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# Design to Divide Attention: An Exploration of Designing Virtual Reality Simulations of Accidents

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This project explores whether and how accidents can be simulated in virtual reality (VR). The divided attention of workers in hazardous workplaces (e.g., construction sites) can lead to accidents. Meanwhile, simulating accidents is different from simulating injuries, because accidents involve human errors. The current project focuses on designing VR scenarios that divide users' attention, cause them to make mistakes, and then lead to accidents. Specifically, the goal of the project is to simulate accidents caused by divided attention to enhance users' attitudes toward relevant safety training and procedure. We also reviewed and discussed the challenges of designing VR scenarios that enable users to experience divided attention. Through a reflective exercise, we generated several patterns that could be generalizable to other simulation scenarios.

***Keywords: virtual reality; construction safety; accidents; simulation***

## 1 Introduction

This paper presents an ongoing project to simulate construction site accidents with virtual reality (VR). Here, we view accidents as undesirable incidents caused by mistakes and/or poor choice of actions. We then explored the possibility of designing simulations of such accidents. The outcomes can contribute to the design of training materials and procedures for labor-intensive and high-risk industries, such as construction and transportation.

## 2 Design context - Fall from height accidents in the construction industry

The construction industry has the highest fatality rate among different industries (Chiang et al., 2018). Among the prevalent types of fatal accidents in this industry, the most common are falls from height (Construction Statistics in Great Britain 2018, 2018). In tackling safety issues in the construction industry, safety training is considered one of the major approaches. Previous studies have focused on improving safety training in terms of knowledge acquisition and retention (e.g., Sacks et al., 2013). However, limited attention has been given to workers' attitudes toward safety training and safety in general.

Getting into the shoes of another person, also known as "perspective-taking," is a major topic in attitude change research (Herrera et al., 2018; Shin, 2018). For example, taking the perspective of the elderly has been demonstrated to enhance people's attitudes toward the aging population and policies relevant to this age group (Oh et al., 2016). Related to this, the goal of the current project is to enable construction workers to take the victims' perspectives on construction accidents in order to improve their safety attitudes. VR is used to provide a perspective-taking experience.

# 3 Design challenge - Simulating accidents, not only injuries

The challenge is how to design a VR simulation of an accident. Accidents are not identical to injuries or incidents that cause damage. For example, Norfolk Police introduced a 360-degree video simulation of a car crash from the victim's perspective to enhance young drivers' safety attitudes related to driving ("Virtual reality goggles for young drivers," 2017). In such a simulation, the viewer does not have control or a role in making decisions. We know that accidents happen as a result of human errors or poor choices of actions. In our project context, it is possible to simulate falling off a roof in VR. However, such an experience would only present the perspective of the injured individual. It may not effectively enhance workers' attitudes, because they would not experience the scenario of making mistakes. Moreover, they would think such injuries would not happen to them and would become detached from the victim's experience. Thus, their safety attitudes cannot be enhanced by using this approach.

In relation to the above, we need to design a VR simulation that enables users to experience accidents as a result of their own mistakes. In turn, we can enhance their safety attitudes by delivering a message that everyone can make mistakes, including themselves. Furthermore, they can fully understand the rationale behind safety procedures (e.g., wearing safety belts, installing fences, etc.), which are designed to prevent injuries when someone makes mistakes.

# 4 Dividing attention in VR simulation

Therefore, the challenge is how to design a VR simulation in which the user faces a situation of performing work-related tasks, making a mistake, and then experiencing the injury as a consequence. Many factors contribute to human errors, such as stress (Roll et al., 2019). In this section, we focus on human errors caused by divided attention.

Divided attention has been identified as one of the reasons for construction accidents (Bentley et al., 2006; Hsiao and Simeonov, 2001). According to Hsiao and Simeonov (2001), more complicated tasks require greater attention from workers. Therefore, they can only allocate less attention to peripheral tasks, such as sitting, standing, and walking. Although these peripheral tasks may seem simple, they still require attention to perform them safely. Concurrent tasks (e.g., walking and inspecting) divide workers' attention, making them less vigilant about hazards present in construction sites (Bentley et al., 2006). Related to this, recent studies have focused on the role of attention allocation in construction safety (e.g. Chen et al., 2018; Hasanzadeh et al., 2019).

We need to design VR simulations of various scenarios in which the users' attention is divided by concurrent tasks. Previous studies have used VR simulations to investigate the influence of divided attention in different contexts, such as driving (Lengenfelder et al., 2002). Researchers in cognition and neuroscience have also used VR to study the phenomenon of divided attention (Camara Lopez et al., 2016).

# 5 Design of the VR simulations

Instead of simulating accidents, we aim to simulate scenarios of hazardous working environments wherein people are error-prone and their mistakes can lead to fatal accidents. Specifically, our goal is to simulate situations in which users are likely to experience accidents caused by their own mistakes. Therefore, the first design criterion is that the concurrent tasks should be designed to require most of the users' attention, because that is where mistakes often happen. The second criterion is that the tasks should be relevant to the context of the construction industry and working on a height. The third criterion is that the VR simulation of the fall should not be too scary because of ethical concerns.

We designed and developed four scenarios with Unity in which the users needed to perform a primary task related to working on a height and a secondary task of avoiding unprotected edges. The consequences of making mistakes in the four scenarios are all the same: falling from a height. However, the four primary tasks in the scenarios vary in terms of the level of complexity involved. The users can move in the virtual environment by walking.

## 5.1 Scenario 1 - Inspecting

A common task in the construction industry is inspecting, and examples of these include checking the completion status of a team's work and regular checking of the quality of a colleague's work. If the inspection requires attention to something above one's head, their attention will be drawn away from hazards near their feet. In the VR simulation, the user is reminded of working from a height situation and the unprotected edge (Figure 1). The primary task is to inspect the word written on the sign above the user's head and choose the answer on the instruction panel. The secondary task is to avoid the unprotected edge. Due to the viewing angle, the user must walk away from the sign to read it clearly. However, that would bring them closer to the unprotected edge.

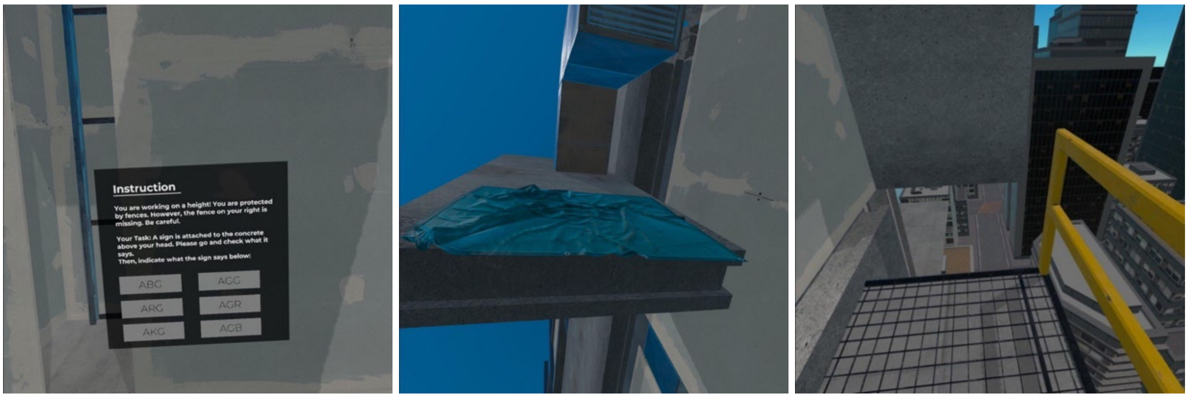


*Figure 1. Screenshots from the VR simulation: (left) the instruction in the VR scenario; (middle) the sign above the user's head; (right) the unprotected edge; Video: https://youtu.be/ofhGfpQYYf4?t=237*

## 5.2 Scenario 2 - Retrieving

The second type of common task we simulated is retrieving. Workers often need to retrieve and bring materials and tools from one place to another. In this scenario, the user is placed in a situation of working next to a large hole (Figure 2). The primary task is to collect all the black buckets scattered on some materials and on a shelf. The secondary task is to avoid the unprotected edge that leads to the hole. The primary task involves counting, which is slightly more complex than the primary task in scenario 1. The visual attention required is on the eye level and above the head. Thus, to perform the task, the user needs to reach out to the bucket further away above the head. However, the bottom of that bucket is where the unprotected edge is.


*Figure 2. Screenshots from the VR simulation: (left) the instruction in the VR scenario; (middle) the black buckets to be collected; (right) the unprotected edge leading to a hole; Video: [https://youtu.be/ofhGfpQYYf4?t=304](https://youtu.be/ofhGfpQYYf4?t=304)*

## 5.3 Scenario 3 - Making

The third type of common task we simulated is constructing. Workers often need to make something according to a specification. In this scenario, the user is placed in a situation of working on a platform next to an unfinished wall (Figure 3). The primary task is to finish the wall by putting numbered bricks on it according to a specific order. The secondary task is to avoid the unprotected edge of the platform. However, in this simulation, the primary task becomes even more complex, because it requires arranging the bricks and checking them against the specification. It also requires the user to reach out to the side where the unprotected edge is.

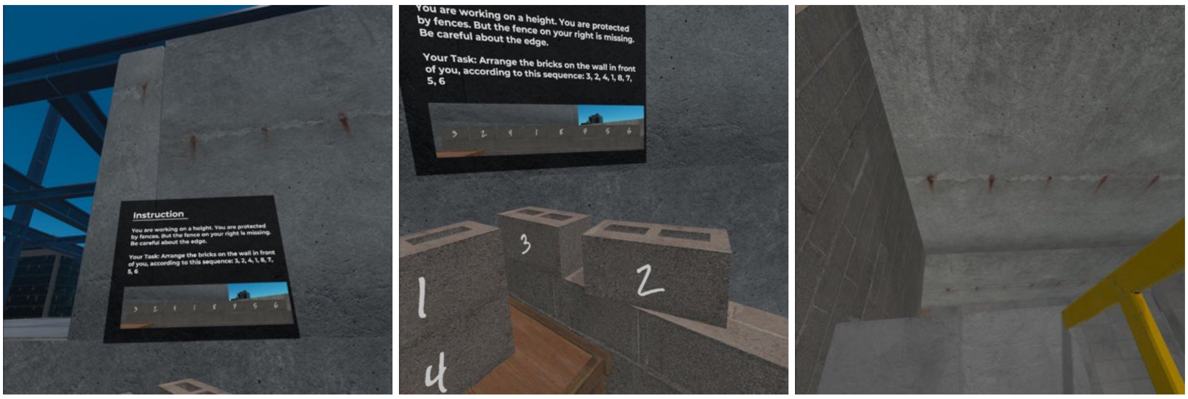


*Figure 3. Screenshots from the VR simulation: (left) the instruction and task specification; (middle) the numbered bricks and unfinished wall; (right) the unprotected edge of the platform; Video: [https://youtu.be/ofhGfpQYYf4?t=22](https://youtu.be/ofhGfpQYYf4?t=22)*

## 5.4 Scenario 4 - Installing

The fourth type of common task we simulated is installing. Workers often need to install a variety of fixtures, such as lights, ceiling, etc. This kind of task requires configuring elements and inspecting them to see if they work. In this scenario, the user is placed in a situation of working on a platform with two unprotected edges (Figure 4). The primary task is to install light bulbs on all the screws above the head. Another layer of complexity is that some of the light bulbs are not working. Thus, the user needs to test and identify the working light bulbs and install them to the ceiling. Some of the screws on the ceiling are slightly away from one of the unprotected edges. The secondary task is to avoid falling to the unprotected edge.


*Figure 4. Screenshots from the VR simulation: (left) the instruction in the VR scenario; (middle) the light screws and an installed light bulb on the ceiling; (right) the unprotected edge of the platform; Video: [https://youtu.be/ofhGfpQYYf4?t=112](https://youtu.be/ofhGfpQYYf4?t=112)*

## 5.5 Falling

There are possible ways to complete the tasks without falling, and falling from a height does not happen if the tasks are successfully completed. To avoid scaring the users too much, whenever the user falls in the VR simulation, a slow motion effect is activated. Thus, they can only see and experience a very slow fall when it happens.

# 6 Pilot study

Six participants (three males and three females, ages: 23–34 years) experienced the four scenarios in randomized order. Three of them were regular users of VR devices from 6–24 months. We presented the VR scenarios to the participants using Oculus Quest 2. Then, we observed their behaviors and interviewed them afterwards.

## 6.1 Initial insights

*Feeling the simulated danger:* In the interviews, the participants expressed that they felt the height in the VR simulation. P4 expressed that the distance he saw was so realistic he felt like he would almost fall (Note: P4 achieved all four tasks without falling). We also observed that the participants attempted to explore safer ways to achieve the tasks. For example, P1 and P3 tried to grab and pull the sign down in scenario 1, P4 tried to walk around the big hole in scenario 2 to reach the buckets, and P5 tried to climb on the unfinished wall by piling up the bricks provided. These findings suggested that the simulations were successful in simulating the hazard of working on a height.

*Designed to fail:* P6 felt that the scenarios were designed intentionally to make them fall. During the exposure to the VR simulation, P1 asked if it was possible to complete tasks without falling. We told him that it was possible to do so. In the interview, he said that, at one point, he thought that it was not possible to complete the tasks without falling. He had doubts on whether the scenarios were actually designed to make them fail and fall.

*Body height and task completion:* It seemed that whether the participants would fall in scenarios 2, 3 and 4 depended on their body height and arm length (Note: P2 and P4 were taller). We did not measure each participant's height because we did not expect such data to be relevant. We only estimated by eyeballing in the video recording to compare their heights with the researcher's. This raises a concern that the possibility of falling is related to the height of the users. As the goal of the simulations is to present the fall as a result of mistakes made in performing the tasks, the setup of the environment (e.g., how far an object is placed outside the edge) may need to be adjusted based on individual users' body measurements.

*Lost in scenario 1:* Some participants (e.g., P2, P3, and P5) could not find the sign above their heads in scenario 1. P3 even re-iterated this during the interview. Hence, clearer instructions and more prominent guides are needed in future simulations.

*Offering alternatives:* Participants P1 and P4 said that in real life, they would have found a safer alternative to achieve the task, such as securing a safety belt or grabbing on to something before reaching out of the unprotected edges. P1 suggested offering a way to give up in the VR scenarios, while P6 mentioned in the interview that she would rely on things in the environment (e.g., use a fence) to complete the task safely. This opens up a new discussion on whether the VR simulation of risky work scenarios should provide alternatives to either safely perform the tasks or to give up in the VR. A safer alternative would be using a safety belt found in the environment, while a give-up option could be talking to supervisors about the safety concerns or refusing to perform the tasks altogether due to safety concerns.

*Simulating* users' feet: P1 expressed that he would like to see his feet, as not being able to do so made it difficult to find exactly where the edge was. Thus, he wanted to use his feet to get a sense of where the unprotected edge was located.

# 7 Discussion and conclusion

There are two important elements that should be considered to accurately simulate accidents in VR. The first is the difficulty level of the assigned task. On the one hand, if the task looks too difficult (e.g., objects are too far to reach) and the users are required to perform it, then it feels as if the researcher is pushing them to fail and, therefore, fall. It would not look like an accident. On the other hand, if the task is too easy, they can complete it without falling. They would not experience any fall, and they would not "experience" an accident. Therefore, the tasks need to be designed in such a way that they seem achievable without the need to exert effort to look for safer alternatives. This is very similar to scenarios in which workers take shortcuts and skip safety protocols in construction sites.

The second element is the availability of choice. When users recognize the risks but are not given an option to not perform the task, they may feel that they are forced to fail (and fall). The suggestion of giving up, such as refusing to perform the task by talking to the supervisor or to counter-propose a safer way to perform the task actually resembles the idea of proactive safety behavior in construction safety.

Thus, based on these initial insights, the design of the VR simulations will be further improved and evaluated in the future.

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