



Investigating the impact of scenario and interaction fidelity on training experience when designing immersive virtual reality-based construction safety training

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ARTICLE INFO

Keywords:

Safety training
Immersive virtual reality (IVR)
Fidelity
Presence
Usability

ABSTRACT

Safety training is an effective method to reduce safety issues. Immersive virtual reality (IVR) for safety training has gained attention in high-risk industries, but the trade-off between realism and abstraction in IVR-based training is not fully understood. This study investigated the impact of scenario and interaction fidelity on IVR-based forklift safety training, focusing on presence and usability. Scenario fidelity varied the Level of Development (LOD) in IVR model (high LOD vs. low LOD), while interaction fidelity varied the control interface (steering wheel and pedals vs. keyboard). A 2-by-2 experiment with 120 participants examined high/low scenario and interaction fidelity. Results showed scenario fidelity enhanced presence and usability significantly, while interaction fidelity had no effect. The realism of training scenarios is more influential for presence and immersion than control interface realism. These findings aim to balance IVR simulation fidelity and learning outcomes and help guide the development of cost-efficient IVR-based safety training.

1. Introduction

Despite respect efforts to improve safety, construction sites are still among the most dangerous workplaces (Mahmoudi et al., 2014; Choi et al., 2019). Among various measures employed to improve safety, worker training has been found to be one of the most effective methods (Burke et al., 2006; Ricci et al., 2016). Recently, the construction industry, as with other high-risk sectors, has shown great interest in adopting virtual reality (VR) technologies for worker safety training. In VR, workers can gain knowledge about safety and learn pro-safety behavior through the virtual experience of dangerous situations without any real risks being posed by the training process (Ragan et al., 2015; Gao et al., 2019; Luo et al., 2021). Furthermore, as immersive virtual reality (IVR) devices such as a head-mounted display (HMD) have become more and more affordable, the construction industry has explored the possibility of expanding the use of IVR safety training

programs in the form of IVR rooms or even home training set-ups (Buttussi and Chittaro 2017; Gao et al., 2019). When compared to traditional methods, IVR safety training has distinctive advantages in improving safety motivation and learning effectiveness (Vergara et al., 2017; Çakiroğlu and Gökoğlu, 2019; Meyer et al., 2019; J. W. Choi et al., 2020; Morélot et al., 2021).

When designing simulation-based training such as IVR training, simulator fidelity is one of the most critical design features, as it not only affects learning outcomes but is also associated with the cost effectiveness of the systems (Dahlstrom et al., 2017; Hamstra et al., 2014; Lefor et al., 2020). While the definition of fidelity could vary depending on the application, one of the traditional definitions is the extent to which the simulator replicates the actual environment (Alessi 1988). For the higher transferability of training from a simulated environment to complicated real-world situations, high-fidelity simulators featuring realistic 3D views and interfaces have been preferred (Hays and Singer

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<https://doi.org/10.1016/j.dibe.2023.100223>

Received 11 June 2023; Received in revised form 29 July 2023; Accepted 29 August 2023

Available online 1 September 2023

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2012). However, the trade-off between realism and abstraction in the context of safety training has not been fully understood, as higher fidelity means an increased cost for developing the IVR system and using more sophisticated IVR devices, which may lower the economic viability of IVR training in practice (Dahlstrom et al., 2017). From a practical point of view, the goal of the IVR training system design is to identify an appropriate balance between the fidelity of simulation and learning outcomes and find an economically feasible solution to achieve that balance.

However, there have been debates on the optimal level of fidelity of VR systems that can help achieve better training outcomes (Balakrishnan and Sundar, 2011; Barbosa et al., 2017; Makransky et al., 2019; Grabowski, 2021; Kim and Rhiu, 2021; Yang et al., 2022). It has been argued in various domains including aviation, maritime transport, medicine, and the military, that higher fidelity can contribute to better transferability of training and learning outcomes (Dahlstrom et al., 2017). However, it is still unclear whether higher fidelity is always desirable in light of training or effectiveness. For example, Ragan et al. (2015) reported that higher scenario fidelity in the VR training system for a visual scanning task did not lead to a better transfer of the skills learned in VR to the real world. Many previous studies on simulation-based training have also argued that fidelity requirements could vary depending on the training task and the intended learning outcomes (Hamstra et al., 2014). While the use of IVR training for safety training is not widely adopted in the construction industry yet, a scientific investigation on the relationship between fidelity and training effectiveness is still lacking. More advanced knowledge on the relationship between simulator fidelity and training effectiveness would provide VR designers and practitioners with clearer insights into how to develop VR-based training systems that are effective in terms of development cost as well as learning outcomes.

This research aims to better understand the impact of interaction fidelity and scenario fidelity on the IVR safety training experience in terms of the sense of presence and usability (Hendrix and Barfield, 1996; Balakrishnan and Sundar, 2011; Jankowski and Grabowski, 2015; Chalil Madathil and Greenstein, 2017). As VR safety training contents, forklift operations were selected, considering that: (1) a forklift truck is one of the most widely used pieces of equipment in industrial fields, including construction; (2) most forklift accidents, like other equipment-related accidents, are associated with the operator's human errors, which can be significantly enhanced by providing safety training (Sarupuri et al., 2017); and (3) forklift operations involve a high degree of complexity for equipment controls that require continuous interaction between users and VR environments. The dependent variables to evaluate users' training experiences, both presence and usability are selected. Presence is one of the most predominant elements related to the effectiveness of training with the IVR system (Balakrishnan and Sundar 2011; Grassini et al., 2020). Usability is the hallmark of a successful VR experience in a human-centered system (Jankowski and Grabowski 2015; Martens 2017). This research involved 120 Hong Kong Polytechnic University student participants in an experimental study using a two-by-two factorial design to evaluate different levels of interaction and scenario fidelity on IVR user training. Based on the results, we discussed our findings on the relationship between fidelity and training performance, which would be helpful for cost-effective VR training system design in various application domains.

2. Literature review

2.1. VR-based safety training

Virtual reality is one of the emerging computer-aided technologies that can be applied in safety training. It uses several types of apparatus, such as 2D displays, the Cave Automatic Virtual Environment (CAVE), and head-mounted displays (HMDs) (Gao et al., 2019; Hasanzadeh et al., 2020). These devices provide different levels of immersion in the virtual

environment, which are non-immersive, semi-immersive, and fully immersive. Non-immersive VR, such as desktop VR and mobile VR, was the most common type for VR safety training due to its ease of use. Chittaro et al. (2018) demonstrated that mobile VR training programs could be more engaging, intuitive, and effective compared with traditional training methods. Recent advances in IVR technologies such as CAVE and HMDs have enabled the creation of more immersive training environments that may enhance learning outcomes in safety training. Previous research efforts have found that CAVE-based learning (i.e., semi-immersive IVR) is effective in learning spatial comprehension, risk perception, and decision making, while traditional classrooms can be a better environment for learning simple and general site safety knowledge (Sacks et al., 2013; Leder et al., 2019). Recently, the use of HMD-based fully immersive VR has been increasing in safety training over the past decade, as such, researchers have demonstrated its efficacy in improving learning motivation and performance and reducing learning duration (Chittaro and Buttussi 2015; Feng et al., 2020; Wu et al., 2020). In addition, HMDs provide a more intuitive way to interact with the IVR environment and tasks, and they offer users an experience with a greater sense of presence and engagement (Buttussi and Chittaro, 2017; Zhang 2017; Tai et al., 2022). These features of HMDs provide comparative advantages, especially for safety training, by enabling trainees to experience real-like safety-related scenarios in a risk-free virtual environment (Morélot et al., 2021). In this regard, IVR safety training has been applied in multiple areas, including aviation (Chittaro and Buttussi 2015), firefighting (Cha et al., 2012), earthquake emergency training (Feng et al., 2020), and construction safety training (Sacks et al., 2013).

2.2. Importance of fidelity in IVR systems

One of the most distinguishing components between traditional and VR training is immersion, which can be defined as the objective level of fidelity a VR system provides (Bowman and McMahan 2007). Even though fidelity is one of the most critical design features in VR training systems, understanding its role in training performance is challenging due to its multifactorial nature (Hamstra et al., 2014). A number of researchers tended to study the fidelity of VR systems by focusing on specific aspects rather than comprehensively investigating different components of VR systems (Kopp and Hanson 2012; Dahlstrom et al., 2017; Lefor et al., 2020). A framework proposed by Ragan et al. (2015) would provide a theoretical foundation for investigating various aspects of VR system fidelity by classifying it into three categories: display fidelity, interaction fidelity, and scenario fidelity. Display fidelity refers to the verisimilitude of output devices and the reproducibility of sensory stimuli. Interactive fidelity refers to the realism of input devices and the simulated interaction between the real world and the virtual environment. Scenario fidelity refers to the similarity of the simulated scene to the real environment and the reproduction of behaviors, rules, and object attributes during the simulation.

Researchers have tended to assume that a high level of fidelity for all three components necessarily leads to training effectiveness in the virtual environment (Ragan et al., 2015). However, more investigation is required to ascertain the truth of this assumption. Several studies have investigated these three aspects of IVR system characteristics, but only individually. For example, Zhang (2017) have found that an HMD-based system (which has high display fidelity) has a higher grade of intuitive and interactive usage than desktop VR, while McGloin et al. (2013) have established that the user's sense of presence is enhanced by adding a controller (with high interaction fidelity) to an IVR system to create more natural control and easier operation. Nonetheless, other researchers suggest that training would be more effective when more authentic scenarios (high scenario fidelity) are provided rather than poor-quality simulations (Hays and Singer 2012).

Thus far, there has been little comprehensive classification and research on the IVR system's characteristics, and the interaction

between these three aspects is rarely mentioned. The lack of such research into the impact of various types of fidelity in combination with training experience is problematic. The user experience on VR systems is not solely based on how realistic the views are. The display fidelity depends heavily on the specifications of the output hardware (HMD), such as resolution, field of view, and update rate, etc., which depend on the degree of development of the technology. However, interaction fidelity and scenario fidelity are much more optional. To some extent, interaction fidelity and scenario fidelity are more affected by IVR system design decisions (Ragan et al., 2015). For example, interactive fidelity can choose various interactive devices, such as keyboards, handles, joysticks, etc., while scenario fidelity can choose to build simple or complicated scenes. Therefore, it is necessary to understand the impact of interaction and scenario fidelity on user experience from the perspective of system design perspective for a more effective IVR system. In this regard, this research focuses on investigating interaction fidelity and scenario fidelity, as well as the interaction between the two.

The interaction fidelity corresponds to the realism of input devices and the simulation of the interaction between the real world and the virtual environment (Ragan et al., 2015). Several types of input devices are used to control VR objects. Examples include keyboards, joysticks, controllers, driving systems, tracking systems, and omnidirectional treadmills (Canessa et al., 2019; Hooks et al., 2020; Ebnali et al., 2021). Regarding immersive virtual reality systems with HMDs, the impact of interaction fidelity on training outcomes has not reached consensus. Buttussi and Chittaro (2017) found that there was no difference between HMDs with an interactive device using a 3-DOF tracker and those with a 6-DOF tracker in terms of their effect on VR-based knowledge acquisition tasks. The results of a study by Diez et al. (2017) also show that different IVR interaction devices used in a fire warden virtual training system, such as a keyboard or a gamepad, were simply a matter of personal preference and were not clearly linked with training effectiveness. Conversely, Yasui et al. (2019) conducted an experiment combining HMD with haptic feedback devices, such as a Leap Motion Controller and gloves, to train young engineers for correct operations in nuclear power plants and observed differences in training effectiveness between different set-ups of control devices.

Scenario fidelity is closely related to the realism of the simulated virtual environment. It therefore corresponds to the level of development of the scene and features such as behavior, rules, and objective properties that are interpreted as content in a virtual reality environment (Ragan et al., 2015). Researchers propose that realistic environment modeling has a significant impact on the sense of presence in VR (Bracken 2005; Bracken and Skalski 2009). However, Ragan et al. (2015) argue that a high level of complexity in a virtual environment, notably visual complexity, can have a negative impact on target detection performance in an IVR. This is because complexity can distract the user and cause cognitive overload, reducing their attention to the task they are performing (Molhemi et al., 2021). Previous research has also demonstrated that it is not always required or beneficial to achieve a high level of scenario fidelity (Schneider, 1985; Rolfe and Staples, 1988). Some researchers suggest that it is more important to optimize the virtual environment for a specific training task (Druckman and Bjork, 1994).

2.3. Factors affecting user training experience in VR

2.3.1. The sense of presence

Presence is conceptualized as the mental process of attention and mental models of the virtual environment (Schuemie et al., 2001). Investigating the scientific nature of presence lies in understanding the extent and mechanism of its occurrence, and such scientific knowledge can be used to build more effective and efficient IVR systems (Usoh et al., 2000). Slater and Wilbur (1997) have described presence as the feeling of “being there,” while Witmer and Singer (1998, p. 225) describe it as “the subjective experience of being in one place or

environment, even when one is physically situated in another.” Presence is one of the substantive factors affecting performance in a virtual environment (Hendrix and Barfield, 1996; Lee, 2004; Ahn et al., 2022). One of the most critical aspects of presence is that the users can virtually experience the same reactions and emotions that are very similar to their real ones, playing an important role in enhancing training performance (Schuemie et al., 2001).

Previous researchers have investigated the user experience and training effectiveness of IVR systems in light of presence (Abbas et al., 2023). Song et al. (2021) demonstrated that the VR crane training system significantly improved self-efficacy, which is one of the important aspects of knowledge gain and performance, by mediating the sense of presence and usability. According to a systematic review and meta-analysis a sense of presence (immersion) created by VR training was one of the most testified to be one of significant moderators of cognitive training in people with dementia and mild cognitive impairment (Xie et al., 2022). However, researchers showed that nursing undergraduate students with a low-moderate level of immersion in a computer/mobile VR training program were also effective in gaining procedural knowledge compared to traditional text or video training (Woon et al., 2021). Rogers et al. (2019) found that moderate interaction fidelity was enough for whole-body movements in a VR game using presence and self-efficacy questionnaires. Aeckersberg et al. (2019) found that low-fidelity simulation training with physical endovascular tool navigation increased motivation in novice trainees compared to conventional video podcast learning through a self-assessment questionnaire. This raised the attention to which degree of the sense of presence would achieve the balance of the training outcome and cost (Cummings and Bailenson 2016).

In addition, presence is a conscious experience with a highly selective and internalized interpretation of the environment (Schubert et al., 2001), and it has been pointed out that the sense of presence may be a manifold experience (Sheridan, 1992; Biocca and Delaney, 1995; Schubert et al., 2001). According to some researchers, the construct of presence includes at least two major components: the sense of location in the VR environment, and the sense of assisting attention concentration or distraction in VR (Schubert et al., 2001). Based on the validated presence measurement theories of Schubert et al. (2001) and Witmer and Singer (1998), this paper describes the subcategories of the sense of presence in the following aspects: general presence (GENP), spatial presence (SPAP), sensory stimuli (SENS), involvement (INV), realism (REAL), distraction (DISTR), an uncomfortable feeling (UNF). These aspects are consistent with the categories of spatial construction and attention allocation (Witmer and Singer, 1998; Schubert et al., 2001). While previous work has revealed various factors that constitute “presence”, there has not been enough further research into the user experience within these subcategories (Buttussi and Chittaro 2017; Grassini et al., 2020; Hasanzadeh et al., 2020). Schwind et al. (2019) conducted an internal investigation of the sense of presence and found that general presence and involvement were affected by visual realism while spatial presence did not have the same effect. This may help to understand what elements of the VR environment would contribute to task performance for different tasks. Therefore, more research is warranted to further clarify the influence of each of these factors on the user experience in the context of VR training.

2.3.2. Usability

Considering the complexity of VR technology and its applications, evaluating the usability of a system is one of the most challenging aspects of creating a successful virtual experience (Martens 2017). “Usability” here covers a wide range of meanings, including qualitative characteristics such as user satisfaction and user comfort, as well as quantifiable characteristics such as user task completion time and task performance accuracy (Bowman et al., 2002; Martens 2017). It can be summarized as the “ease of use” or “usefulness” of the interactive system. By focusing on usability during the development of a VR system

(Bowman et al., 2002), developers are more likely to create a virtual environment that meets the user's training needs, thereby enhancing their learning experience (Jankowski and Grabowski 2015; Martens 2017). Experiments have shown that presence has a notable influence on the usability and, hence, the efficacy of a system. Chalil Madathil and Greenstein (2017) adopted the metrics of both presence and time for the completion of tasks in an experimental study to compare the efficacy of three types of collaborative systems: traditional labs, VR set-ups, and Webex (a web-based screen sharing). They found that there was little difference between completion times but that the VR collaborative systems helped participants experience greater involvement than the other two systems (Chalil Madathil and Greenstein 2017). Brade et al. (2017) mentioned that virtual environments can substitute real environments when achieving a high sense of presence in user experience research, while all presence factors would be significantly related to usability in the CAVE. Another researcher (Jankowski and Grabowski 2015) used both spatial presence and the mean time duration of tasks to investigate three types of interface (a VR interface, a stereoscopic display, and a monoscopic display) for mobile robot teleoperation. The results showed that while completion times differed significantly between the three interfaces, the VR interface showed greater subject participation and interaction awareness. Although these studies explored different types of interfaces or operational systems, they did not dive into the effect of innate components of VR systems, for such example scenario fidelity or interaction fidelity, on efficacy the user training experience.

3. Research methods

This study aims to investigate how the different levels of scenario and their interaction fidelity would affect user experience such as sense of presence and usability that are the indicators of training effectiveness through an experimental study. The training task is to deliver safety knowledge during diverse forklift operations at construction sites. According to Al-Jundi and Tanbour (2022), low and high scenario fidelity correspond to "3D models with simple geometry (wireframes)" and "3D models with rendering and animation that are highly realistic to the real world," respectively. This is consistent with the Level of Development (LOD) used to describe the precision of a building information model. Therefore, we used "VR models with high LOD" and "VR models with low LOD" as the representation of high and low scenario fidelity. VR models with high LOD possess relative elements that encompass a precise representation of reality, enable easy interaction, and provide a highly realistic and immersive experience for users in the simulated environment. While the VR models with low LOD represent the opposite, leading to a simplified simulated environment and sacrificing realism and accuracy of the interaction. To be more specific in this research, high scenario fidelity corresponded to rendering realistic ground, containers, pallets, warehouse, and buildings in the construction site while low scenario fidelity only included simple wireframe walls, direction

arrows, and the destination box in the scene. For interaction fidelity, the market offers various input devices, such as a keyboard, controller, navigation, hand-tracking devices, body tracking devices, etc. (McMahan, 2011; Anthes et al., 2016). McMahan (2011) noted that keyboards, mice, VR controllers, and game controllers all belonged to the same level of fidelity because one can only use buttons to provide a similar degree of control over objects in the VR environment. Even though these devices provide sufficient controls for forklift operations, they are quite different from real forklift controls that use a steering wheel and pedals. Therefore, we chose a *keyboard* as low interaction fidelity and a *steering wheel and pedals* as high interaction fidelity. The sense of presence was measured through post-questionnaire survey while the usability was represented by the completion time of VR training. Fig. 1 shows the research framework with independent and dependent variables of the experimental design.

3.1. Hypotheses

The following three research questions were intended to be addressed by this research design: (1) Do different levels of scenario fidelity (e.g., different degrees of detail representing a construction site) have an impact on trainees' sense of presence or usability in IVR-based safety training? (2) Do different levels of interaction fidelity influence trainees' sense of presence or usability in IVR-based safety training? (3) Do scenario fidelity and interaction fidelity have any interactions in creating those effects? These questions with meaningful answers can provide insights into the most critical conditions affecting the effectiveness of an IVR-based safety training system and the efficiency creating one. Fig. 3 visualizes the hypotheses and the experiment design used to collect data to test the hypotheses.

For this experiment, an interactive IVR-based forklift operation safety training system was used. Specifically, four different training tasks, covering basic forklift driving, loading, and transportation operations, were utilized in this study. The high interaction fidelity condition of the system was realized by setting it up with a steering wheel and pedals, while the low interaction fidelity condition was realized by setting up a keyboard. The idea behind these settings is that the steering wheel and pedals are similar to the control devices of a real forklift, thereby providing a more realistic feeling of driving a forklift than a keyboard. On the one hand, the condition of high scenario fidelity was created by adding more background details to the virtual environment so that the VR user might feel that they are on a construction site. On the other hand, the low scenario fidelity condition was created by removing those background objects that represented items at a construction site, as shown in Fig. 2. These variations in scenario fidelity and interaction fidelity allow the research team to test whether and how much a user's sense of presence and usability in the IVR training system is affected by these conditions, i.e., the three hypotheses.

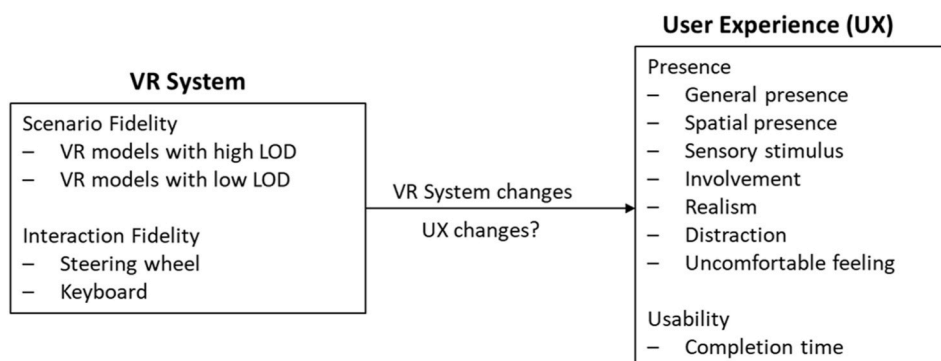


Fig. 1. Research framework: LOD stands for Level of Development.

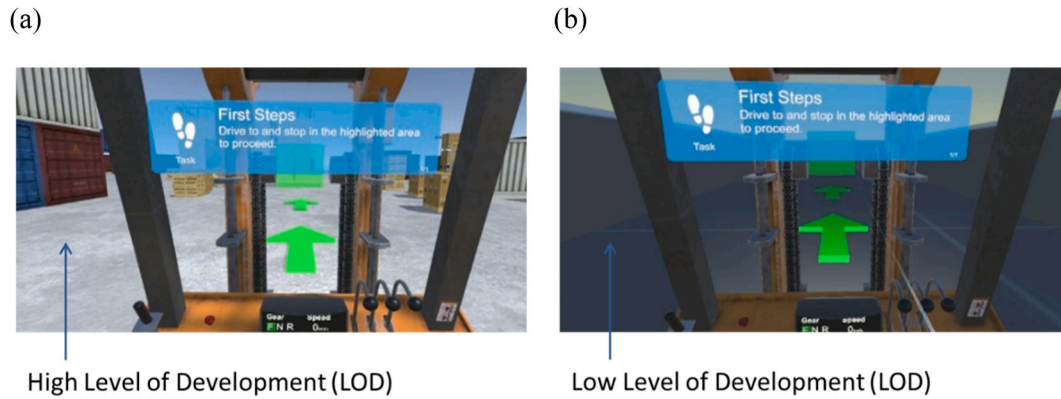


Fig. 2. Different levels of scenario fidelity: (a) High LOD: with realistic ground, containers, pallets, warehouse, and buildings; (b) Low LOD: with simple wireframe walls, direction arrows, and the destination box.

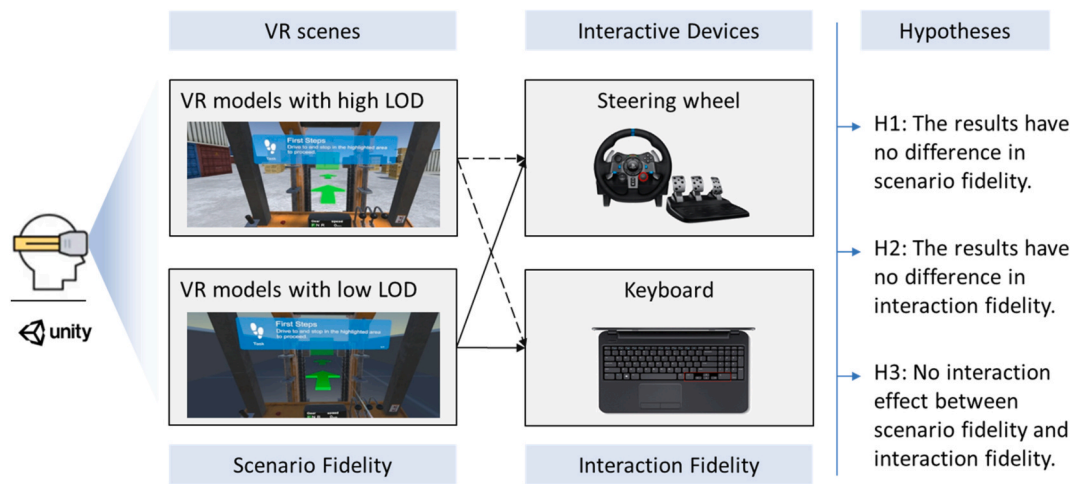


Fig. 3. Experiment design: LOD stands for Level of Development.

3.2. Apparatus

The IVR-based safety training program was run on a Dell G3 laptop, with an Intel(R) Core (TM) i7-8750h CPU at 2.20 GHz, 8 GB of RAM, and a GTX 1060 Graphic card. All participants were equipped with a head-mounted display (Samsung Odyssey+) (2018). This HMD involves cutting-edge technology with a dual 3.5-inch Anti-SDE AMOLED display offering up to a 110-degree field of view and a resolution of 1440×1600 pixels per eye. It also features an exceptional AKG built-in headphone that supports 360-degree spatial audio.

For control devices, a Logitech G29 device, which includes a steering wheel and pedals, was used to create the high interaction fidelity condition. The control device used to create the low interaction fidelity condition was the normal, built-in keyboard on the laptop. In the latter

case, the up and down arrow keys were used to accelerate or brake the forklift, the left and right arrow keys were used for turning, and the control and 0 keys on the side were used for gear shifting. In both settings, a gaming joystick was used to control the fork of the forklift, for example, by moving the fork up and down or tilting it. Figs. 4 and 5 show the different control device settings given to the two groups of participants in the experiment.

3.3. Training modules performed by participants

The IVR-based forklift operation safety training program consists of four modules: (1) training introduction, (2) forklift driving training, (3) forklift lifting training, and (4) task-based training, as shown in Fig. 6. These training scenarios cover the most basic forklift operation tasks,

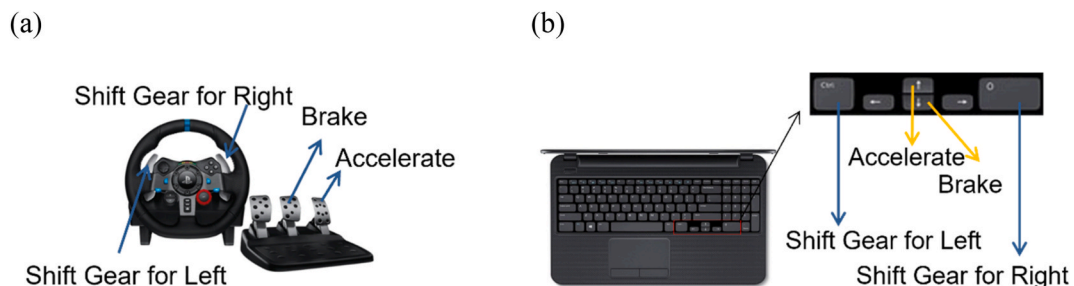


Fig. 4. Different levels of interaction fidelity: (a) High: Gaming steering wheel and pedals (Logitech G29); (b) Low: The keyboard.



Fig. 5. Participants in IVR with different interaction fidelity: (a) Participants with steering wheel and pedals; (b) Participants with the keyboard.

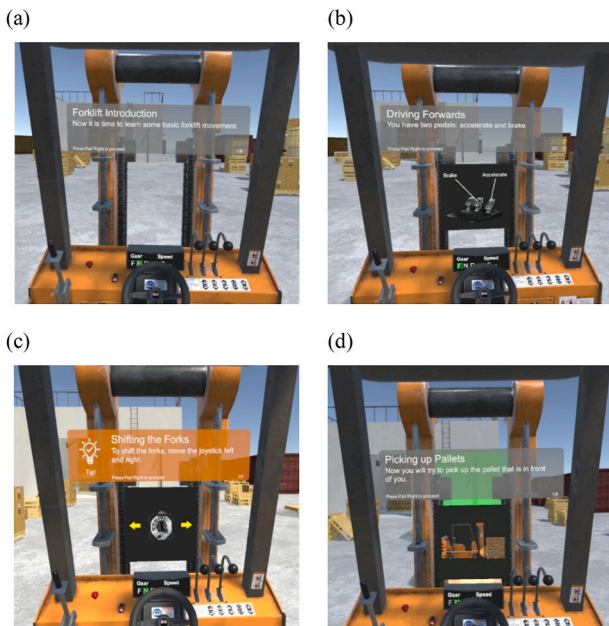


Fig. 6. Example of forklift safety training modules: (a) Training introduction; (b) Forklift driving training; (c) Forklift lifting training; (d) Task-based training.

including pre-operation, traveling, maneuvering, and load handling. In all modules, the user is guided by pop-up instruction messages telling them what to do and what to be cautious about. According to OSHA forklift operation instruction ([Occupational Safety and Health Administration \(OSHA\), 2022](#)), eight forklift safe operation guidelines are embedded in the training program, including (1) check surroundings before forklift driving, (2) drive slowly, (3) look in the direction of travel, (4) no operation of forks while moving, (5) approach pallet safely, (6) load pallet correctly, (7) secure pallet, and (8) travel with forks at the lowest safe height, and users receive real-time feedback messages on how they are performing against each of the safety guidelines as they go through the training modules. Whenever the user violates any of the guidelines, a feedback message box pops up on the display, instructing them regarding what went wrong. It may require the user to restart the task or the entire scenario if they keep ignoring the warning messages. This feedback-based learning model is enabled as the IVR training system monitors every move that the user makes with their head, hands, and feet using the sensors in the HMD and VR control devices.

3.4. Measurement

The most common approach to measuring the sense of presence in VR is the post-test questionnaire. The questionnaire used in this study was adapted from the Igroup Presence Questionnaire (IPQ) ([Schubert et al., 2001](#)) and Witmer and Singer's Presence Questionnaire (WSPQ) ([Witmer and Singer 1998](#)), both of which are the most widely used and well-established instruments for measuring the sense of presence. The WSPQ consists of measuring control factors, sensory factors, distraction factors, and realism factors, and the measurement system is regarded as reliable and mature ([Witmer and Singer 1998](#)). Sample questions included in the WSPQ are "How responsive was the environment to actions that you initiated (or performed)?" and "How proficient in moving and interacting with the virtual environment did you feel in the experiment?"

One weakness of the WSPQ is that it measures factors that affect presence but not the sense of presence itself ([Slater 1999](#)). To address this issue, this study also adapted elements of the IPQ, which is deemed to measure the sense of presence more directly ([Schubert et al., 2001](#)). IPQ includes four sections corresponding to four factors: general presence, spatial presence involvement, and experienced realism. The IPQ therefore focuses more on the subjective feelings of perception, sensation, awareness, and attention than the realism of operation ([Slater, 1999; Schubert et al., 2001](#)). An example of the type of question or statement considered in the IPQ is: "I had a sense of acting in the virtual space rather than operating something from outside."

Researchers have criticized both these questionnaires for not including any questions about uncomfortable feelings a VR user might experience, such as feeling dizzy or sick ([Bowman and McMahan 2007](#)), which is one of the potentially important dimensions affecting the sense of presence. For this reason, this study included one more question, "Did you feel dizzy or sick while operating the forklift in the IVR environment?" to measure the aspect of comfort as well. [Table 1](#) shows the resulting, comprehensive questionnaire used in the research to measure the sense of presence. For each of the measurement items, the participants provide a response on a five-point Likert scale based on how much they agree with the statement.

To measure usability, the task completion times of four forklift safety training VR tasks were recorded. These four tasks were mainly to experience the VR safety training environment, not to learn forklift operation skills. Task completion time is a reliable and objective usability indicator, and it can also reflect the operability of the VR system and the convenience of user operations.

3.5. Participants and procedure

For this experiment, graduate students from the Faculty of Construction and Environment at Hong Kong Polytechnic University were recruited. A total of 120 participants (73 male, 47 female) aged 27 years old on average participated in this study, and they were randomly allocated into four different groups: (1) high-interaction-fidelity and high-scenario-fidelity group (HIHS-IVR, $N = 30$); (2) low-interaction-fidelity and high-scenario-fidelity group (LIHS-IVR, $N = 30$); (3) high-interaction-fidelity and low-scenario-fidelity group (HILS-IVR, $N = 30$); and (4) low-interaction-fidelity and low-scenario-fidelity group (LILS-IVR, $N = 30$). All participants had a background in civil engineering, and each participant engaged in the experiment alone while guided by the experimenter.

[Fig. 7](#) shows the procedure that each participant followed in their session. When they arrived at the experiment room, they were given a brief introduction of the research background and goals, and their consent was collected. Then, they were given a brief instruction on how to put on the headset, use the control devices, and start up the software program. Then, the timer was reset to record the entire time the participant took to finish all four training modules. After finishing all four modules, participants were asked to fill out the PQ used in this

Table 1
Presence questionnaire (PQ).

Category	Subscale	Question/Statement	Source
General Presence (GENP)	GENP1	In the computer-generated world, I had a sense of "being there."	IPQ
Spatial Presence (SPAP)	SPAP1	Somehow, I felt that the virtual world surrounded me.	IPQ
	SPAP2	I felt like I was just perceiving pictures.	IPQ
	SPAP3	I did not feel present in the virtual space.	IPQ
	SPAP4	I had a sense of acting in the virtual space rather than operating something from outside.	IPQ
	SPAP5	I felt present in the virtual space.	IPQ
Sensory Stimuli (SENS)	SENS1	How much did the visual aspects of the environment involve you?	WSPQ
	SENS2	How much did the auditory aspects of the environment involve you?	WSPQ
	SENS3	How well could you identify sounds?	WSPQ
	SENS4	How well could you actively survey or search the virtual environment using the device (e.g. wheel, joystick)?	WSPQ
Involvement (INV)	INV1	I was not aware of my real environment.	IPQ
	INV2	I was completely captivated by the virtual world.	IPQ
	INV3	How responsive was the environment to actions that you initiated (or performed)?	WSPQ
	INV4	How compelling was your sense of objects moving through space?	WSPQ
	INV5	How involved were you in the virtual environment experience?	WSPQ
	INV6	How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?	WSPQ
	INV7	How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?	WSPQ
	INV8	Were you involved in the experimental task to the extent that you lost track of time?	WSPQ
Realism (REAL)	REAL1	How real did the virtual world seem to you?	IPQ
	REAL2	How natural did your interactions with the environment seem?	WSPQ
	REAL3	How natural was the mechanism that controlled movement through the environment?	WSPQ
	REAL4	How much did your experiences in the virtual environment seem consistent with your real-world experiences?	WSPQ
	REAL5	How well could you move or manipulate objects in the virtual environment?	WSPQ
	REAL6	How much delay did you experience between your actions and expected outcomes?	WSPQ
Distraction (DISTR)	DISTR1	I still paid attention to the real environment.	IPQ
	DISTR2	How aware were you of the real world surrounding you while navigating in the virtual world (i.e., sounds, room temperature, other people, etc.)?	IPQ
	DISTR3	To what extent did events occurring outside the virtual environment distract from your experience in the virtual environment?	WSPQ
	DISTR4	How much did you focus on using the display and control devices instead of	WSPQ

Table 1 (continued)

Category	Subscale	Question/Statement	Source
		the virtual experience and experimental tasks?	
	DISTR5	How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?	WSPQ
	DISTR6	How much did the control devices interfere with the performance of assigned tasks or with other activities?	WSPQ
Uncomfortable Feeling (UNF)	UNF1	Did you feel dizzy while operating the forklift in the IVR environment?	

Note: IPQ: Igroup Presence Questionnaire; WSPQ: Witmer & Singer's Presence Questionnaire.

study.

3.6. Analysis of experimental data

The questionnaire data were analyzed using IBM SPSS Statistics 25 software. As there are two independent variables, scenario fidelity and interaction fidelity, and the experiment was conducted following a two-by-two factorial design, a two-way analysis of variance (two-way ANOVA) test was deemed most suitable to test the influence of any of the independent variables as well as their interactive effect on the dependent variables (i.e., the sense of presence ratings and the task completion time).

4. Results

4.1. Difference in the sense of presence under different fidelity conditions

4.1.1. Difference in the presence total mean score between different groups

Tables 2 and 3 show the results of the two-way ANOVA test on the presence score. It is shown that scenario fidelity has the main effect ($F(1,116) = 9.338$ and $p = 0.003$) on the presence score in terms of the results of high LOD ($M = 3.413$, $SD = 0.334$) and low LOD ($M = 3.233$, $SD = 0.311$), respectively. In comparison, interaction fidelity does not show any statistically significant impact ($F(1,116) = 1.690$, $p = 0.196$) on the presence score. Additionally, the two-way ANOVA result shows that there is no interaction effect between scenario fidelity and interaction fidelity ($F(1,116) = 0.153$, $p = 0.696$), which means that the effect of scenario fidelity on the sense of presence is not influenced by the levels of interaction fidelity and vice versa.

The results can be more intuitively reflected in the pairwise comparisons, as shown in Table 4 and Table 5. In the pairwise comparisons of scenario fidelity, the mean difference between high LOD and low LOD is 0.203 ($p = 0.016$) and 0.157 ($p = 0.046$) under the same device group of wheel steering or keyboard. In the pairwise comparisons of interaction fidelity, meanwhile, the mean difference between wheel steering and keyboard is 0.100 ($p = 0.234$) and 0.054 ($p = 0.522$) under the same background condition of high LOD or low LOD. Fig. 8 visualizes this result; the bar graph showing the mean of the sense of presence score does indicate a difference between the high LOD and low LOD groups, but there is no such noticeable difference between the wheel steering and keyboard groups. This result indicates that the participants, on average, reported a different level of sense of presence when their IVR training environment had a different level of detail representing a construction site, but their sense of presence ratings did not significantly differ when they were operating the VR forklift with a more realistic control device such as a steering wheel and pedals or just a keyboard.

4.1.2. Detailed analysis of presence subscales

GENP, SPAP, SENS, INV, REAL, DISTR, and UNF are the seven subscales of presence identified here. We conducted the pairwise

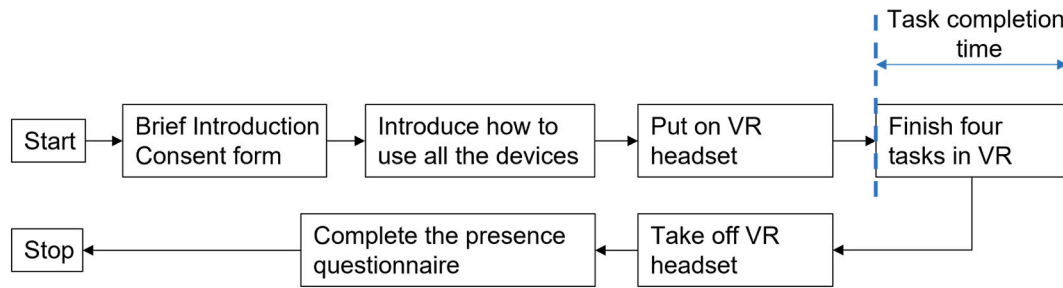


Fig. 7. Experimental procedure.

Table 2

Descriptive statistics of presence total mean score.

Dependent variable: presence total mean score				
Scenario Fidelity	Interaction Fidelity	Mean	Std. Deviation	N
High LOD	Steering Wheel	3.463	0.294	30
	Keyboard	3.363	0.367	30
	Total	3.413	0.334	60
Low LOD	Steering Wheel	3.259	0.352	30
	Keyboard	3.206	0.266	30
	Total	3.233	0.311	60
Total	Steering Wheel	3.361	0.338	60
	Keyboard	3.284	0.328	60
	Total	3.323	0.334	120

LOD: Level of Development.

Table 3

Tests of between-subject effects: presence total mean score.

Dependent variable: Presence total mean score					
Source	Type III Sum of Squares	df	Mean Square	F	Sig. ^a
Scenario fidelity	0.973	1	0.973	9.338	0.003*
Interaction fidelity	0.176	1	0.176	1.690	0.196
Scenario fidelity * Interaction fidelity	0.016	1	0.016	0.153	0.696
Error	12.083	116	0.104		
Total	1338.128	120			

* The mean difference is significant at the 0.05 level.

^a Adjustment for multiple comparisons: Bonferroni.

comparisons for these presence subscales on scenario fidelity and interaction fidelity (as shown in Tables 6 and 7), respectively. In the aspect of scenario fidelity, GENP ($F(1,116) = 5.942, p = 0.016$), SPAP ($F(1,116) = 5.839, p = 0.017$), and UNF ($F(1,116) = 4.112, p = 0.045$) showed a significant difference between high LOD and low LOD. GENP and SPAP clearly reflect a marked increase in the sense of overall presence and spatial presence at high scenario fidelity. Despite the fact that UNF differs significantly in the two levels of scenario fidelity, UNF's average presence scores were relatively low, with results of 2.317 and 1.917, respectively. Another point worth noting is that although SENS

did not show significant differences between two levels of scenario fidelity, it still showed a certain difference in the presence score (Have EN = 3.742, No EN = 3.588), which can still reflect an increase in visual stimulation. When it comes to interaction fidelity, only the subscale of SENS showed significant differences ($F(1,116) = 4.62, p = 0.034$), which can well elaborate that the steering wheel and the keyboard did provide different tactile stimuli for the user. In addition, the presence scores of SPAP and INV in the steering wheel group did show a slight distinction from the keyboard users, with results of 3.690 vs. 3.587 and 3.610 vs. 3.498. These may imply that the steering wheel contributes to the feeling of space and involvement even though these devices were not in the participants' line of sight.

4.2. Difference in task completion times under different fidelity conditions

The results of the two-way ANOVA test on completion time were consistent with the presence total mean scores. As can be seen in Tables 8 and 9, scenario fidelity also showed the main effect ($F(1,116) = 27.191, p = 0.000$) on completion time, with its two levels corresponding to 26.217 min and 20.233 min, respectively. Interaction fidelity did not show a significant difference between the steering wheel and keyboard in terms of results for completion times ($F(1,116) = 0.000, p = 0.988$), and their completion times at these two levels were almost the same, corresponding to 23.217 min and 23.233 min, respectively. In addition, there was no interaction effect on completion time between scenario fidelity and interaction fidelity ($F = 0.026, p = 0.873$).

As can be seen more intuitively from Fig. 9, based on the results of pairwise comparisons, under the condition of using the same set of external devices, the task completion time appeared to show a significant difference when changing the scene fidelity of the internal IVR environment. The mean difference for the steering wheel group is 6.167 min ($p = 0.000$) between high LOD and low LOD, while that for the keyboard group is 5.800 min ($p = 0.001$), as shown in Table 10. Although there were many operational tasks in the IVR model, such as driving the forklift forward, reversing the forklift, operating the fork, and lifting the pallet, there was surprisingly little difference between the two variants of external device in terms of task completion time, with mean difference results of 0.617 min ($p = 0.918$) and -0.200 min ($p = 0.902$), respectively (as shown in Table 11).

Table 4

Pairwise comparisons: scenario fidelity.

Dependent variable: Presence total mean score							
Interaction fidelity	Scenario Fidelity		Mean Difference (I-J)	Std. Error	Sig. ^a	95% Confidence Interval for Difference ^a	
	(I)	(J)				Lower Bound	Upper Bound
Wheel steering	High LOD	Low LOD	0.203	0.083	0.016*	0.038	0.368
Keyboard	High LOD	Low LOD	0.157	0.083	0.046*	−0.008	0.322

LOD: Level of Development.

* The mean difference is significant at the 0.05 level.

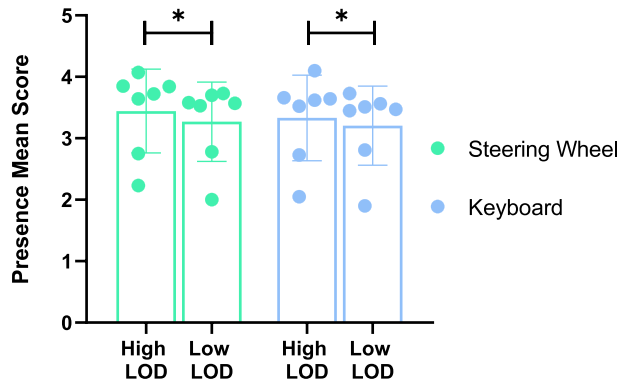
^a Adjustment for multiple comparisons: Bonferroni.

Table 5

Pairwise comparisons: interaction fidelity.

Dependent variable: presence total mean score							
Scenario fidelity	Interaction Fidelity		Mean Difference (I-J)	Std. Error	Sig. ^a	95% Confidence Interval for Difference ^a	
	(I)	(J)				Lower Bound	Upper Bound
High LOD	Wheel steering	Keyboard	0.100	0.083	0.234	-0.065	0.265
Low LOD	Wheel steering	Keyboard	0.054	0.083	0.522	-0.112	0.219

LOD: Level of Development.

^a Adjustment for multiple comparisons: Bonferroni.**Fig. 8.** Presence mean score in four groups.

Note: LOD: Level of Development; * The mean difference is significant at the 0.05 level.

5. Discussion

This study aimed to investigate two kinds of fidelities represented by the IVR system. This was achieved by conducting an IVR-based forklift operation training program. The degree of scenario fidelity was changed

Table 8

Descriptive statistics of task completion time.

Dependent variable: Task completion time				
Scenario Fidelity	Interaction Fidelity	Mean (min)	Std. Deviation	N
High LOD	Steering Wheel	26.300	7.689	30
	Keyboard	26.133	7.771	30
	Total	26.217	7.665	60
Low LOD	Steering Wheel	20.133	4.305	30
	Keyboard	20.333	4.467	30
	Total	20.233	4.351	60
Total	Steering Wheel	23.217	6.916	60
	Keyboard	23.233	6.932	60
	Total	23.225	6.895	120

LOD: Level of Development.

Table 6

Pairwise comparisons for presence subscale: scenario fidelity.

Dependent variable: Presence subscale score							
Presence Subscale	Score		Mean Difference (I-J)	Std. Error	Sig. ^a	95% Confidence Interval for Difference ^a	
	Scenario Fidelity					Lower Bound	Upper Bound
	(I) High LOD	(J) Low LOD					
General presence (GENP)	4.083	3.717	0.367	0.150	0.016*	0.069	0.665
Spatial presence (SPAP)	3.757	3.520	0.237	0.098	0.017*	0.043	0.431
Sensory stimuli (SENS)	3.742	3.588	0.154	0.110	0.166	−0.065	0.373
Involvement (INV)	3.581	3.527	0.053	0.094	0.571	−0.133	0.239
Realism (REAL)	3.670	3.564	0.106	0.097	0.276	−0.086	0.298
Distraction (DISTR)	2.741	2.797	−0.056	0.080	0.483	−0.215	0.102
Uncomfortable feeling (UNF)	2.317	1.917	0.400	0.197	0.045*	0.009	0.791

LOD: Level of Development.

* The mean difference is significant at the 0.05 level.

^a Adjustment for multiple comparisons: Bonferroni.**Table 7**

Pairwise comparisons for presence subscale: interaction fidelity.

Dependent variable: Presence subscale mean score							
Presence Subscale	Score		Mean Difference (I-J)	Std. Error	Sig. ^a	95% Confidence Interval for Difference ^a	
	Interaction Fidelity					Lower Bound	Upper Bound
	(I) Steering Wheel	(J) Keyboard					
General presence	3.883	3.917	−0.033	0.150	0.825	−0.331	0.265
Spatial presence	3.690	3.587	0.103	0.098	0.294	−0.091	0.297
Sensory stimuli	3.783	3.546	0.237	0.110	0.034*	0.019	0.456
Involvement	3.610	3.498	0.112	0.094	0.234	−0.074	0.298
Realism	3.644	3.589	0.056	0.097	0.566	−0.136	0.247
Distraction	2.766	2.772	−0.006	0.080	0.940	−0.165	0.153
Uncomfortable feeling	2.150	2.083	0.067	0.197	0.736	−0.324	0.457

* The mean difference is significant at the 0.05 level.

^a Adjustment for multiple comparisons: Bonferroni.

Table 9
Tests of between-subject effects: task completion time.

Dependent variable: Task completion time					
Source	Type III Sum of Squares	df	Mean Square	F	Sig. ^a
Scenario fidelity	1074.008	1	1074.008	27.191	0.000*
Interaction fidelity	0.008	1	0.008	0.000	0.988
Scenario fidelity * Interaction fidelity	1.008	1	1.008	0.026	0.873
Error	4581.900	116	39.499		
Total	70385.000	120			

* The mean difference is significant at the 0.05 level.

^a Adjustment for multiple comparisons: Bonferroni.

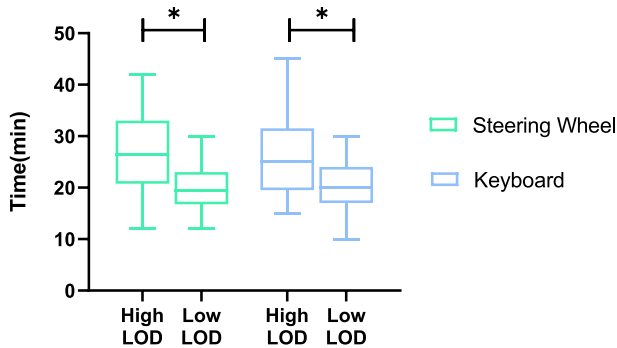


Fig. 9. Task completion time in four groups

Note: LOD: Level of Development; * The mean difference is significant at the 0.05 level.

by changing the LOD of the VR models, while the level of interaction fidelity was changed by using a steering wheel or a keyboard. Specifically, the participants were required to complete four forklift operation tasks in an IVR environment with the four conditions mentioned above. The purpose of this experiment was to assess the users' training experience, namely their sense of presence and usability (completion time), after they had experienced four training sections in IVR. The data show that there was a significant difference in the user training experience when transforming the scenario fidelity, but not when transforming the interaction fidelity. In terms of the sense of presence, participants

experienced a higher sense of presence when there was a higher level of scenario fidelity; in terms of the completion time, participants spent less time on a task when there was a lower level of scenario fidelity.

5.1. The sense of presence in different levels of scenario fidelity

The result that a difference in the level of scenario fidelity leads to a difference in the sense of presence highlights the importance of the realism of a simulated virtual environment in the context of IVR-based safety training. In particular, the results of the analysis on the sub-scales of presence, which show a difference between the high and low fidelity groups, help us understand which aspects of the sense of presence are affected by such differences in the virtual environment. The user feels much less of a sense of "being there" or "feeling present in the virtual space" in the case of low scenario fidelity (as in the GENP and SPAP questionnaire items). These findings resonate with those of Buttussi and Chittaro (2017, p.1073): "The identification of relations between events ... and actions to perform, as well as relations between performed or omitted actions ... had thus a more prominent role than the acquisition of accurate spatial information. Therefore, scenario fidelity could have played a more important role than display fidelity in learning the procedures."

As the sense of presence is an important indicator of how much the user feels that the situation is real, it is logical to expect that the user (or trainee) will be more engaged with the simulated environment and the learning tasks when they feel a strong sense of presence. Such a positive relationship between engagement and training/learning effectiveness in the context of IVR-based learning is supported by previous research findings (Crandall and Karadogan 2021; Zea et al., 2021). These findings, then, could be used to justify the efforts made to create realistic IVR objects and environments as part of investing in an effective IVR-based safety training system.

5.2. The sense of presence in different levels of interaction fidelity

The finding that differences in degrees of interaction fidelity do not lead to a significant difference in the sense of presence might imply that an IVR-based safety training system that uses generic VR control devices, such as handheld VR controllers or even a keyboard, can still be effective for training purposes. High interaction fidelity (such as steering wheels, pedals, levers, and buttons exactly as those used in a real forklift), which enables a full range of actions to be performed by the trainee in a variety

Table 10
Pairwise comparisons: scenario fidelity.

Dependent variable: Task completion time							
Interaction fidelity	Scenario Fidelity		Mean Difference (I-J) (min)	Std. Error	Sig. ^a	95% Confidence Interval for Difference ^a	
	(I)	(J)				Lower Bound	Upper Bound
Wheel steering	High LOD	Low LOD	6.167	1.623	0.000*	2.953	9.381
Keyboard	High LOD	Low LOD	5.800	1.623	0.001*	2.586	9.014

LOD: Level of Development.

* The mean difference is significant at the 0.05 level.

^a Adjustment for multiple comparisons: Bonferroni.

Table 11
Pairwise comparisons: interaction fidelity.

Dependent variable: task completion time							
Scenario fidelity	Interaction Fidelity		Mean Difference (I-J) (min)	Std. Error	Sig. ^a	95% Confidence Interval for Difference ^a	
	(I)	(J)				Lower Bound	Upper Bound
High LOD	Wheel steering	Keyboard	0.167	1.623	0.918	-3.047	3.381
Low LOD	Wheel steering	Keyboard	-0.200	1.623	0.902	-3.414	3.014

LOD: Level of Development.

^a Adjustment for multiple comparisons: Bonferroni.

of situations, is often highly impractical or extremely costly in most normal circumstances. Accordingly, this research finding helps to remove some of the burden of designing highly complicated, realistic control interfaces for every IVR-based training system. However, there is a caveat. The reason that interaction fidelity appears to be less important in the results may be because the measurement items used in this research (e.g., IPQ and WSPQ) are not closely linked with motor controls. If the purpose of an IVR-based training system is to consider such motor-control aspects, then the realness of the control interface and devices would instead be of utmost importance. When, however, the training purpose is mostly about perceptions, awareness, and conscious decision making, the low level of interaction fidelity can still be tolerated and does not critically damage the effectiveness of the training system.

5.3. The subscale of presence: personal discomfort

In terms of the subscales of presence, it is worth mentioning that the experience of personal discomfort (e.g., dizziness) in the IVR environment does not seem to impact the user training experience, based on the results that UNF has a relatively low score in terms of the sense of presence. Other researchers have also found that simulator sickness does not occur frequently and has no apparent impact on task performance (Grassini et al., 2020). A low level of UNF experience was directly supported by the fact that no participant decided to quit the experiment because of UNF symptoms. Intriguingly, it was found that UNF has a relatively higher score when there is a higher level of scenario fidelity; participants tend to have a greater degree of discomfort when more details of texture are added to the IVR scenario (Jaeger and Mourant, 2001; Davis et al., 2015; Chang et al., 2020). This finding is in line with the work of Chang et al. (2020, p.1669) "This unexpected result might originate from the sensory discrepancy between visual and vestibular information." In other words, the more realistic the simulated environment, the stronger the participants' sense of immersion and participation; but when the participants drove the forklift in IVR, they were still sitting in a chair in the actual environment, which would continuously cause a conflict between visual and vestibular information, so their degree of discomfort increased.

5.4. Usability in both scenario and interaction fidelity

For the metric of usability, significant differences were observed for task completion time when the scenario fidelity was changed but not when the degree of interaction fidelity was adjusted. Participants spent a longer completion time in a simulated IVR scene in high LOD. This implies that when the details or complexity of an environment increase and users become more immersed in the virtual experience, they may need more time to complete the task. Some researchers point out that task completion time can be regarded as one of the objective measurements of cognitive load (DeLeeuw and Mayer, 2008; Chevalier et al., 2009; Han et al., 2021). Studies have shown that using even simple VR techniques in education and training can increase the cognitive load of users compared with traditional training methods such as video because the virtual environment requires more cognitive resources and working memory (Meyer et al., 2019; Ebnali et al., 2021).

This balance between engagement and complexity is worth exploring. While it is understood that VR technology can enhance a user's training interest, motivation, and performance (Han et al., 2021; Chen et al., 2022), excessive VR scene details or animations can distract users and increase their cognitive load (Parong and Mayer 2018), thus affecting their training experience and task performance (Chen et al., 2022). Pashler (1994) and Posner and Petersen (1990) have pointed out that it is important to achieve an appropriate level of cognitive load because an individual's cognitive resources are limited, and a heavy cognitive load can impair an individual's performance when information overload occurs. That is not to say the simplest scenario is the best,

but rather that VR materials can be simplified as much as necessary to meet the training requirements (Meyer et al., 2019; Chen et al., 2022). Hence, perfecting the VR scenario requires a fine balance. The design of a VR training system should fully consider all its components, characteristics, and effectiveness to avoid placing an unnecessary cognitive load on a user during training.

6. Contributions

The findings of this study have several theoretical and practical implications. Even though this study focused on VR-based forklift safety training, it is believed that these findings could provide useful insight into designing VR safety training modules for other types of construction equipment. First of all, one of the important theoretical contributions of this study is the systematic exploration of virtual reality training systems by identifying the impact of different fidelities on safety training. This research uncovered that interaction fidelity may have less impact on the sense of presence and usability, and this could imply that we can pay less attention to the input devices of VR systems and look for relatively inexpensive alternatives when adopting VR systems for safety knowledge training. Secondly, this study also highlights the importance of scenario fidelity in VR safety training because of its significant impact on the sense of presence and usability. A high level of scenario fidelity not only improves the sense of presence but also increases the task completion time of four safety training tasks. This may imply that high scenario fidelity may increase users' cognitive load as the scene becomes more complicated. Therefore, it is important to fully understand the trade-off between realism and abstraction in the context of safety training. Thirdly, other researchers can use the framework in this study to explore other fidelity measures, such as display fidelity, or conduct a deeper study on scenario fidelity, such as by providing other VR elements to test the learning in the context of different VR-based safety training programs. Last but not least, findings from this study can be applied when designing other mixed reality-based training systems, such as augmented reality-based ones, since these training systems have similar fidelity components.

7. Limitations and future directions

There are several limitations in the present study that suggest avenues for future research. This study was conducted to discover how different levels of scenario fidelity and interaction fidelity affect the user's training experience, especially in terms of their sense of presence and usability. Although the presence questionnaire is based on two valid measurements, it is still limited in a subjective way. Objective methods such as electroencephalogram (EEG) and skin conductance may offer other means of measuring the sense of presence. It should also be noted that we only adopted completion time as the metric of usability, which may not fully reflect the full user training experience in terms of evaluation criteria. More outcomes, such as task performance accuracy, learning engagement, learning attitude, and cognitive load, can be considered in future studies. Furthermore, it is best to systematically consider experimental design along the fidelity continuum, such as adopting low, medium, and high levels of scene fidelity and interaction fidelity to generate multilevel comparisons of results to avoid experimental bias. In addition, because the four forklift operation tasks conducted in this experiment focused more on IVR training experience than skill training, it can be more cautious to adopt the findings in this study when applied to operation skill training (Pedram et al., 2020). Meanwhile, the training programs can also provide more safety knowledge and skills in the future. Lastly, the subjects in this study were novice forklift drivers. Such a novice training group does not represent how the entire forklift operator community feels about VR training environments. It should be noted that the forklift safety training tasks used in the study were designed to give participants an understanding of the operating environment for those who do not have any prior experience

driving a forklift. Therefore, the graduate students participating in the experiment could be suitable for the VR tasks in this study. However, experienced forklift operators may have different opinions. Therefore, further studies would be needed to see if there is any impact of such prior experience of operating an accurate forklift on their VR-based training experience and usability.

8. Conclusion

The emergence of new technologies such as IVR provides an opportunity to achieve more precise and personalized services for safety training. This study systematically compares the effects of two components of an IVR system, namely scenario fidelity and interaction fidelity, on the user training experience by measuring the sense of presence and task completion time. Results from a study of 120 participants show that scenario fidelity has a significant effect on both presence and completion time, while interaction fidelity has no effect on either. The sense of presence is an important indicator of how real users feel the IVR scenarios are, and this in turn affects their learning motivation and engagement. Presence, therefore, highlights the importance of scenario realism in an IVR-based training system. At the same time, it has been pointed out that certain external devices are not that necessary if the training is primarily about user satisfaction, perceptions, awareness, and conscious decision-making. This illustrates that the realism of the IVR scenarios is more important than the authenticity of the IVR control interface for the user training experience. It was found that participants spent more time on scenarios with a detailed environment than ones with fewer details, since task completion time correlates with the cognitive load of users.

The findings of this study provide significant implications for simulator designers and safety practitioners in terms of effective and economic applications of IVR-based safety training. The research results imply that creating realistic VR scenes would be important for enhancing trainees' training experience, while including all the visual details in the scene might not help increase training outcomes. A hypothesis that can be constructed based on the result is that the complicated visual details in the VR environment increase the trainees' cognitive load and may not help with increasing training effectiveness or efficiency. Based on these implications, it may be possible to recommend that VR-simulator training system developers focus on creating realistic scenarios for training while worrying less about the realism of the scenes and visual details of the simulated environment in VR. From a safety practitioner's point of view, it is a promising result that interaction fidelity can be addressed with fewer efforts when the trainings concern more about cognitive skills and decision-making skills.

Despite the usefulness of these findings in terms of IVR training design, we should be careful when interpreting the results for different types of training. Safety training is largely about developing cognitive and decision-making skills related to what to look for and what to do in certain situations for the safety of oneself and co-workers. This could be the main reason why interaction fidelity was not a significant factor in safety decision-making training. Instead, if the IVR training is designed to transfer operation skills from virtual to real environments, the results could be different. It is expected that further studies on the fidelity of VR training systems would contribute to proposing design guidelines for compound design and decision-making during VR training system development.

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.

Data availability

Data will be made available on request.

Acknowledgments

This research study was supported by the General Research Fund (PolyU 15220519) from the Research Grants Council, Hong Kong, and the 2022 Hongik University Research Fund, Republic of Korea.

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