by overemphasizing some components or missing important details. Other considerations are whether the empathy and perspective-taking mental processes automatically occurs when seeing an unfamiliar scene, or must it be deliberately evoked. Will the VR-operating designers be able to make effective use of contextual elements in the VEs to deepen their understanding of the users, or will they just focus on what storylines or tasks guide their attention to. While designers will have to deal with these important questions when implementing VR for empathic design, the answers are yet to be investigated.

2.5 Research questions

This study aims at exploring the following research questions: (1) whether VR operating designers can develop empathy for unfamiliar user groups when solely based on objective experience without narratives and, (2) whether VR operators can make effective use of task-irrelevant contextual information in the VEs. To this aim, we designed two VEs that simulated the scenes viewed by people with red-green colour vision deficiency (CVD), containing elements with different levels of contextual richness.

3 METHOD

3.1 Participants

23 undergraduate and graduate students (F=6, M=17, mean age = 25.56) from a Finnish university provided informed consent to participate in this study. All participants were fluent in English. Five participants were identified as having minor colour vision deficits, while the other 18 had normal colour vision. Thus, none of the subjects were considered to have substantial colour vision issues.

3.2 Materials

3.2.1 Apparatus

An HTC VIVE VR device was used as the immersive display device for this study. The device contains a head-mounted display (HMD) and two controllers. The resolution of the HMD is 1080 x 1200 pixels per eye, with 110 degrees of field of view and a refresh rate of 90 Hz. The controllers are implemented with Steam VR tracking sensors. This device can track activities within 15 m3 (3.5m x 3.5m area). The virtual environment was constructed with Unity 3D. Multiple components in the constructed environments were based on packages available in the Unity Asset Store.

3.2.2 Questionnaires

In this study, multiple measurements were adopted in assessing the following aspects:
Color vision test: Ishihara test
Before the experiment, the Ishihara test was conducted to determine the color vision condition of each participant. This test usually takes the form of color plates that contains hidden digits or patterns of objects (i.e., animals) that have been proven effective in identifying red-green color deficiency (Birch, 1997).
Empathy test
Questionnaire of Cognitive and Affective Empathy (QCAE) was used to measure the empathy level of the participants. QCAE consists of 19 items that assess the level of cognitive empathy and another 12 items for affective empathy. The cognitive empathy items were based on two subscales, perspective taking (PT) and Online simulation (OS), while the affective empathy items measure three subscales: Emotion contagion (EC), Peripheral responsivity (PER), and Proximal responsivity (PRO). Each item is measured on a 1-4 Likert scale, where 1 represents strongly agree with the statement, and 4 represents strongly disagree with the statement.
Problem-identification answer sheet
In order to assess how the participants perceived the difficulties faced by people with CVD, this study asked participants to write down their responses to the question: "What are the five most important issues in the lives of people suffering from color vision deficiencies?" before and after experiencing the virtual environment. If exposure to the virtual environment affect the participants' perception of this issue, we argued that their responses should reflect those changes.
Demographic questionnaire
After each participant concluded the experiment trial, a demographic questionnaire was delivered that included age, gender, and frequency of visiting the assigned environment (See section 3.3.1).

3.3 Experiment design

3.3.1 Stimuli design

Virtual Environment
Two virtual environments (VE) were created to examine the impact of the level of detail in VE on participants' empathy.
Detail-rich: Grocery store
The detail-rich condition VE simulates a common grocery store, which contains three aisles filled with fruits and packed food, as shown in Figure 1a and 1b. The items on the shelves are designed to be interactable and affected by gravity force. Participants can pick up, carry, throw, and put down these items. In this case study, interaction tasks only involve the middle aisle, while the other two aisles will serve as sources of contextual information for richer details. Participants can still observe and interact

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with the items in those aisles, but their tasks in this experimental condition would not specifically direct their attention to these items.

(a) Top-Down View of Grocery Store (b) Aisle View of Grocery Store (c) Top-Down View of Library (d) Aisle View of Library

Figure 1. Virtual environment configurations

This VE is considered detail-rich because it provides more information thanwhat is required to complete the assigned tasks. For instance, while the task itself may only require distinguishing between red and green apples in CVD color mode, the environment includes additional items that are difficult to differentiate in this mode, such as blueberries and small tomatoes, fresh and cooked meat, or red texts on green packages.

Detail-simple: Library

The detail-simple VE simulates a scenario in a library, as shown in Figure 1c and 1d. The library VE has an identical room structure as the grocery store, where four rows of bookshelves divide the room into three sections. The books on the bookshelves are color-coded (such as red for fantasy, green for non-fiction, yellow for sci-fi, etc.). All books are interactable and affected by gravity force, which can be picked up, carried, thrown away, and put down by the participants. Similar to the grocery store VE, tasks only involve books located in the middle aisle, while the other two aisles serve as background context. In this scenario, however, the contextual information offered by the other two contextual aisles is redundant as they essentially convey one simple idea: people with CVD will have difficulties differentiating between specific colours on the book cover.

Colour Mode Design

Both VEs are designed with a normal colour vision mode and a CVD mode. The CVD mode of both VEs simulates the world as viewed by individuals with protanopia (red-green deficiency), which is achieved through a Unity-based CVD filter by Alan Zucconi. The comparisons between the normal filter and the CVD filter are shown by Figure 2.

(a) Grocery Store: No filter (b) Grocery Store: CVD filter (c) Library: No filter (d) Library: CVD filter

Figure 2. a. Grocery store, b CVD mode grocery store, c: Library, d. CVD mode library

3.3.2 Task design

In both VEs, the tasks involve searching for three items with certain colours and bringing them to the counter desk of the store or library under the CVD mode. These tasks are deliberately designed to avoid eliciting any compassionate feelings in order to determine whether the experience alone will evoke empathy.

In the grocery store VE, participants were asked to find three randomly assigned items whose colours are difficult to identify under the CVD mode. In the library VE, they were requested to find three books that belong to three different categories based on their color-coded covers. For each participant, three target categories were randomly selected from a total of six ones.

3.4 Procedures

The following steps are taken in the experiment:

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Pre-VR stage
First, an Ishihara test was administered to establish the individuals' colour vision conditions. They were then asked to complete the QCAE empathy assessment and identify the top five difficulties faced by individuals with CVD. This was used as a comparison baseline. Then, each participant was randomly assigned either to the detail-rich VE (grocery) or the detail-simple VE (library).
VR-task stage
After calibrating the VR equipment, participants were given five minutes to freely explore their assigned VE in the default colour mode. Then, the VE was switched to CVD mode and participants were given their item-search tasks. There was no time limit for the completion of the task. After they brought the correct objects to the counter desk in the grocery VE or library VE, their task was considered accomplished.
Post-VR stage
Upon completion of the VR experiment, participants were asked to respond again to the QCAE assessment and identify the top five difficulties they perceived for people with CVD. Their answers were then compared to the baseline. After the experiment, they completed a demographic questionnaire about personal information and previous exposure to the assigned environments (grocery/library).

3.5 Data analysis

Empathy Scores
The differences between the pre-VR and post-VR empathy QCAE ratings were calculated and analysed using the t-test to assess whether there were significant changes in the empathy states of the participants.
Perceived Difficulties with CVD
The participants' responses to the question of "What are the five most important issues in the life of people suffering from colour vision deficiencies" were coded along four dimensions: (1) task relevance, (2) accuracy; (3) misconceptions; and (4) changes compared to the baseline. The task relevance and accuracy dimensions were coded based on a 1 to 5 scale, with 1 representing non-relevant and no accuracy and 5 representing extremely relevant and accurate. If participants identified less than five difficulties, the missing ones were recorded as 0. Responses are considered task-relevant if they deliberately mention one of the following aspects: (1) insufficient infrastructure support, (2) inconsiderate design of common items, (3) inherent inconveniences of CVD, or (4) details pertaining to the assigned VEs. The misperception dimension is coded according to whether the participant mentions incorrect knowledge regarding CVD, where 1 indicates the presence of the misconception and 0 indicates its absence. Changes relative to the baseline are coded according to the following criteria: 2 points for each new item mentioned after the VR experience, 1 point for reordering one item, and 0 points if nothing changes. Three researchers coded 100% of the contents. Although they had initial disagreement on 11% of the content, they discussed the disputes together until reaching full consensus. To compare how these dimensions differ before and after gaining the VR experience, a series of correlation analyses were conducted.
Impact of detail richness
In order to determine the effect of detail richness, t-test comparisons were made between the detail-rich and detail-simple conditions in terms of their QCAE empathy scores, task relevance, accuracy, and misconceptions regarding their difficulties.

3.6 Hypotheses

The following hypotheses are formulated:

- H1: Experience in a colour-deficient VE can increase empathy of people with CVD.
- H2: Colour-deficient VR experiences are anticipated to reduce participants' misconceptions regarding CVD, and enable VR operators to recognize the design inconsiderate to people with CVD more accurately.
- H3: Contextual information in VE will influence the empathy and knowledge states of VR operators.

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4 RESULTS

4.1 Quantitative analysis

QCAE Empathy Questionnaire

As shown in Figure 3, there is no statistically significant change in any dimension of QCAE scores between before and after the VR experience, indicating that there is no evidence for a change in the empathy states of the participants.

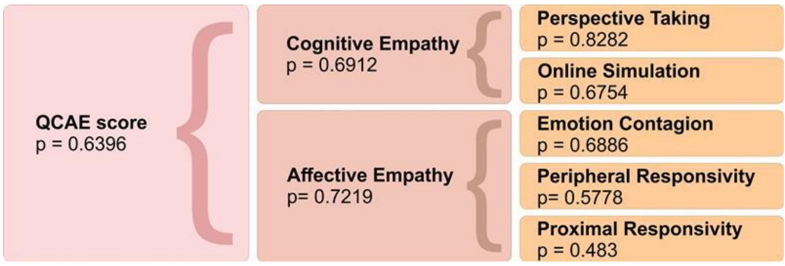

Figure 3. T-tests of QCAE scores before and after VR experience

Perceived Difficulties

As shown by Table 1, participants' perceptions of the difficulties of CVD were significantly more task-relevant (p = 0.018) and more accurate (p = 0.041) after the VR experience, while no significant differences in the misconceptions dimension were found. Moreover, the detail-rich condition showed significant differences in task relevance (p = 0.03615), accuracy (p = 0.0382), and misconception reduction (0.04637), whereas the detail-simple condition showed no significant changes in any of these three dimensions. These results collectively indicate that (1) the VR experience reliably elicited task-relevant knowledge, (2) the VR experience reliably increased the accuracy of the perception of the difficulties of CVD, and (3) the rich contextual details in VE reliably increased the relevance, accuracy, and reduced the misconceptions of the perception of the difficulties of CVD.

In summary, the results rejected H1 but supported H2 and H3.

Table 1. Properties of perceived difficulties before and after VR experience (p<0.05)*

p-value	Overall	Detail-rich Grocery VE	Detail-simple Library VE
Task-Relevance	0.01838*	0.03615*	0.2367
Accuracy	0.04117*	0.0382*	0.3298
Misconception	0.09216	0.04637*	0.7503

4.2 Qualitative analysis

The content of the participants' perceptions of CVD difficulties also yielded interesting findings that are reported as follows.

VR experience effectively led participants to realize the difficulties conveyed by the VEs.

After the VR experience, 14 out of 23 participants noted that the bulk of products were not designed by taking the CVD community in consideration, while seven participants explicitly highlighted the insufficient infrastructure support for the CVD community. Six additional participants mentioned new facts about the inconveniences faced by people with CVD that were not mentioned in the pre-VR questionnaire. Only three participants mentioned specific details about grocery shopping or library browsing. This indicates that after experiencing VEs that replicated the life of persons with CVD, participants were able to recognize the difficulties they experience and effectively detect the actual underlying design problems to solve.

VR experiences helped participants to articulate their perceptions about CVD difficulties.

After the VR experience, participants were able to explain their views regarding the challenges encountered by the CVD community in a more accurately and concretely way. For example, some of them identified specific concepts such as "traffic" or "driving" among the top difficulties in the pre-VR questionnaire, and in the post-VR questionnaire they were able to expand their responses to "traffic lights and traffic signs sometimes lack sufficient non-colour information" or "the color-coded routes may be difficult to view by the CVD people". Similarly, relevant responses such as "cannot

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read maps" and "cannot read charts" in the post-VR questionnaire were reframed as "trouble in reading color-coded information". It is promising that VR experiences not only allowed participants to recognize the inconveniences brought by CVD, but also led them to address the exact design flaws associated with those problems, such as infrastructure that excessively relies on color-coding and lacks further visual clues, as is often the case with maps, suggesting that this methodology is particularly well suited for design research.

VR experiences can trigger task-irrelevant new facts that originate from the same underlying problems

In addition, it has been observed that participants were able to retrieve new information that was not directly related to the assigned VEs but is due to the similar design problems after VR exposure. For example, in the post-VR questionnaire, they highlighted issues such as "sports games can be difficult to watch since the colour of the jersey may not be identifiable for those with CVD" and "hard to use user interfaces that do not take CVD into account" after experiencing the inconveniences in the grocery store and library, which are all the result of inadequate design support. The retrieval of these details revealed that the VR experience prompted participants to understand the problem at hand and elicit the correct knowledge representation to deal with it.

Tendency to overestimate the impacts of CVD on daily lives

In the post-VR questionnaire, participants tended to exaggerate the burden of CVD on people's daily lives. Several participants noted that people with CVD are unable to "maintain work-life balance," "enjoy life as much as others," "appreciate art," and "communicate matters related to colours," which apparently overestimated the inconveniences induced by CVD. It is a sign that VR operators estimated the impact and frequency of inconsiderate designs based solely on their VR experiences, as opposed to a combination of their daily and VR experiences.

5 DISCUSSION

5.1 Knowledge was elicited, but not empathy

The analyses of the QCAE empathy score and the participants' perceived difficulties of CVD collectively responded the first research question: VR experience can reliably increase VR operating designers' knowledge and reduce their misconceptions about unfamiliar groups of people, but it will not automatically elicit their empathy. An underlying reason may be attributed to the fact that empathy is an effortful mental process (Cameron et al., 2019), which requires emotional evocative sensory cues (Martingano et al., 2021) or deliberate instruction (Ahn et al., 2013) to be activated. This finding also helps to explain some divergences regarding the types of empathy VR experiences might elicit (Martingano et al., 2021; Ventura et al., 2020), with the likely cause being the different ways in which operators are guided to interact with the virtual world (i.e., storytelling versus interaction tasks). In other words, merely immersing VR operators in a VE that simulates the life scenarios of their unfamiliar community will not automatically lead them to adopt the perspectives of other groups under consideration. The overestimation of the impact of CVD-related difficulties on daily life suggests that while assimilating knowledge received from VR experiences, participants adopted their own perspectives rather than those of the CVD community. To activate empathic mental processes of VR operators, deliberate perspective-taking instruction seems to be necessary.

5.2 Impact of contextual elements in VE

The statistically significant difference between the performances of participants in the detail-rich and detail-simple conditions responded the second research question, confirming that VR operators can use task-irrelevant contextual details in understanding the situations experienced by the simulated population. This finding suggests that VR operators would consciously or subconsciously utilize the VE contexts to enhance their understanding about unfamiliar people. This may happen even if their attention is not consciously directed to the additional contextual elements that highlight the inconveniences to the target populations during interaction, which is one of the primary objectives of the VR-based empathic design approach. It should be noted that richness of details should be reflected by the diversity of phenomena presented, as opposed to various visual stimuli that exhibit the same design problem to solve.

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5.3 Design implications

While findings have implications for the design of empathic VR environments, they also bring new challenges. Since neutral tasks and objective experience proved to enhance knowledge but not empathy, subjectivity might be an inherent property of empathic VR experience. Moreover, given that task-irrelevant contextual elements in VE have been shown to affect what VR operators may learn from the experience, deciding what contextual details to include in VE can be a substantial source of bias. Therefore, how to cope with this subjectivity to reduce bias becomes a critical design consideration when developing empathic VR experiences. Tolerance for biases may vary depending on the attempt to employ VR as a medium for evoking empathy. If inspiring empathy is the ultimate goal, subjectivity is less of a problem, in which case emotionally intense stimuli and narrative strategies may be good strategies to elicit affective empathy along with compassionate feelings (Martingano et al., 2021). When increased empathy is the approach for gaining a deep understanding of unfamiliar populations, like in the case of VR-based empathy design, perspective-taking and ultraism tasks (like helping CVD people to distinguish colours) that stimulate cognitive empathy can be seen as effective techniques to this aim (Ahn et al., 2013; Ventura et al., 2020).

5.4 Limitations and future directions

Due to limitations related to the scope of the study, alternative hypotheses that could not be tested in this experiment will be considered in future follow-up studies. For instance, a possible reason for the discrepancy between the increased knowledge and the unchanged cognitive empathy to be tested in a longitudinal study could be that cognitive empathy requires time to consolidate, and hence immediate changes are not reflected. In addition, the effects of neutral tasks compared to deliberate instruction for empathizing can be also tested. Another factor to consider is to further ensure compatibility between the two VEs, especially regarding the contextual visual cues used in the design of the environment, such as controlling the colours of the floors, walls, and other contextual element to avoid potential biases. Moreover, the lack of embodied experience may be one of the contributing factors to the insufficient empathy changes found in this study. Embodied experience with virtual avatars as a way to reliably increase participants' empathy towards CVD individuals can be explored. Furthermore, the ultimate goal of the VR-based empathy design approach is to enable designers to develop more user-friendly systems, interfaces, or products based on their deepened understanding of target users. Therefore, how to effectively consider empathy and knowledge to enhance design success should be also investigated.

6 CONCLUSION

This study explored a VR-based empathic design strategy by investigating how to help VR operators to successfully experience virtual scenarios and facilitate quality empathic experiences. Based on two VEs simulating the red-green colour vision deficient environments, we explored whether VR design operators can spontaneously generate empathy based on objective experiences, and whether they can successfully use contextual features in VEs to this aim. Results revealed that explicit instructions are necessary to elicit empathy from operators, whereas contextual features can be used even without conscious attention.

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