# How Sounds Influence People's Safety Decisions - Human Interaction with a Virtual Reality Simulator

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**ABSTRACT**

**Safety decisions made by construction workers on-site directly affect the rate of accidents and injuries. Virtual Reality safety simulators have been created for training workers in site safety. This paper examines the effect that sound has on the realism of virtual reality simulators and the effect that virtual reality training has on subsequent behavior in the physical world. A Virtual Reality environment was built for the tests. Tests involved maneuvering a wheelbarrow around a construction site. Safe and unsafe routes were available. Participants were divided into two groups, those with background sounds in their simulation and those without. A physical environment was built to investigate if use of the virtual reality environment resulted in behavior changes. Participants also completed questionnaires after the tests to discover why participants acted the way they did. The paper is unique in testing users with and without sound in a construction safety simulator. Preliminary study results show that people are likely to perceive more risks when there is no background sound which results in fewer accidents. Results of the paper are useful for those creating virtual reality simulators. Limitations of the research are that it applies to a very specific problem and results need to be generalized over a larger set of problems. Future research is also required to determine what sound range (in terms of decibels) is best for virtual reality training.**

**Keywords –**

**Safety Decision; Construction Sounds; Virtual Reality Simulator**

## 1 Introduction

### 1.1 Sound and Safety

The construction industry is recognized as having a higher rate of injuries and fatalities than most other industries [19], [20], [21], [22]. Thus a major focus of construction managers is on safety issues. There are many factors that contribute to construction safety and health issues, such as the level of health and safety awareness among employees, the level of legal enforcement, awkward postural requirements for equipment operators, and noise [15]. Construction sites are noisy environments. Haslam et al (2005) found that in some cases, a high level of background noise contributes to construction accidents by making it difficult to understand instructions [5]. Much research has focused on hearing loss caused by loud noise on construction sites [17], [18]. Noise can result in people's distraction or depression, which will affect people's safety decisions. Researchers also found that although there is no direct association between environmental noise and mental health, anxiety and depressive symptoms are more prevalent in people living under high noise exposure, especially people who are extremely sensitive to sound [14]. However, the influence of sound and noise on construction worker's behavior has been less extensively investigated. This paper investigates how sound and noise affects construction site worker's safety decisions.

This paper will distinguish between background noise (sound that comes from other construction activities and mainly functions as a distraction), and salient sound (sound that helps the worker sense and interpret their work and surrounds). McDonald et al. (2000) found that salient sounds enhance early perceptual processing of visual stimuli [7]. Based on this research, Hecht et al. (2006) implemented a multimodal virtual environment experiment, including visual, sound, and haptic (tactile) feedback. Results showed that the sense of presence is greater in the multimodal virtual environment than in a purely visual environment [6]. Thus sound can be both helpful and a hindrance. This paper seeks to investigate how this relates to virtual reality simulation.

### 1.2 Virtual Reality Simulator

A virtual reality environment is a simulated environment generated by a computer [23].

Past studies have evaluated many applications of virtual reality. One theme has been to investigate whether virtual reality is a valuable tool for construction engineering education. Two experiments described in Messner et al. (2003) demonstrated the high educational value by having students develop 4D CAD models for a building project, and immersing students in a virtual construction project and allowing them to develop a construction plan for the facility [8]. Sacks et al. (2006) studied the effectiveness of conventional safety training with virtual reality, and found that training with virtual reality was more effective, and also enabled the participants to retain concentration for longer, than traditional safety training [11]. Another popular topic of virtual reality research in construction is building information modelling (BIM). Automated rule-based safety checking systems on BIM platforms can automatically identify potential safety hazards and suggest corresponding prevention methods [16].

However, generally the focus of virtual reality research has been on the construction process and little research has been done on the worker's activities. Potonnier et al. (2013) conducted an experiment to test the ability of a virtual environment based assembly task simulator to evaluate physical risk factors in ergonomics, where they found that using virtual reality for ergonomic evaluation of assembly tasks is still challenging, as it takes a lot of detail in the simulation for it to work effectively [9].

This study will test whether people behave similarly in virtual environments to the way they behave in physical environments and test how sound affects the effectiveness of using virtual reality as a teaching method for construction safety training. The virtual reality simulator used in this study contains an avatar that research participants can manipulate to perform analogous actions to those in the physical world.

The hypotheses of this study are:

1. Initial behavior in the virtual world will mirror the expected initial behavior in the real world.
2. Behavior learnt in a virtual world will subsequently be used in the real world, including safety lessons and vice versa.
3. The addition of sound to the virtual reality simulator will increase the similarity of people's behavior in the virtual world and the real world and hence increase the likelihood that people will use safe working methods.

The paper elaborates the experiments to be used in this study (both virtual and physical environment tests) and presents some preliminary results from the virtual reality simulator.

## 2 Research Method

### 2.1 Test Environment

#### 2.1.1 Virtual Reality Environment

In this study a 3D virtual reality simulation of a construction site was created. Participants were given the task of moving virtual bricks around a construction site using a virtual wheelbarrow. The particular characteristic of the site was that there is an excavation or void between the origin and destination points for the bricks. Participants could decide to either take a longer route around the excavation or a shorter route across a thin plank that lay across the excavation. The idea being to see if participants would recognize that the plank would probably break under a load of bricks. Participants controlled the movement of the wheelbarrow with keyboard and mouse.

The reason a wheelbarrow is used in the simulation is that it provides some difficulty in maneuvering and so participants are originally told that they are engaged in a wheelbarrow simulation rather than a safety simulation. This is to prevent, or at least minimize, the Hawthorne Effect [24].

Figure 1 shows a plan view of the site, showing the alternative routes. Figure 2 shows what the participant sees when using the virtual reality environment.

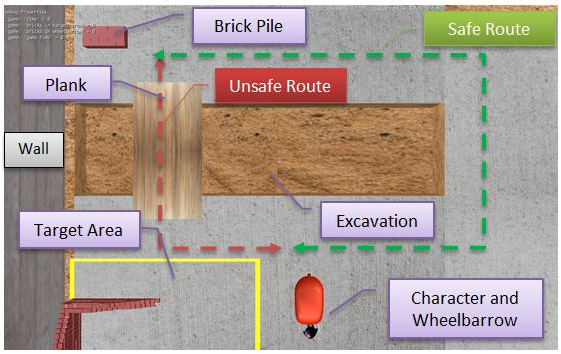


Figure 1 Plan view of the virtual environment

In Figure 2, the camera view represents the participant's field of vision. They could look around by moving the mouse. The W, S, A, and D keys are used to push/pull the wheelbarrow, or move left/right. Note that these keys are the standard keys used for these controls in first person computer games because of their appropriate positioning.

Figure 2 Player's view of the virtual environment

The background sounds implemented in the simulation involved the sounds of a truck, unloading of steel and a reciprocating saw. These sounds made up the construction noise. Salient sounds were generated when the participant performed certain actions, such as the sound of footsteps, the wheel rolling on the ground, and the wood plank creaking when loaded.

There were also some sound effects related to the consequence of mistakes added to the virtual reality simulator, such as the sound of the wheelbarrow falling over, the wheelbarrow breaking if it is overloaded, or the person screaming if they fall into the excavation. These sounds were used to enhance the severity of consequences to the participants.

#### 2.1.2 Physical Environment

The task will also be repeated in a laboratory, where an identical physical environment will be set up. The excavation and test environment will be marked on the floor using tape. The plank will be represented by a piece of plywood lying flat on the ground. Participants will be asked to move the 'bricks' (appropriately sized tissue boxes) using a real wheelbarrow to a target area.

The aim of repeating the task in the laboratory is to validate the results given by virtual reality simulator tests, and to evaluate the effectiveness of using virtual reality simulation as a training tool.

As participants can hear the sound of their own construction activities (salient sounds), in the physical environment, only the background sound of construction noise will be added to the environment. Construction noise will be played by mobile phone and transmitted through headphones.

### 2.2 Subjects

Subjects of the preliminary study were drawn from university students majoring in civil engineering, or construction management. The reason they were chosen was because they have some general knowledge of the construction industry. After the tests each subject was told that the experiments were actually investigating safety rather than wheelbarrows and asked to answer a questionnaire involving basic information such as their age group, gender, construction industry working experience and first person computer game experience, as well as their feedback about the virtual reality simulator.

Figure 3 shows a participant interacting with the virtual reality simulator.

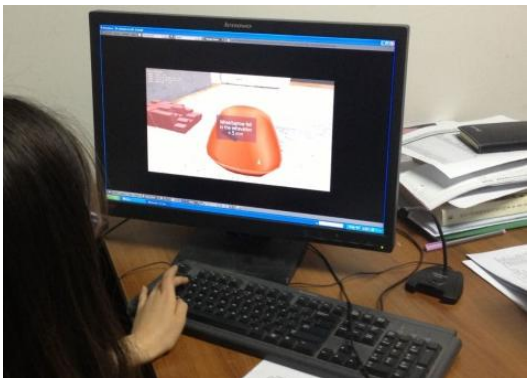

Figure 3 Participant pushing the wheelbarrow inside the with virtual reality simulator

To make sure the decisions made by participants were not influenced by other people, participants were not allowed to communicate to each other about the tests before everyone had completed the tests.

### 2.3 Test Procedure

The procedure of the tests involves tests planning (subjects grouping), and main body of tests (induction, trial, tests, debriefing and questionnaire/interview).

#### 2.3.1 Subjects Grouping

Since the laboratory space for the physical environment tests are only available for a limited time, some of the subjects will perform both tests while other will only perform the virtual tests.

The participants that perform both tests will be randomly divided into four groups: Groups A1 and A2 will have sound effects in their virtual environment. Groups B1 and B2 will not. Groups A1 and B1 will interact with the virtual environment first. Groups A2 and B2 will interact with the physical environment first so that they will form a control group in regards to interacting with the physical environment without previously interacting with the virtual environment. This grouping and sequencing test the validity of virtual tests results and the value of using virtual reality as a training tool.

Participants that only interact with the virtual environment will be randomly divided into three groups: Group A will have background and salient sound effects

in their virtual environment, Group B will have salient sound effects only, and group C will have silence. This will test the effect of sound effects on safety decisions.

Prelininary tests have been performed using the virtual enviornment and subjects from groups A and C.

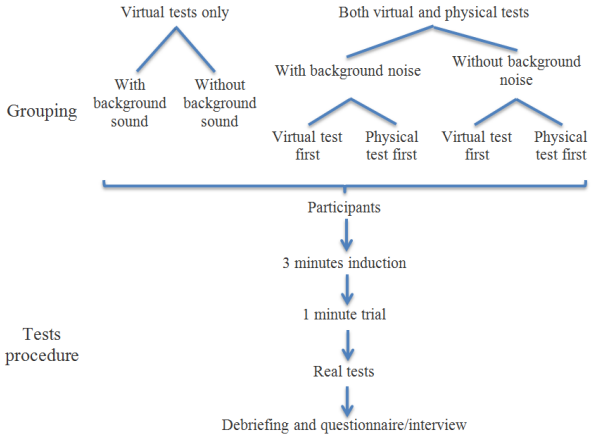


Figure 3 Procedure of the tests

### 2.3.2 Procedure and rules

During the preliminary tests, each subject was provided with a 3 minute induction of how to interact with the virtual reality simulator and the (pretend) aim of the study and their tasks in the simulator. A different environment was used in the instruction video to avoid the route used in the instruction video predisposing the participants' minds towards one route or another. After watching the video, participants were given a 1 minute trial to familiarize themselves with the virtual reality simulator before the real tasks began.

Participants were given the task of moving 60 virtual bricks from a brick pile to a target area without damage using a virtual wheelbarrow. 20 minutes were given to finish the task. If the participant made a mistake a time penalty was applied. The length of time deducted from the total time is related to the severity of the consequence of the mistake. If participants could finish the task in 8 minutes, they would win a 10-dollar reward.

### 2.3.3 Debriefing and Data Collecting

Participants will be initially told that they are testing the wheelbarrow simulation and comparing the virtual environment to the physical environment so that their responses will not be affected by knowing that the research was about safety. After finishing the test, each participant will be debriefed about the actual nature of the experiment being about safety behavior. They will then be asked to fill in a questionnaire, and if necessary, interviewed by the researcher regarding his/her behavior during the tests and asked to rate how similar the virtual reality environment is to the physical environment using a 5 point Likert scale.

Data will be collected through participants' feedback in the questionnaire or interview, as well as their rate of success in the tests. Participants' behavior will be recorded by screen capture software (virtual tests) or video camera (physical tests) for later analysis.

## 3 Preliminary Results

The following section presents preliminary results from a small sample used for ensuring that the test procedure works. A full size sample will be tested to obtain statistically rigorous results.

### 3.1 Sense of presence in virtual reality simulator

From the preliminary study, results show that participants that interacted with the virtual reality simulator with background sound rated their sense of presence higher on the scale than those who did not have background sound. They also rated that the realism of the virtual reality environment higher.

Questions were asked about participants' feel of: (1). Similarities between the virtual environment and the physical environment, (2). Similarities between the difficulty of controlling the wheelbarrow in the virtual environment and the physical environment.

Table 1 presents participants' sense of presence in the virtual reality environment using a 5 point Likert scale (0 – Not at all, 5 – Nearly the same).

Table 1. Participants' feedback on virtual reality environment

| Question about similarity with real world | With Sound | Without Sound |
|---|---|---|
| Environment | 3.6 | 3 |
| Control of wheelbarrow | 3.6 | 3 |

Note that the results in Table 1 are from different people and so a larger sample is required to ensure that the differences are not just due to the individuals involved.

### 3.2 Completion of tasks

Participants that interacted with the virtual reality simulator without background sound have a higher rate of completing the given task than those with background sound. They also identified more risks involved in the virtual construction site when doing the tasks than those with background sound, which resulted in fewer accidents happening during the tests.

The time participants used to complete the tasks and the number of accidents (wheelbarrow fell in the

excavation because of inappropriate control, wheelbarrow fell in the excavation because of plank overload, wheelbarrow broke because of overload, people fell in the excavation) happened during the tests are the data collected after the tests.

Participants' perception of risks and safety decisions were measured by answering the following questions:

a) Indicate the route used and give the reason of choosing the route,
b) Indicate the range that includes the approximate number of blocks put in the wheelbarrow each time, and the reason of selecting that number,
c) Tick on the risks that participants perceived when doing the task.

Table 2 is a list of the risks related to the task in the virtual environment and the percentage of participants that identified each risk.

Table 2. List of risks and accident scenarios

| # | Risk | Background sound | |
|---|---|---|---|
| | | With | Without |
| 1 | The weight of bricks put in the wheelbarrow may be greater than the capacity of the wheelbarrow. | 0.67 | 0.67 |
| 2 | Bricks may fall from the pile when disturbed. | 0.67 | 1.00 |
| 3 | When a brick is put in the wheelbarrow inappropriately, it may break. | 0.67 | 0.67 |
| 4 | When a brick is taken off the wheelbarrow in appropriately, it may break. | 0.00 | 0.33 |
| 5 | The plank may break if overloaded. | 0.67 | 0.33 |
| 6 | The wheelbarrow may fall into the excavation if not steered accurately | 0.67 | 1.00 |
| 7 | The wheelbarrow may fall over if not balanced | 0.67 | 0.67 |
| Total | | 4.00 | 4.33 |

From Table 2, it could be seen that the total number of risks identified by participants without construction background sound is larger than those with construction background sound.

### 3.3 Other information from interviews

From the interviews, participants interacted with the virtual reality simulator with background sound complained the reason that they didn't consider much risks was being annoyed by the background sound. Some of them attempted to turn down the sound or take off the headphone during the tests (they were asked not to do this by the investigator).

Most participants think that the virtual reality simulator is helpful in construction safety training, and participants who have failed finishing the tasks or identified few risk factors in the tests agreed that the virtual reality simulator helped safety training to a large degree.

## 4 Discussion

This paper has presented preliminary results of an investigation into the effects of sound on safety decision making on construction sites, using a virtual reality simulator. The validity of using a virtual reality simulator as a research and training tool has been evaluated by previous studies [13], and will be further evaluated in this study by comparing the results of virtual tests and physical tests.

From the preliminary tests results, the addition of sound to the virtual reality simulator did make a difference compared to the silent condition. However, results showed that background sound is actually detrimental. The addition of sound to the virtual reality simulator actually decreased people's likelihood of making safe decisions.

Arezes et al (2006) studied the relationship between individual risk perception, the outcome value for hearing preservation and the use of hearing protection devices. It has been found that the workers who better recognize risk tend to use hearing protection more consistently [1]. This study may lead to a new discovery on the benefits of using hearing protection devices that it could also reduce the chance of the occurrence of accidents on construction sites because of better concentration. Future research will further study the model of sound affecting people's safety decisions. The reason why the background noise of construction site contributes to construction workplace accidents may be because of the negative effect on people being annoyed by the noise is larger than the positive effect of people being made aware of the risks through salient sounds. The project will continue by investigating the effect of salient sound separately from background sound.

Similar studies in the transport field have found that noise due to new infrastructure seems to exert a negative influence on short term verbal memory and to increase both visual and noise annoyance depending on the distance from the noise source [10].

## 5 Conclusions

The results of this study highlight the probable importance of using hearing protection devices, not only for health reasons, but also for safety reasons.

Background noise on construction sites appears to increase the likelihood of occurrence of workplace accidents.

The paper is unique in testing users with and without sound in construction safety simulators. As mentioned previously, the study was designed as a pilot investigation of the effects of construction sound on people's safety decision. Future study will refine the study methods and enlarge the sample size in order to collect adequate and accurate data.

## 6 Limitations

There are some limitations in this research program:

1. The simulator needs to be improved to be closer to real world.
2. It applies to a very specific problem and results need to be generalized over a larger set of problems.
3. The results come from preliminary study, so the sample size needs to be larger.

Based on these limitations the following steps are being taken to refine the study:

1. The types of sound that have main effect on people's safety decision and whether they are positive or negative effects.
2. Keep testing which dB of construction sound is the dB that balances the positive and negative effects of construction sound on people.
3. Increase the number of participants.

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