Assessing Employee Risk due to Exposure to Hazards with a VR Simulator

Nir Keren, Tavion Yrjo, Alon Klekner, Pete Evans, David DeHass, Angela Leek

Iowa State university

Ames, IA

nir@iastate.edu, ttyrjo@iastate.edu, aklekner@iastate.edu, pmevans@iastate.edu, ddehass@iastate.edu aleek@iastate.edu

ABSTRACT

The presence of hazards in the workplace is inevitable. Some hazards are visible and easy to recognize. Other hazards, such as noise, radiation, and air quality, are invisible. When invisible hazards do not possess acute health concerns, they might go unnoticed, leading to chronic health conditions often detected after years of exposure. Certified Industrial Hygienists and some seasoned occupational safety professionals with a proper academic background are capable of identifying these hazards, evaluating their extent, and recommending controls for reducing risk levels. However, even seasoned occupational safety professionals might struggle in interpreting data collected from monitoring the workplace for these invisible hazards.

AssessVR (the Simulator) is a virtual reality (VR) simulator that utilizes a technology that integrates VR video with VR digital elements to allow interaction in the VR video environment. The Simulator enables students and safety personnel to experience hazard recognition processes (e.g., noise, particles, radiation), design evaluation strategy, and recognize risk levels from analyzing data collected within simulations.

A desktop version of the Simulator was made available to students in an Industrial Hygiene course at Iowa State University. The Simulator was modulated to serve for the assessment of noise hazards. The simulation scene was of an industrial machine room with multiple typical sources of noise. Students were tasked to examine the machine room for hazardous noise and deploy a set of sound level probes to monitor the machine room.

The quality of noise-probes placement had low-to-moderate correlations with a few aspects of Presence and interactivity indices. Perceptions of simulator affordances were not correlated with characteristics of Presence and interactivity indices. Perception of simulator utility had moderate correlations with features of Presence; these correlations were highly significant.

ABOUT THE AUTHORS

Nir Keren is an Associate Professor of Occupational Safety at the Department of Agricultural (ABE) and Biosystems Engineering at Iowa State University and a Faculty Fellow at the Virtual Reality Application Center (VRAC), also at Iowa State University. Before pursuing an academic career, Nir was an engineer and a manager in the capital energy and process industries. In ABE at Iowa State University, Nir teaches Occupational Safety courses. In VRAC, Keren's interest in virtual reality is threefold: (1) Examining the decision making of employees of mission-critical occupations under stress, (2) utilize virtual reality for improving safe design and engineering practices, and (3) enrich engineering and technology curriculum with experiential learning engagements.

Nir received a Ph.D. in Interdisciplinary Engineering from Texas A&M University in 2003, an M.S. in Management and Safety Engineering from the Ben Gurion University in Israel in 1998, and a B.S. in Mechanical Engineering the Ben Gurion University in 1990.

Tavion Yrjo is a graduate student in the Human-Computer Interaction program at Iowa State University, co-majoring in Industrial and Agricultural Technology. Tavion received a B.S. in Software Engineering from Iowa State University in 2021. Tavion develops virtual reality simulations to supplement employee safety training with experiential learning endeavors.

Alon Klekner is a graduate student in Industrial and Agricultural Technology at Iowa State University, focusing on Occupational Safety. Alon earned his B.S. in Mechanical Engineering from Iowa State University in 2020.

Pete Evans is an assistant professor in the Industrial Design department at Iowa State University with over 25 years of industry experience. Pete's teaching, scholarship and research involve mixed reality (VR and AR) simulation; digital communications, prototyping and design; impacts of 21st-century skills on K-16 students and workforce; UXUI, human computer interaction and human centered design; phenomenology and perceptual cognition. He also founded and coordinates the FLEx (Forward Learning Experience) - a mobile design & STEM outreach program.

Pete received a Master of Industrial Design from Iowa State University in 2017, a Human Computer Interaction Master Certificate from Iowa State University in 2014, and a Bachelor of Architecture from Iowa State University in 1995.

David Dehass is an instructional designer at the Brenton Center at Iowa State University (ISU). Before coming to ISU, David worked for the University of Alaska. He has over 10 years of experience in working with Alaska Native communities on projects spanning place-based learning and Indigenous perspectives on the use of new technologies. He currently works in the areas of e-learning, virtual environments, interactive 360 labs, and accessibility, as well as the effects of the pandemic on accelerating the move to online learning. David received a Ph.D. in Rural Technology Management and an M.A. in Cross Cultural Studies from the University of Alaska Fairbanks.

Angela Leek, CHP is a Certified Health Physicist and is currently the Radiation Control Program Director with the Iowa Department of Public Health. Angela has over 20 years of experience in the radiation safety and protection field and is currently a graduate student pursuing her Ph.D. in the Industrial and Agricultural Technology program within the Agricultural and Biosystems Engineering (ABE) Department at Iowa State University. Angela completed her M.S. in Radiation Health Physics at Oregon State University.

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BACKGROUND

New and affordable virtual reality (VR) headsets and the increase in computational power substantially accelerated the use of extended realities for training employees. Educating and training the workforce with VR technology became quite common (e.g., Carruth, 2017; Grabowski & Jankowski, 2015). The use of virtual reality to develop safety skills has also gained significant momentum. Cakiroglu & Gokoglu (2019) demonstrated that training in VR significantly improved fire safety behavioral skills. Leder and colleagues compared virtual reality and PowerPoint as methods for delivering safety training. Eiris, Ghesisari, and Esmaeli (2020) compared desktop-based safety training using 360-degree panorama and static virtual reality technique; their study demonstrated that 360-degree panorama delivered a higher sense of realism but made hazard identification more difficult. Jeelani, Han, and Albert (2020) tested training effectiveness in improving hazard recognition and hazard management in virtual reality. Their results demonstrated a 39% improvement in hazard recognition and a 44% improvement in hazard management performance.

For conducting risk assessment in VR, the majority of literature is associated with medical and interventional efforts. A literature search revealed very few studies on VR or relevant technology and risk assessment. In one study, Barkokebas and Li (2020) were able to identify tasks with high ergonomic risk through tracking motion in VR. Puschmann, Horlitz, Wittstock, and Schutz (2016) found that compared to document-based and CAD (Computer-Aided Design)-based risk assessments, VR-based risk assessments helped the participants discover more risks and design flaws. They developed a framework for using 3D visualization to imitate operational motion in construction manufacturing and analyze ergonomic risk. They proposed their framework allows obtaining risk assessment via data postprocessing and then proactively modifying workstations to tasks demand for carrying the tasks out safely.

As presented in the abstract, hazards such as noise, radiation, and air quality, are invisible. When invisible hazards do not possess acute health concerns and are not associated with pain, such as overexposure to hazardous noise, these hazards might go unnoticed, leading to chronic health conditions often detected after years of exposure. The National Institute of Occupational Safety and Health (NIOSH, https://www.cdc.gov/niosh/topics/noise/default.html) states that "*Occupational hearing loss is one of the most common work-related illnesses in the United States*" and that "*Each year, about 22 million U.S. workers are exposed to hazardous noise level.*" Further, Plog & Quinlan (2010) reported that an estimated 1.7 million workers in the U.S. in the age range of 50-59 have significant hearing loss that justifies compensation through Workers' Compensation programs. The cost to the industry due to overexposure to noise is estimated to exceed $500 million. Thus, beyond the preservation of workers' hearing quality, there is a significant monetary aspect for preventing overexposure to noise hazards and conserving workers' hearing equity.

Certified Industrial Hygienists and seasoned occupational safety professionals with a proper academic background are capable of identifying these hazards, evaluating their extent, and recommending controls for reducing risk levels. However, even seasoned occupational safety professionals might struggle in interpreting data collected from monitoring the workplace for these invisible hazards. A team at Iowa State University (ISU) developed AssessVR. AssessVR (the Simulator) is a virtual reality simulator that utilizes VR video combined with VR digital technology to allow interaction within the VR video environment. The objective of developing the Simulator was for students in safety programs and safety personnel in the industry to experience hazard recognition processes (e.g., noise, particles, radiation), design evaluation strategy, and recognize risk levels from analyzing data collected within simulations.

A desktop version of the Simulator was made available to students in an Industrial Hygiene course at ISU. The Simulator was limited to noise hazard assessment. The scene in the Simulator was of an industrial machine room with multiple, typical industrial sources of noise. Students were tasked to examine the machine room for hazardous noise and deploy a set of sound level probes to monitor the machine room. Following is a detailed description of the Simulator.

THE SIMULATOR

The Simulator was created with the game engine Unity. The scene was captured with Insta360 Pro II Spherical VR 8K. The camera captured the machine room in 17 spots, allowing for observing the entire space of the machine room. Subjects could teleport from one teleportation spot to another by clicking on the teleportation spots with their mouse (see Figure 1). Digital elements overlayed on the VR video scene allowed facilitating interactivity in the simulation. Interactivity features included the following elements:

- Selecting the type of probes (Figure 1 - was limited to noise meter in the study)
- Number of probes available (Figure 1 – was limited to six in the study)
- Visible reading of noise level in current subject location (Figure 1)
- Deploy sound level probe: Clicking on the 'Rec' button and dragging it to the scene will deploy a probe to the desired location (Figure 2). Dashed vertical line and shadow on the ground assisted with visualizing the probe location. Clicking on the red X button canceled the probe.

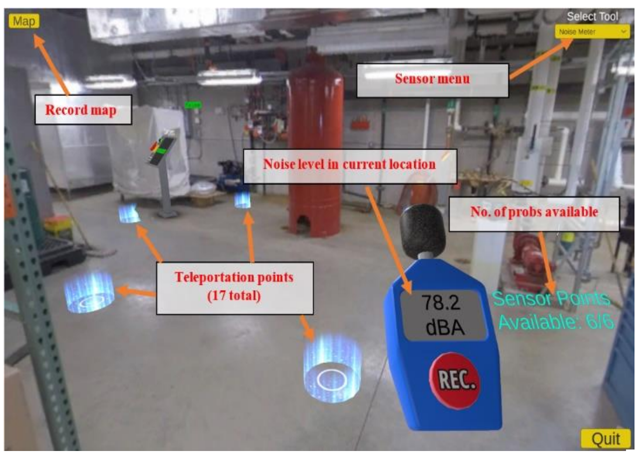

Figure 1. Simulator Features

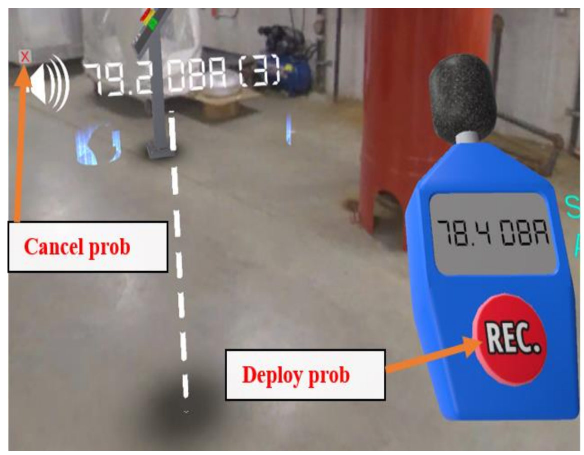

Figure 2. Deploying Sound Level Probe in the Scene

Subjects could examine equipment for proper working conditions by clicking the ‘Inspect machine’ buttons on the equipment control podium (Figure 3 on the left). Equipment status will then be presented. For example, inspection information in figure 3 on the right shows the pump is anchored to the ground properly. On a different source of noise, the inspection indicates that a driving belt needs to be replaced. The scene also included several pneumatic leaks (Figure 3 on the left at the bottom). Subjects could fix leaks by clicking on the ‘Fix Leak’ buttons. Subjects could turn equipment on and off (Figure 4) and examine the equipment operation status on the noise level. Each interaction with equipment and fixing the leak immediately affected the noise level measured. Thus, subjects could notice the effect of each one of the noise elements in the machine room on noise level, instantaneously. The highest noise level in the machine room, when all sources of noise are silent, was 60 dBA, the setpoint noise level. The highest noise level when all sources of noise are generating the highest noise level was 89 dBA.

To facilitate noise level measurements at any point in the machine room, the noise level from each source needs to be calculated based on the distance from the source, and then the sum of the noise levels, from all sources, needs to be added. Noise level at a distance of *d* from a noise source was calculated with equation 1:

$$dB_{at\ distance\ d} = dB_{at\ source} - 20 \times Log(d) + 2.5dB \qquad (1)$$

Where ‘*dB at a distance d*’ is the noise level at a distance of ‘*d*’ feet from the noise source.

The combined noise level of several sources was calculated with equation 2:

$$dB_{sum} = \sum_{i=1}^{n} 10^{\frac{L_i}{10}} \qquad (2)$$

Where dB_{sum} *is the combined noise level at a point,* L_i *is the noise level from source i at the measurement point, and n is the number of noise sources.*

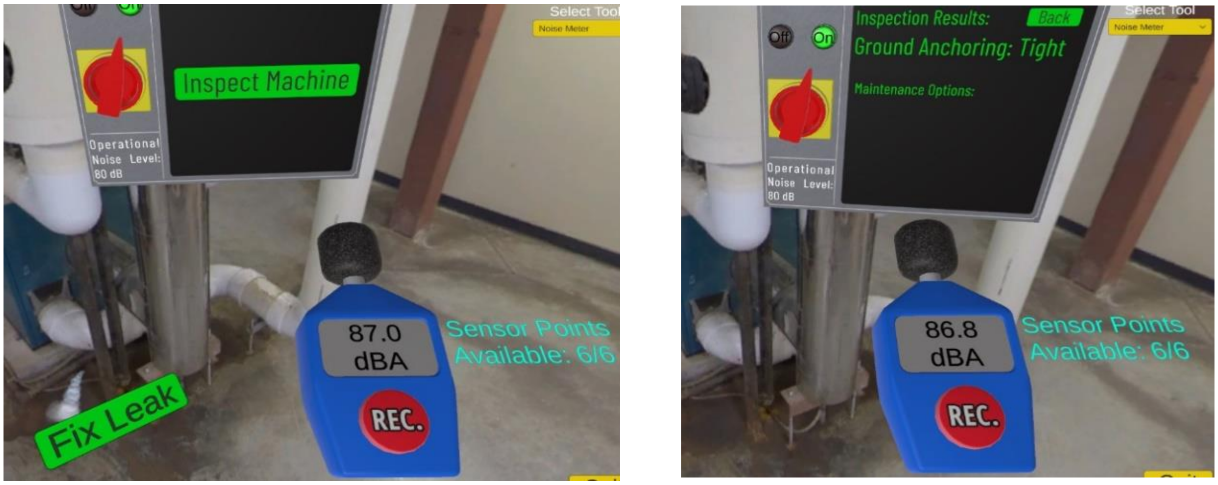

Figure 3. Controlling Noise Sources in the Simulator

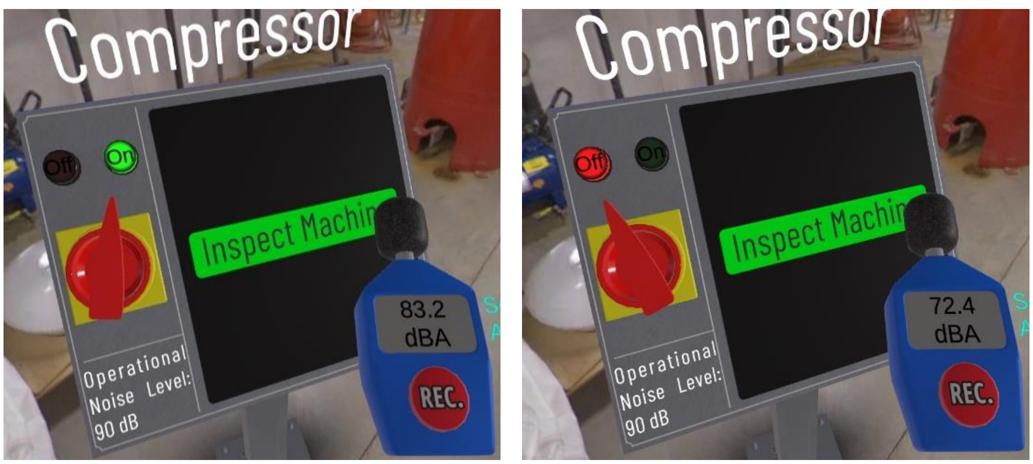

Figure 4. Controlling Equipment in the Simulator

Clicking on the ‘Map’ button (Figure 1) presented a bird’s eye view of the machine room and the locations of the probes subjects deployed. Additional control allowed subjects to record the map (Figure 5a). When exiting the simulation, the Simulator generates a noise level map (Figure 5b) and an Excel spreadsheet that logs all interactions during the simulation and the noise level reading from each probe in a frequency of 5 seconds. These files become available to the subjects and the research team.

RESEARCH QUESTIONS

The objectives of this project were to assess the Simulator's potential to enhance the risk assessment skills of safety personnel and to cover the gap between student risk assessment ability and the academic rhetoric of risk assessment. Here we aimed at assessing the effect of *Presence*, level of interaction in simulation on quality of probe deployment, perceptions of the Simulator affordances, and perceptions of The Simulator utility.

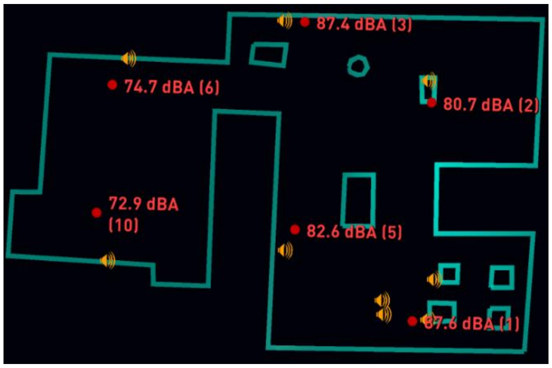

Figure 5a. Map with Probes Deployed in the Scene

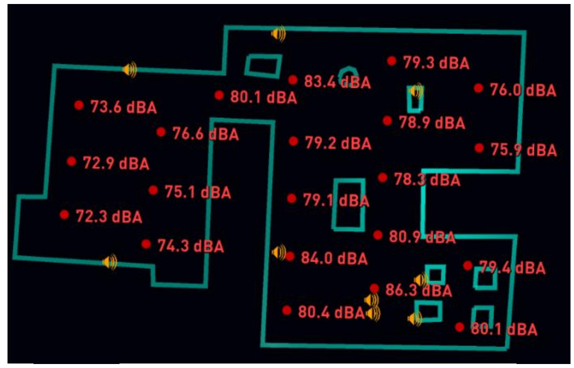

Figure 5b. Noise Level Map

Pearson's correlations were used to examine the following research questions:

1. To what extent is Map Quality correlated with the *Presence* and the level of interaction in the simulation?
2. To what extent are the perceptions of the simulation affordances correlated with the *Presence* and level of interaction in the simulation?
3. To what extent are the perceptions of the utility of the Simulator correlated with the *Presenc*e and the level of interaction in the simulation?

For *Presence*, we adopt Sanches-Vives and Slater's definition as follows: "…*Presence in virtual reality as the extent to which people respond realistically within a virtual environment, where response is taken at every level from low-level physiological to high-level emotional and behavioral responses*" (2005, p. 335).

METHODOLOGY

The study was reviewed and approved by the Iowa State University Institutional Review Board (Study ID 21-149). A desktop version of the Simulator was made available to 38 students in an Industrial Hygiene course at Iowa State University. Three students did not consent to use data from their experience in this research. Three other students chose not to participate.

Students engaged in the simulation after they completed the Occupational Hearing Loss learning module. They could either download the Simulator to their personal computers or take the simulation in a computer lab on campus. The simulation started with a tutorial. Upon completion, students were asked to examine the machine room in the scene for hazardous noise levels. They were instructed to deploy a set of six sound level probes in a way that they think will optimally monitor the machine room for noise level. After completing the simulation, students participated in a post-simulation survey, where they reported their perceptions and experience (described below).

The post-simulation survey included a few technical questions but was mainly focused on collection of perceptions of presences, simulator affordances, and simulator utility.

SUS questionnaire (Usou, Caena, Arman, and Slater, 2000) was used for *Presence*. The SUS questionnaire consisted of six items that represented the following three aspects:

- **'Being there'**: The sensation of 'being there' in the virtual environment.
- **'Dominance of virtual environment vs. the dominance of reality'**: The extent to which the virtual environment becomes the dominant reality over the real world.
- **'VR experience as a place or an image/multimedia'**: The extent to which the virtual environment experience is remembered as a place visited in the real world rather than just seen as images or other multimedia format.

Students ranked their *Presence* experience on a 7-point Likert scale, as presented in Table 1.

Table 1: SUS *Presence* Questionnaire and Their Relevant Aspect

Code	Question	*Presence* aspect
Q1	I had a sense of 'being there' in the machine room. 1 (Not at all) … 7 (Almost all the time)	Being there
Q2	There were times during the experience when the machine room was the reality for me... 1 (At no time) … 7 (Almost all the time)	Dominance of VE vs dominance of reality
Q3	The machine room seems to me to be more like… 1 (Images that I saw) … 7 (Somewhere that I visited)	VR experience as a place or an image/multimedia
Q4	I had a stronger sense of… 1 (Being elsewhere) … 7 (Being in the machine room)	Being there
Q5	I think of the VR machine room as a place in a way similar to other places that I've been today... 1 (Not at all) … 7 (Very much so)	Dominance of VE vs dominance of reality
Q6	During the experience, I often thought that I was really standing in the machine room. 1 (Not very often) … 7 (Very much so)	VR experience as a place or an image/multimedia

SUS overall *Presence* was also calculated as the mean of means of questions 1-6 in Table 1.
The Simulator was designed to allow subjects to explore the machine room, measure noise, deploy sound level probes, control noise level by interacting with equipment, fix noisy elements, and assess noise hazard risk by means of the last three items. We titled these elements 'Simulator affordances.' Table 2 present the Simulator affordances questionnaire. Students were asked to share their perception using a 7-point Likert scale, as follows:

Table 2: Simulator Affordances Questionnaire

Code	Question
Q7	I was able to measure noise or place (and eliminate) noise sensors anywhere noise measurement deemed needed. 1 (Not at all) … 7 (Very much)
Q8	I was generally able to explore areas with noise hazards in the machine room. 1 (Not at all) … 7 (Very much)
Q9	I was able to conduct a noise hazard assessment in the machine room. 1 (Not at all) … 7 (Very much)
Q10	I was able to control the level of noise in the machine room. 1 (Not at all) … 7 (Very much)

Students were asked to rank their perception of the utility of the Simulator on the three elements in Table 3, using a 7-point Likert scale, as follows:

Table 3: Simulator Utility Questionnaire

Code	Variable description
Q11	My experience in assessing noise levels in the machine room improves my ability to conduct noise hazard assessments in other places in the future. 1 (Not at all) … 7 (Very much)
Q12	My experience in assessing noise levels in the machine room complemented the content of the Hearing Loss learning module. 1 (Not very often) … 7 (Very much)
Q13	Simulations similar to the one in the machine room will enhance the learning experience and learning outcome of other learning modules and courses. 1 (Not very often) … 7 (Very much)

We also collected interactivity data as described in Table 4:

Table 4: Simulation Interactivity Indices

Code	Variable description
ST	Sim time: Overall time spent in the simulation (Seconds)
#TPU	Number of teleport points used (from the 17 teleport points available)
#Ts	Number of times subjects teleported in the simulation
CM	Control manipulations: number of times subjects interacted with items in the simulation (teleportation excluded)

To get a glimpse of the students' ability to assess risk, we examined their probe deployment maps. In our simulation, the distance among noise sources was significant enough where the highest noise levels were at the equipment. We used the scoring grid in Figure 5c to rank the deployment of the probes with respect to the location of the sources of noise. A shorter distance between a probe and a source of noise resulted in a higher score. We termed the final score for a map 'Map Quality Score'.

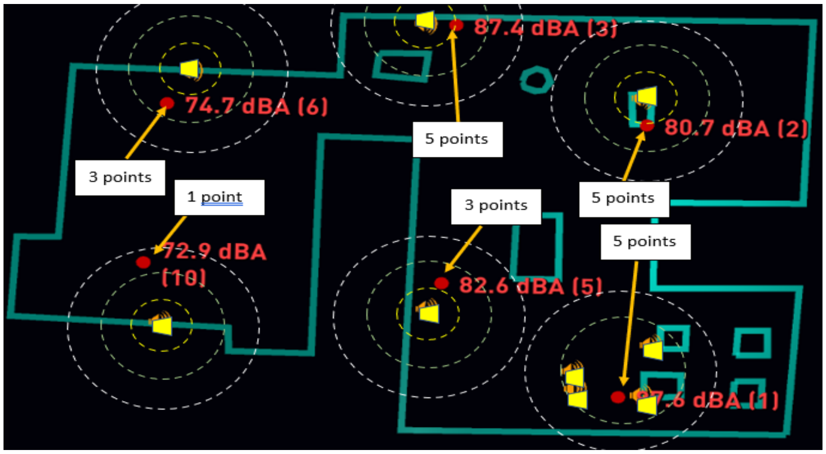

Figure 5c. Map Quality Scoring Grid

RESULTS

The following tables provide the results of the analyses in detail. Table 5 presents the number of data points (*n*), means *(M)*, and standard deviations (*SD)* for all study variables.

Table 5. n, Means, and Standard Variations for All Variables

Code	Variable (shortened)	*n*	*M*	*SD*
Q1&Q4	Presence 'Be there' aspect	29	4.25	1.53
Q2&Q5	Presence 'VR Dominance' aspect	29	3.72	1.65
Q3&Q6	Presence' Experience as' aspect	29	4.52	2.13
Q1…Q6	Presence overall	29	4.30	4.38
Q7	Was able to measure noise and place sensors…	32	5.56	1.39
Q8	Was able to explore noise hazards…	32	5.72	1.22
Q9	Was able to conduct noise assessment…	32	5.63	1.24
Q10	Was able to control noise level	32	5.36	1.29
Q11	Experience improves ability to assess noise hazard in the future	32	4.56	1.87
Q12	Experience complemented hearing loss module content	32	5.16	1.69
Q13	These types of simulations will enhance other learning modules	32	5.09	1.89
ST	Simulation time	29	550	395
#TPU	Number of teleport points used	29	11.5	6.0
#Ts	Number of times teleported	29	29.1	23.1
CM	Control manipulations	29	7.8	9.6

Table 6 presents the correlation between Map Quality and the three aspects of *Presence*, the overall *Presence*, and interactive items listed in Table 4.

Table 6. Map Quality Correlation with *Presence* and Interactivity Indices

Variable	*DF*	*r*	*p*
Presence 'Be there' aspect	27	.24	.2207
Presence 'VR Dominance' aspect	27	.39	.0383**
Presence 'Experience as' aspect	27	.26	.1820
Presence overall all	27	.34	.0807*
Simulation time	27	.26	.1737
Number of teleport points used	27	.51	.0064***
Number of times teleported	27	.33	.0980*
Control manipulations	27	.35	.0635*

*** Correlation is significant at the 0.01 level
** Correlation is significant at the 0.05 level
*Correlation is significant at the 0. 1 level

Table 7 presents the correlation between Simulator Affordances and the three aspects of *Presence*, the overall *Presence*, and interactive items listed in Table 4.

Table 7. Simulator Affordances Correlation with *Presence* and Interactivity Indices

Variable		Q7		Q8		Q9		Q10	
	DF	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Presence 'Be there' aspect	30	.15	.3976	.32	.0769*	.32	.0795*	.31	.0830*
Presence 'VR Dominance' aspect	30	.10	.5645	.19	.3006	.27	.1318	.25	.1595
Presence 'Experience as' aspect	30	.12	.5209	.09	.0628	.22	.2321	.21	.2516
Presence overall all	30	.14	.4596	.21	.2427	.29	.1045	.28	.1196
Simulation time	30	.31	.1038	.35	.0628*	.01	.6885	.16	.4234
Number of teleport points used	30	.00	.9702	.11	.5373	-.01	.7765	.02	.9107
Number of times teleported	30	.05	.7863	.15	.2997	-.16	.4291	.02	.9404
Control manipulations	30	.02	.9151	-.05	.7807	-.26	.1700	.04	.8442

*** Correlation is significant at the 0.01 level (2-tailed)
** Correlation is significant at the 0.05 level (2-tailed)
*Correlation is significant at the 0. 1 level (2-tailed)

Table 8 presents the correlation between Simulator utility and the three aspects of *Presence*, the overall *Presence*, and interactive items listed in Table 4.

Table 8. Simulator Utility Correlation with *Presence* and Interactivity Indices

Variable		Q11		Q12		Q13	
	DF	*r*	*p*	*r*	*p*	*r*	*p*
Presence 'Be there' aspect	30	.48	.0056***	.60	<.00001***	.58	.0005***
Presence 'VR Dominance' aspect	30	.51	.0031***	.63	<.00001***	.57	.0006***
Presence 'Experience as' aspect	30	.37	.0361**	.39	.0279**	.46	.0077***
Presence overall all	30	.50	.0037**	.59	.0003***	.59	.0004***
Simulation time	30	.16	.4085	.04	.8366	.04	.8495
Number of teleport points used	30	-.03	.8746	-.06	.7607	.07	.7054
Number of times teleported	30	.02	.9052	-.11	.5453	.15	.4530
Control manipulations	30	.06	.7474	-.06	.7622	.02	.8894

*** Correlation is significant at the 0.01 level (2-tailed)
** Correlation is significant at the 0.05 level (2-tailed)
*Correlation is significant at the 0. 1 level (2-tailed)

DISCUSSION

Sanchez-Vives and colleagues (2005) state that *Presence* is considered high only when ratings are '6' or '7' on the 7-point Likert Scale. Accordingly, we defined *Presence* as 'high' when *Presence* item values were '6' or higher. We also described *Presence* as 'moderate' when *Presence* item values were '4' or higher, but less than '6'. Otherwise, Presence was considered 'Low.' Figure 6 presents levels of three aspects of *Presence*. Generally, along with the three aspects, 17% of subjects reported a 'High' *Presence* level, 50% reported 'Moderate' *Presence* level, and 33% reported 'Low' *Presence* level. Provided that the simulation did not occur in a full-scale VR headset, the distribution of levels of *Presence* was not surprising. Michailidis, Terkidsen, and Mayer (2019) reported presence was 1.3 times higher in VR headsets than on PCs.

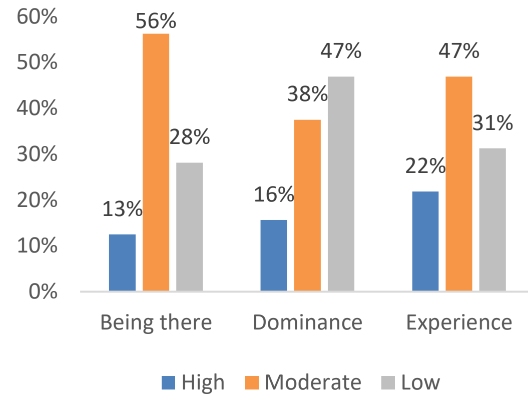

Figure 6. *Presence* Levels

Map Quality: Correlation levels in Table 6 show that Map Quality was significantly correlated with VR as a Dominant reality, but the strength of this correlation is medium at best. Similarly, the correlation of Map Quality with the overall level of *Presence* was marginally significant and weak. Correlation of Map Quality with the number of teleport points used was medium but highly significant; examining the entire machine room is essential for developing a mental model of the problem since noise sources were spread throughout the machine room. The number of times subjects teleported during their journey in the simulation and the number of times subjects manipulated controls in the simulation (i.e., started and stopped equipment, fixed leaks, deployed and canceled probes, and examined equipment for proper maintenance) were weakly correlated with Map Quality, and these correlations were marginally significant.

Simulator Affordances:

The post-simulation survey consisted of four questions/statements regarding the extent to which the Simulator afforded various functions. The statements addressed the ability to deploy probes (Q7), the ability to explore areas in the machine room (Q8), the ability to conduct a risk assessment in the room (Q9), and the extent to which subjects could control the level of noise in the machine room (Q10). Q8, Q9, and Q10 were weakly correlated with the three aspects of *Presence*, and the correlations were marginally significant. Only one other item was weekly correlated with Q8 – Simulation time. When examining the levels of affordances (Figure 7), the levels of affordances ratings are pretty high. The standard deviations are not, entailing that there is a consensus regarding the simulator's high affordances. When ratings are high, and there are consensuses regarding the height of the affordances, then variability is low, and thus, correlations are hard to find.

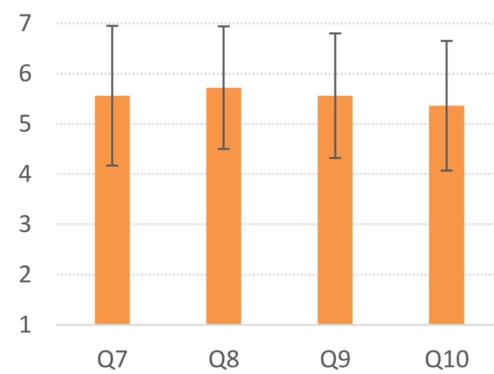

Figure 7. *Simulator Affordances*

Simulator Utility

The post-simulation survey consisted of three statements that addressed the following utility items:

1. The merit of the experience with the simulator in improving subjects' ability to conduct noise hazard assessments in other places in the future (Q11)
2. Whether the experience complemented the content of the Occupational Hearing Loss learning module (Q12), and,
3. If they believe similar simulators will enhance the learning experience and learning outcome of other learning modules and courses (Q13).

The correlations of simulator utility items (Q11, Q12, and Q13) with the three aspects of *Presence* and the overall *Presence* rating were medium to medium-strong positive (Table 8). For most of them, the correlation was highly significant. Correlations with activity indices pretty much did not exist.

CONCLUSIONS

A literature review for the relationships and associations between task performance and *Presence* presents that Slater (1999) alerted researchers and educators not to assume a positive correlation between *Presence* and task performance is yet valid. For example, Youngblut and Huie (2003) found that task performance had a medium but significant correlation between *Presence* and task performance. On the other hand, Cooper, Milella, Cant, et al. (2018) found a negative, significant relationship between *Presence* and performance measures. One prominent element of task performance that most likely contribute to this inconsistency is that tasks and their measures vary tremendously. As indicated in the Background section, the literature search failed to identify publications on workplace-related risk assessment in VR to benchmark the results herein. The weak-medium but positive correlation between Map Quality and 'VR Dominance as a reality and with the overall *Presence* may improve when these simulations are conducted in a full-scale VR headset.

The high-level ratings and the low variance in simulator affordances, and the lack of association with other variables, indicate that the Simulator design for pursuing the desired activity was proper.

The medium-strong positive and highly significant correlations between the perceptions of the utility of the Simulator and all *Presence* items are encouraging. Our results are also consistent with Lerner and colleagues' (2020) findings, who observed a strong, significant correlation between experiencing *Presence* and training effectiveness. We hypothesize that deploying the simulator in a full-scale model in a VR headset will enhance the sense of Presence and thus increase the perceptions of Simulator utility.

The Simulator's next development phase should emphasize incorporating Flow elements (Michailidis, Balaguer-Ballester, and He, 2019; Csikszentmihalyi-mihalyi1975, 1990). More specifically, the dimensions of merging action and awareness, providing immediate and unambiguous feedback, and creating an intrinsic motivation toward the task should be of high priority. We believe implementing these elements will further enhance the perception of utility and enhance the quality of risk assessments.

The complexity associated with risk assessment of hazards such as noise, particles, and radiation hinders the development of simulators for training and education for this assessment. The thought process and design principled behind the Simulator development can guide the development of similar simulators for training safety personnel in the industry, military personnel evaluating hazardous conditions, and educators who wish to provide their students firsthand, field-like risk assessment experience.

LIMITATIONS

The Simulator can operate on a PC and in a VR headset. The Industrial Hygiene course comprises students who take the class on campus and students who take the class remotely, online. The constraints of providing equal learning opportunities prevented us from deploying the study in a full-scale mode with VR headsets. Further, as indicated in the Conclusion section, we believe we can improve the educational experience further by enhancing the Simulator design with Flow elements.

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