Social Influence on Construction Safety Behaviors: A Multi-user Virtual Reality Experiment

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ABSTRACT

The construction industry is a high-risk industry in terms of job site safety. Construction workers' unsafe behaviors has been criticized as a key driving factor of construction safety incidents. A variety of studies indicate that social influence greatly affects workers' safety behaviors. However, the social influence on workers' safety behaviors in hazardous situations has not been well explored, partially due to the difficulty of simulating hazardous situations in the real world. To overcome this limitation, this research utilized a Multi-user Virtual Reality (MVR) system with motion tracking function to simulate hazardous scenarios to study how social influence affects construction workers' safety behaviors. A hazardous virtual environment with a plank between two high-rise buildings was created to simulate the high-rise walking scenarios of iron workers in construction projects. A human-subject experiment (n=126) was conducted to investigate the role of social influence in a simulated scenario involving walking across a narrow plank between two virtual high-rise buildings. The participants walked through the plank in the virtual environment while observing different scenarios, such as seeing a person slowly walking across the plank or falling from the plank. Participants' behaviors, such as the time taken to walk across the plank, were recorded and analyzed to understand effects of social influence. The results of the experiment indicate that social influence played an important role in safety behaviors in the virtual hazardous situation. In addition, the developed MVR system is able to serve similar experiment in the future.

INTRODUCTION

Nearly 80% of the construction safety incidents and accidents are caused by human errors (Garrett and Teizer 2009), and most of these human errors are caused by construction worker's unsafe behaviors (Choudhry and Fang 2008). A variety of factors including lack of safety awareness, work stress, organizational factor, and economic factor have been found to affect construction workers' safety behaviors

(Choudhry and Fang 2008). One recently identified root cause of unsafe behaviors is social influence at the work site, which is often referred to as safety climate or safety culture. Evidence has shown that a positive safety climate can reduce unsafe behaviors in the construction projects (Zohar 2010). At the same time, the interpersonal social interactions can influence construction workers' safety behaviors (Jiang et al. 2010; Mullen 2004). However, investigation of how social influence affects workers' safety behaviors in hazardous situation has not been well explored. This study focused on investigating the social norms and social learning under social influence process. To be more specific, this study aims to address two research questions: 1) how is social norm formed and what is its impacts on construction safety behaviors? 2) How social influence affects people's safety behaviors in the hazardous situation. Cialdini and Trost (1998) defined social norms as rules and standards that are understood by a group of people and guide constrain social behaviors. Meanwhile, according to social learning theory (Grusec 1992), there are two ways in reinforced learning (Bandura and Walters 1963)– award and penalty. It remains unclear about the way in which showing negative consequences (penalty) of unsafe behaviors affects construction workers' safety behaviors. Since hazardous situations are difficult to simulate in real-world scenarios due to practical safety issues, a Multi-user Virtual Reality (MVR) system has been developed to evaluate the impact of social influence on safety behaviors in hazardous situations. Numerous VR studies indicate that high-fidelity virtual environments can provide a strong sense of presence and cause participants to respond realistically (Slater 2009). Thus, this MVR system can be an effective approach to study safety behaviors in dangerous scenarios. A hazardous virtual environment with a plank between two high-rise buildings was created to simulate the high-rise walking scenarios of iron workers in construction projects. This study focuses on simulating the phycological process and behavior reaction of people in high-rising walking scenario. There are two objectives in this study: First, the study aims to test the usability and feasibility of the MVR system to study human behaviors in hazardous situation. Second, this study aims to investigate how social influence (social norm and social learning) affects people's safety behaviors in the hazardous situation.

RELATED WORK

Social Influence in Construction Industry

Blascovich (2002) defined social influence as a process that people influence each other implicitly as well as explicitly. Studies have evaluated the effectiveness of social influence in different contexts. For instance, Jain et al. (2013) studied the impact of social influence on energy consumption behaviors. They conducted an empirical experiment to investigate the correlation between social network and energy consumptions in residential buildings. The results indicated that social influence had positive effects on energy savings based on energy consumption feedback. Meanwhile, social influence has also been investigated for safety behaviors of construction workers. Choi et al. (2016) studied the impact of social norms and social identifications on safety behaviors of construction workers. They collected empirical data from 284 workers in the United States and found that construction workers' safety behavior was affected by the social norms and especially workgroup norms.

Virtual Reality in Construction Safety Area

Due to the evolution of recent technological developments, VR has become an affordable and accessible new approach to study construction safety problems. Brooks (1999) defined VR as a responsive 3D virtual environment that the user can experience through dynamic viewpoint control. Different from traditional 3D applications, VR can not only provide a high fidelity virtual environment but also realistic interactions with various construction components (Kamat et al. 2010). Numerous studies have found that VR can provide a strong sense of presence (Slater 2003), train specific behaviors(Ragan et al. 2015), and trigger similar user behaviors as in the real world (Heydarian et al. 2015). As a result, researchers have started to use VR to study construction safety problems. For instance, Sacks et al. (2013) investigated the effectiveness of using VR on construction safety training. The researchers compare the performance of safety training by using traditional classroom training with visual aid and using a 3D immersive environment on a large wall display. They found significant advantages of using VR training for stone cladding work and cast-in-situ concrete work. The VR training helped participants maintain attention and concentration during the safety training process. Meanwhile, the effectiveness of VR training has also been illustrated for promoting construction safety. Zhao and Lucas (2015) developed a VR-based safety training system to improve construction workers' electrical hazard awareness and intervention knowledge. Their system can effectively help users to rehearse electrical hazard tasks.

EXPERIMENT

Overview

The primary goal of this experiment is to investigate the effects of social influence (social norm and social learning) on construction workers' safety behaviors in hazardous situations. The design of our experiment follows the assumption that a high-fidelity virtual environment can realistically simulate a real-world hazardous scenario and the participants behave realistically in the virtual environment. **Figure *1*** shows the VR setup and virtual environment. The study required participants to walk across a plank between two high-rise buildings while observing three different experimental conditions: 1) a scenario with no other people in the virtual environment (*control* group), 2) a scenario where the participant watches another avatar quickly walking across a plank and then fall off (*falling* group), and 3) a scenario where the participants watches another character slowly walk across the plank without falling (*non-falling* group). The time it took for participants successfully walk across the plank was measured as the performance indicator in this experiment.

There are two hypotheses for this experiment. The first is that the *falling* group would take longer time to cross than the *non-falling* group. The reason for this is that since the participants saw the avatar falling, they might be expected to think it would be safer for them to walk slowly and carefully across the plank. The second hypothesis is that the non-falling group takes less time than the control group. Since the participants saw the pre-play avatar safely walking through the plank, it gains more confidence and set a walking example for them to quickly walk through the plank. An MVR system (Shi et al. 2016) with motion capture feature was used as the study instrument in this research. The developed system consists of an RGB-D camera, VR technique, and cloud networking. The function of the developed system is to capture the depth and actual motions of the user in real time and synchronize the captured data to the animations of the avatar in the virtual environment. **Figure *2*** illustrates the framework of the developed system.

Virtual Environment System Design

The first step of the research was to create a hazardous scenario in the virtual environment. The high-rise building scenario was built with a virtual plank that was carefully calibrated to match the real size and position of a wood plank in the real world. By matching the physical and virtual objects, this allowed participants to feel the edge of the plank with their feet, which provided greater tactile realism and sense of height for the high-rise scenario. **Figure *1*** shows the virtual environment along with the physical setup and real wooden plank. The length of the plank in the real world was 10 ft.

Figure 1. Views of the environment and motion capture system used in the experiment. The left image shows the real-world setup, the middle shows the first-person view in VR, and the right image shows a perspective view.

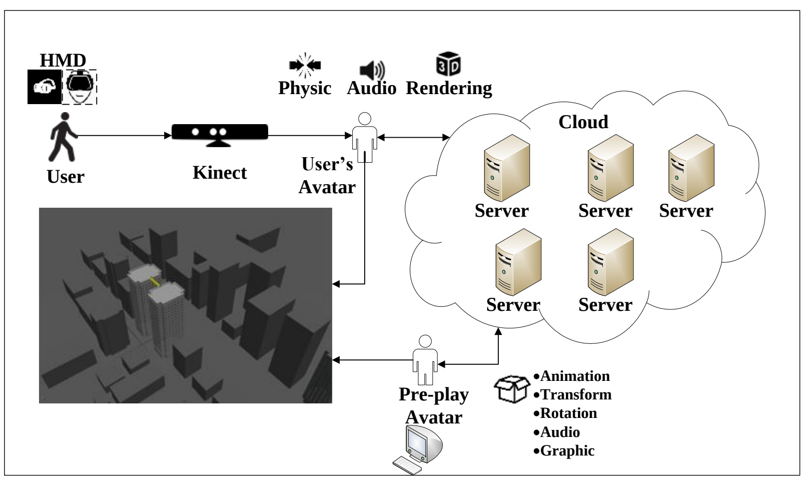

Figure 2. The framework of the system

Unity 3D was used to create the virtual environment. The building model was modified with physical features to allow participants to freely walk on the top of the buildings and plank. Participants viewed the environment through first-person perspective and also had character avatar for their bodies. The avatars were also created with physical features so they could realistically fall from the plank in the virtual scene. Participants navigated using real physical walking. A Microsoft Kinect was used for real-time body and movement tracking so participants' physical motions could be mapped to their virtual avatars. Previous research has shown that navigation via real walking can allow a high sense of presence in VR (Usoh et al. 1999). To achieve the multi-user functionality, the study application used Photon Unity Networking (PUN), a third-party cloud server to enable different users to interact in the same virtual environment. Collision geometry was used to automatically record the time between when participants started walking and when they reached the end of the virtual plank. Figure 3 shows the perspective view of the virtual environment and the colliders used for recording the time.

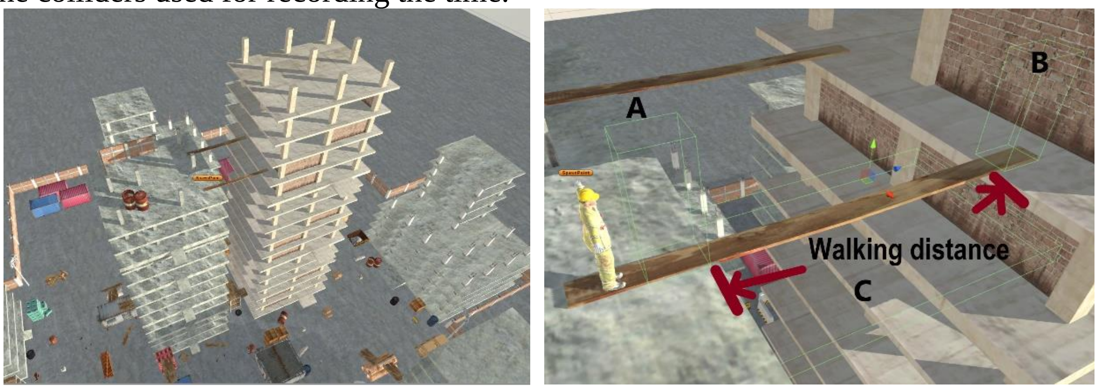

Figure 3. The left image shows the perspective view of the virtual environment. The image on the right shows the colliders that were used for recording the time.

Movement Tracking

As mentioned above, a Microsoft Kinect was used to capture participants' body motion to enable real walking for the experiment. The Kinect uses an RGB-D camera and was originally designed to provide a more interactive gaming style for Microsoft Xbox console. However, at an inexpensive price and with relatively good performance, it became a popular tool among researchers who carried out studies related to body motion capture in the construction field (Han and Lee 2013). Specifically, it was widely used in the field of virtual reality. It can be used for either detecting the motions of the user or navigating the virtual environment (Dam et al. 2013).

The experiment used the depth information captured by the Kinect to synchronize physical body movements with the virtual avatar. To achieve these functions, the skeleton tracking function provided by Microsoft Kinect SDK (Microsoft 2016) and a wrapper library (Filkov 2014) integrated with Unity were used in the VR application. Using this function, the position of each joint can be retrieved using the SDK, which can be used to update the position joints of the avatar in the virtual environment. In this study, Oculus Rift CV1 was used as the Head Mounted Display (HMD) device for providing the virtual environment for the users.

Participants

The study was approved by our organization's review board for human-subjects research. 126 participants (90 males, 36 females) took part in the study. All participants were recruited by email. Participants' age ranged from 18 to 66, with a median age of 23. 115 of them were students (58 were undergraduate students, 57 were graduate students) and 11 were university staff. Participants were from a variety of disciplines, and most of them were construction science students and architecture students. 69 participants reported that they regularly played video games. 49 participants reported that they had VR experience before the experiment. Each participant was randomly assigned to one experimental condition (*control*, *falling*, or *non-falling*) before the experiment. At the outset of designing the experimentation, research team's biggest concern was on the potential existence of participants' bias effect. To be proactive from this issue, as described above, participants were carefully and randomly chosen to be logical in setting up a research assumption that participants are not biased in handling any danger by the level of education, experience, and age.

Procedure

For each participant, the study procedure took approximately 15 to 30 minutes. The study procedure consisted of three stages: the preparation stage, the plank walk stage, and the post-study interview phase.

Preparation Stage - After signing a consent form describing the experiment, the participants were asked to provide their basic demographical information (gender, age, and occupation). Participants were also asked if they had video game experience and VR experience since these experiences can influence participants' task performance in virtual scenarios (Enochsson et al. 2004). Next, participants were introduced to the virtual environment and familiarized with the tracked movement, view control, and synchronization between physical and virtual bodies. For this familiarization portion of the study, the virtual avatars were positioned away from the edge of the building so that the plank was visible but not accessible. This way, participants could see and understand the plank-walk scenario without feeling the stress of being close to the edge of the high-rise building. Participants were given instructions about the scenario and told they would be asked to walk across the plank without falling. The participants had 5 minutes to familiarize the virtual environment and motion capture features before they started the walking section.

Plank Walk Stage – After the familiarization, the participant's view and avatar were automatically transitioned to near the edge of the building and the plank. Participants were instructed to step onto plank (with the physical plank now matching the virtual). For the *falling* and *non-falling* conditions, participants then watched the other avatar walk across the plank (and fall in the *falling* condition). Participants were then instructed to walk across the plank. Figure 4 shows examples of participants walking through the plank in the experiment.

Interview Stage - After the plank walk session, the experimenter conducted an interview to collect qualitative data from participants about the experience. We asked four open questions and one question with a 5-point Likert scale: 1) *How was the VR experience? Can you explain how did you feel in the virtual environment? 2) Was there anything that made it easier or harder to walk across the plank in the virtual environment?* 3) *What do you think about the avatar on the other plank?* 4) *Do you think the movement/behavior of the avatar affected you or your walking?* 5) *Can you rate how much you think the avatar's movement/behavior affected your walking/behavior? (1-no effect,5-strong effect)*. The participants were also asked for any other comments or feedback at the end of the interview session.

Figure 4. Example of participants walked through the plank in the experiment.

RESULTS AND ANALYSIS

There were 42 participants in each of the control, falling, and non-falling groups of our experiment. Based on the 1.5 interquartile range (IQR) rule for outlier handling, 5 outliers were removed from the results. After removing the outliers, there were 40 participants in the control group, 40 in the falling group, and 41 in the non-falling group. For each condition, we report the mean (M) and standard deviation (SD) of the time taken to walk across the plank. The *control* group had M = 23.46 and SD = 14.8, the *falling* group had M = 16.62 and SD = 9.03, and the *non-falling* group had M = 18.56 and SD = 10.31. Since gender (Cutmore et al. 2000), video game experience, and VR experience (Enochsson et al. 2004) play important roles in people's VR performance, we analyzed the data of the experiment by these factors. We did not find any significant difference based on gender or video game experience, However, we found a significant effect ($p = 0.025$) due to control group, falling group, and non-falling group for the participants who had VR experience. In order to rule out the unwanted influence of different VR experiences, we analyzed the participants who have VR experience in the experiment.

Walking times in the different groups were found to not be normally distributed based on the results of Shapiro-Wilk tests of normality, so the data did not meet the assumptions required for parametric statistical testing. Since the data was nonparametric, a Kruskal-Wallis test was used to compare the times across conditions, and we used $\alpha = 0.05$ as the threshold for significance. The reason why the standard deviations are high in the control group is that there is no walking example in the control group. The participants adopted different and personalized strategy in the walking speed selection. Thus, the standard deviations are high in the control group (M = 26.42 and SD = 15.91). However, for the non-falling group, there was a pre-play avatar walk across the plank before the participants walked. The pre-play avatar set a walking example for the participants in the non-falling group. The phenomenon of social norm formed in the non-falling group. Thus, the mean and standard deviations (M = 22.36 and SD = 9.41) became lower compared to the control group. Moreover, for the falling group, when the participants saw a pre-play avatar falling from the plank, the avatar's falling strongly affected participants' walking behavior. All the participants walked faster to across the plank. The mean and standard deviations (M = 14.5 and SD = 7.77) of the falling group became lower compared to the non-falling group. We found a significant effect ($p = 0.025$) for the participants who had VR experience. A post hoc Conover's test found differences between control group and falling group ($p=0.036$), and between the falling group and non-falling group (p=0.042). We did not find significant differences between control group and non-falling group (p=0.855). These results suggest that social influence had an effect on walking behaviors for the participants who were more familiar with VR and simulated 3D environments, which could be because those participants are more accustomed to perceiving and reacting to environmental changes. The results of the experiment also reveal that social norm was formed in the non-falling group compared to the control group (hypothesis #2) and the pre-play avatar's falling condition strongly changed participants' walking behavior (reject our hypothesis #1). Figure 5 shows the result of participants who had VR experience.

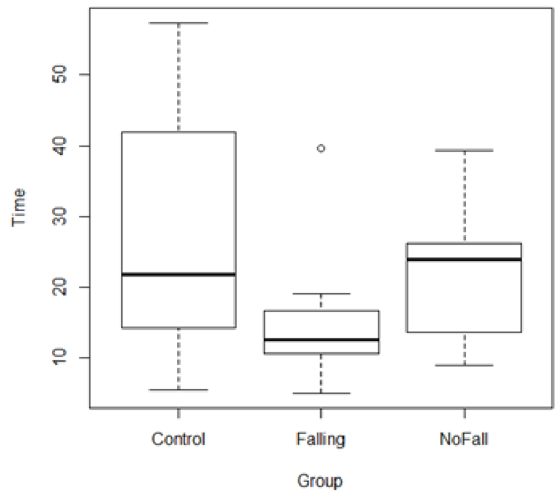

Figure 5. The image shows the results of participants who have VR experience

CONCLUSIONS AND DISCUSSION

The developed MVR system was introduced, and its potential for studying human safety behavior was illustrated for real-world construction scenarios by conducting a human-subjects experiment. Based on participants' feedback, the virtual environment can provide a realistic experience of being in a hazardous situation in the construction project. This study contributes to social influence in the construction industry in two ways: (1) it indicates that observation sets the basis of social norm formation, where participants who observed the other avatar's walking tended to select a walking speed in a narrower range. In other words, the individual difference on walking speed has been reduced by a potentially formed social norm. Based on the experiment results, the walking time in the control group is quite discrete. When there is walking example shown before the participants walked, the walking time becomes concentrated. The social norm formed in the non-falling group. (2) This study also indicated that other people's unsafe behaviors (falling behaviors in this study) affect participant's walking behavior in the hazardous situation. Based on the experiment results, when participants saw the avatar falling from the plank, all the participants in the falling group walked faster. This was probably because the participants wanted to quickly resolve the hazardous scenario, which could lead to more mistakes and unsafe behaviors in the hazardous situation.

Several limitations still need to be addressed in the future study. First, the calibration accuracy between participant's actual movements and virtual animations still need to be improved. Some participants mentioned that there were slight movement mismatches in the virtual environment when they rotated their bodies or walked on the plank. These mismatches affected participants' feeling of presence (that is, the sense of really "being there" in the simulated world). More accurate motion tracking could be used for future systems. Second, this study focused on studying how social influence affects people's behaviors in high-rise buildings and hazardous scenarios. Other hazardous scenarios need to be identified and simulated in the future studies. Lastly, the animation realism of the experimenter-controlled avatar could still be improved, as some participants commented that the realism of the other avatar may have affected their responses and reactions in the virtual environment.

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