Effects of Environmental Noise Levels on Patient Handoff Communication in a Mixed Reality Simulation

Matt Gottsacker
gottsacker@knights.ucf.edu
University of Central Florida
USA

Nahal Norouzi
nahal.norouzi@knights.ucf.edu
University of Central Florida
USA

Ryan Schubert
ryan.schubert@ucf.edu
University of Central Florida
USA

Frank Guido-Sanz
frank.guido-sanz@ucf.edu
University of Central Florida
USA

Gerd Bruder
bruder@ucf.edu
University of Central Florida
USA

Gregory Welch
welch@.ucf.edu
University of Central Florida
USA

ABSTRACT

When medical caregivers transfer patients to another person's care (a patient handoff), it is essential they effectively communicate the patient's condition to ensure the best possible health outcomes. Emergency situations caused by mass casualty events (e.g., natural disasters) introduce additional difficulties to handoff procedures such as environmental noise. We created a projected mixed reality simulation of a handoff scenario involving a medical evacuation by air and tested how low, medium, and high levels of helicopter noise affected participants' handoff experience, handoff performance, and behaviors. Through a human-subjects experimental design study ($N = 21$), we found that the addition of noise increased participants' subjective stress and task load, decreased their self-assessed and actual performance, and caused participants to speak louder. Participants also stood closer to the virtual human sending the handoff information when listening to the handoff than they stood to the receiver when relaying the handoff information. We discuss implications for the design of handoff training simulations and avenues for future handoff communication research.

CCS CONCEPTS

• **Human-centered computing → Virtual reality**; **User studies**.

KEYWORDS

Patient handoffs, virtual and mixed reality, environmental noise, human-subject research

ACM Reference Format:
Matt Gottsacker, Nahal Norouzi, Ryan Schubert, Frank Guido-Sanz, Gerd Bruder, and Gregory Welch. 2022. Effects of Environmental Noise Levels on Patient Handoff Communication in a Mixed Reality Simulation. In *28th ACM Symposium on Virtual Reality Software and Technology (VRST '22), November 29-December 1, 2022, Tsukuba, Japan.* ACM, New York, NY, USA, 10 pages. https://doi.org/10.1145/3562939.3565627

VRST '22, November 29-December 1, 2022, Tsukuba, Japan

ACM ISBN 978-1-4503-9889-3/22/11…$15.00
https://doi.org/10.1145/3562939.3565627

1 INTRODUCTION

In the course of injury to treatment to discharge, medical patients are often transferred between caregivers. This transfer of care is known as a *patient handoff*. Handoffs are crucial in medical care because the miscommunication of injuries, symptoms, or treatments can lead to serious consequences for the patient, including death. In fact, up to 80% of serious medical errors may be attributed to handoff errors [30]. Because of the increased environmental distractors and stressors, handoff communication during emergency situations or mass casualty events (e.g., a natural disaster) where people experience critical medical conditions requiring multiple levels of care and providers are of particular interest. Because these critical situations are rare and carry high stakes, opportunities to train in real natural settings are limited. Therefore, simulating scenarios of patient handoffs in critical settings is valuable for training purposes. In addition, patient handoffs, especially during emergencies, can be detrimentally affected (or rendered ineffective) by environmental factors such as noise or other distractions. Environmental noise during handoffs can be distracting, or otherwise negatively affect the quantity and quality of patient information being conveyed, which can negatively affect the patient's health and safety [31].

To build on related research on mixed reality (MR) simulations of patient handoff scenarios [16, 32, 37], we created a projection-based MR simulation of an emergency patient handoff situation, and investigated how its realism, including environmental noise, affected participants' experiences, behaviors, and handoff performance. In the simulation, a virtual human (the Sender) communicated information about a patient to an experiment participant, who then relayed the handoff information to a different virtual human (the Receiver). The simulation virtual environment included a helicopter to suggest that the handoff is occurring as part of a medical evacuation by air.

With this simulation scenario, we arrived at the following research questions:

- RQ1 How does simulated noise level affect participants' experience of the handoff?
- RQ2 How does simulated noise level affect participants' handoff performance?
- RQ3 How does simulated noise level affect participants' behavior?

To examine these research questions, we conducted a human-subjects experimental study ($N = 21$) that tested three levels of environmental noise (low, medium, and high) and their effects on handoff communication. The virtual environment was equipped to simulate these levels as helicopter noise, and they were carefully calibrated to ecologically useful decibel levels using a sound level meter. Additionally, we recorded an expert handoff participant sending the prepared handoff scenarios at each noise level and calibrated the simulated Sender's audio volume to match his real-world volume. We measured participants' experiences through subjective questionnaires and their performance through a validated handoff assessment tool. To measure their behavior, we tracked their movements in the simulation and recorded their handoff speech audio, which we then respectively analyzed to understand participants' proximity to the virtual humans and speech loudness. We found that the addition of noise increased participants' subjective stress and task load, decreased their self-assessed and actual performance, and changed their proxemics and speech behavior. Specifically, participants both stood closer to the Sender when receiving the handoff compared to the Receiver when giving the handoff, and they moved closer to the Sender over the course of receiving the handoff than they moved toward the Receiver. Additionally, participants spoke louder with louder environment noise. Apart from participants' speech loudness, we did not find any significant differences between the medium and high noise levels, suggesting that the volume of the noise does not affect the participant's training experience as much as the presence of competing audio signals.

2 BACKGROUND

In this section, we first define patient handoff and the different approaches used for its standardization and present the value of exploring novel technologies such as mixed reality simulation as an effective and flexible mechanism for training healthcare professionals on patient handoffs.

2.1 Patient Handoffs

Across disciplines and professions, a *handoff* is characterized as the communication task to transfer vital information from one person or group to another, with the goal to preserve the information completely and accurately [19]. For instance, among healthcare providers, *patient handoffs* are routinely performed to ensure that vital health information about the patient is preserved even if the patient is moved from one location to another or a shift change occurs in a hospital or clinic [22]. Patient handoffs generally involve three core roles: the Sender is the person who has had custody of the patient and needs to convey relevant information about the patient to the receiver; the Receiver is the person who is now assuming custody of the patient and needs to gather relevant information about the patient from the Sender; and the *patient* is the person being transferred from the Sender to the Receiver. When people communicate, they use grounding, which is a coordination process that establishes a shared set of knowledge, beliefs, and assumptions [7]. In a patient handoff, the Receiver often establishes a common ground with the Sender by reading back the patient information after the Sender has finished speaking.

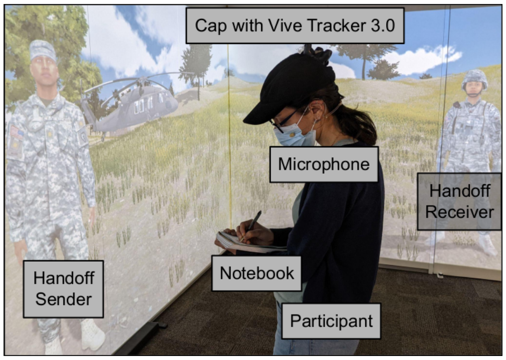
Poor communication in such settings can increase the risk for patients [20], which emphasizes the importance for students in healthcare domains to learn and train how to communicate patient information accurately, clearly, and concisely, independently of social or environmental distractors or stressors. Handoffs in emergency settings present particular challenges to communication because patients are often transferred between different care providers and to different physical locations, which makes the handoff the only opportunity for caregivers to share information [4, 34, 40]. While recent advances in this field supported the systemization and standardization of handoffs with protocols like IBID [17], SBAR [28], MIST [33], or I-PASS [36], poor communication is still prevalent across a wide range of contexts from nurses caring for inpatients in hospital settings to first responders and combat casualty care providers performing handoffs in less controlled settings [2, 39]. The field of patient handoffs remains understudied, especially when it comes to the evaluation and adaptation of handoff procedures as well as educational methods and tools for healthcare students to learn effective procedures and improve their communication skills [12, 14, 17, 22].

2.2 Virtual Handoff Training

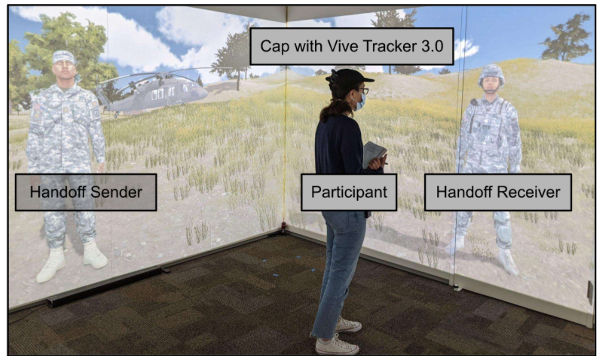
Recent advances in simulation-based training, in particular in the fields of nursing and combat casualty care, leverage a variety of technologies including audio and video, mannequins [24], handoff speech understanding [38], and/or virtual reality (VR) or MR technologies [3, 11, 16, 32, 37]. Such simulation-based training experiences can serve multiple purposes including the provision of training modules for circumstances that are difficult to faithfully reproduce in real life, which facilitates student performance improvement by training them in more realistic settings and providing a safe environment to detect errors that can lead to negative patient outcomes [25, 42].

Such simulation-based training modules that utilize MR/VR technology open opportunities for continuous and flexible exposure of healthcare professionals to training at different stages of their education and career due to their lower logistical difficulties as opposed to live simulations with real healthcare professionals [26, 42]. For instance, during an MR team-based communication skills training, White et al. [42] identified that professional nurses did not always communicate critical information about the patient to other virtual team members during patient handoff; thus, emphasizing the importance of utilizing such training modules in an ongoing manner. Beyond logistical flexibility, such training modules allow healthcare professionals to adopt different points of view during their education. For instance, Stuart et al. [37] found that participants who observed a virtual human nurse conduct a triage assessment felt more confident in their ability to do the same in the future.

While promising results are gained from VR/MR handoff training modules, past work emphasizes the importance of realism during such training modules [25, 26, 35]. However, in the context of patient handoff, simulation realism has received less attention. Because emergency situations typically cause handoffs to occur in chaotic environments [39], we are particularly motivated to study the influence of environmental noise in high-stakes outdoor patient handoff scenarios where poor audibility and time pressure can constrain the communication grounding process [7]. Previous research has shown that simulations can cause stress in participants related to noise and urgent events that require their response in immersive [8–10] and non-immersive [1] settings.



(a) Participant receiving the Handoff



(b) Participant sending the Handoff

Figure 1: Participants listened to the Sender describe details about the patient and took notes. Then, they went to the Receiver to relay all the information they captured.

3 EXPERIMENT

In this section we present our experiment evaluating the effects of environmental noise levels on patient handoff communication, behavior and performance. The study protocol was approved by the institutional review board of our university.

3.1 Participants

After initial pilot tests with two professional nursing educators and six outside members of our local university community, we estimated the effect size of the expected strong effects, and based on a power analysis with G* Power 3 [13], we made the decision to recruit 21 participants from our university nursing community (4 male and 17 female; ages between 18 and 25, $M = 20.0$, $SD = 2.1$). All the participants had normal or corrected-to-normal vision and hearing. None of the participants reported known visual or vestibular disorders, such as color or night blindness, dyschromatopsia, or a displacement of balance. The participants were 11 pre-nursing students, 9 nursing students, and 1 health sciences student from our university, who responded to open calls for participation, and received a monetary compensation for their participation.

3.2 Material

To investigate the influence of environmental noise on participants' handoffs, we prepared an immersive virtual space consisting of a virtual human handoff Sender, a handoff Receiver, and a virtual environment designed together with a healthcare Subject Matter Expert (SME) as an ecologically valuable scenario. The SME has extensive experience with both performing emergency patient handoffs in the field and training caregivers to perform such handoffs. As shown in Figure 1, the environment was set in a field, with two emergency caregivers and a helicopter to evacuate the patient.

To test the effects of audio stressors on participants, we tested three levels of helicopter noise[1] added to the virtual environment:

- **Low Noise**: 36 dBA
- **Medium Noise**: 69 dBA
- **High Noise**: 75 dBA

[1]https://www.youtube.com/watch?v=2RtDgTm6rn4

The High Noise decibel level was selected to sound very loud but with care for participants' hearing. Continuous exposure to noise levels exceeding 85 dBA created by helicopter sounds can lead to hearing loss [21]. Thus, we positioned our participants at a distance from the helicopter that ensured that the volume level in our simulation averaged 75 dBA, did not require hearing protection, and provided a substantial gap between potentially hazardous noise levels. The Medium Noise decibel level was chosen to be 6 dBA lower than the High Noise condition, which halved the sound pressure level and halved the volume perceived by participants [41] compared to the High Noise condition. This level was achieved by halving the volume control of the simulation application. The Low Noise condition was the ambient volume of our laboratory (i.e., no sound except for the fans of various computers and projectors). We calibrated the volume of the helicopter noise to the desired dBA levels using a SLM25TK Sound Level Meter[2].

3.2.1 Scenario. The SME developed four clinical vignettes related to trauma injuries. These vignettes served as clinical backgrounds for the handoff scenarios. Three clinical vignettes describing different patients and injuries were utilized in the experiment, and a fourth vignette for training was used for training participants in a comparable experimental trial handoff. We recorded the SME speaking all of the handoffs with each level of noise (Low, Medium, High) in the background while recording the dBA levels from the Sound Level Meter. We then mixed the SME's speech audio with the helicopter noise at the proper level and calibrated the volume of the speech audio from the speakers to match with the previously recorded dBA levels. Additionally, the first, third, and fourth author (the SME) together verified the speech audio sounded as loud as the SME's speech when we recorded his speech. We performed these steps to ensure that the speech audio qualities would be realistic for each noise level.

3.2.2 Physical Setup. The patient handoffs occurred within an immersive virtual environment shown in Figure 1, surrounding the participant on four walls of a 4 m × 4 m interaction space. Overhead short throw projectors provided edge-to-edge imagery with 1080p

[2]https://www.tekcoplus.com/products/slm25tk

resolution for each wall. All four projectors were driven from a single high-performance rendering desktop computer and a single rendering application. The projectors displayed the virtual imagery monoscopically. The desktop computer had an Intel Core i9-10900X CPU, 2 NVIDIA Quadro RTX 6000 GPUs each with 24 GB of dedicated RAM, and 64 GB of DDR4 system RAM. The application was created with the Unity 2020.3.16f1 game engine. Each wall consisted of multiple seamless floor-to-ceiling matte while panels, with two walls also containing access doors. When closed, the matte white doors were flush with the walls, allowing for little or no interference of the projected imagery. Floor-level tabs provided a means for opening the doors from within the interaction space in lieu of handles, which would occlude or distort projected imagery.

On the back of one of the center panels in each wall, a mounted transducer turned the entire tile into a speaker for audio output. By connecting the four wall speakers through an amplifier to the desktop PC, surround sound audio drivers mapped each hardware output channel to correspond to spatial environmental audio that matches the position/direction of the physical wall tile. The environmental audio from the helicopter came from all four wall speakers (i.e., it surrounded participants). The virtual, projected Sender was positioned to match the physical location of one of the wall audio output devices, ensuring that the spatial positioning and volume for the handoffs that participants received was as accurate as possible.

Both the Sender and Receiver rigged avatars were from the Rocketbox library [15]. The Sender's mouth was animated in sync with the handoff speech audio using LipSync Pro[3]. They were animated using a looping idle animation from Adobe Mixamo[4].

A Vive Base Station 2.0 unit mounted in one of the upper corners of the space allowed a Vive Tracker 3.0, attached to a cap worn by participants, to provide the participants' head position and orientation during the handoff interactions. With a field of view of 240 degrees, the tracker provides millimeter positional accuracy and sub-degree orientational accuracy [5].

Participant audio was recorded in .wav audio format using a worn, wireless SAMSON XPD2 Headset[5].

3.3 Methods

3.3.1 Study Design. We used a full-factorial within-subjects design with one factor (**Noise Volume**) and three levels (**Low Noise** at 36 dBA, **Medium Noise** at 69 dBA, and **High Noise** at 75 dBA).

The Low Noise level is valuable because it served as a baseline of running the simulation with no distracting environmental noise. On the other hand, the High Noise level tested more realistic audio level given the simulation's virtual environment. At half of the High Noise volume, we used the Medium Noise level to test how some (but not an overwhelming amount of) environmental noise affected handoff participants.

In total, each participant experienced one training trial at the Low Noise level and three experimental trials (one at each of Low, Medium, and High) while they were performing both handoff tasks (receiving and sending) in sequence and at the same noise level. The experimental trials were tested in randomized order.

[3]https://assetstore.unity.com/packages/tools/animation/lipsync-pro-32117
[4]https://www.mixamo.com/
[5]http://www.samsontech.com/samson/products/wireless-systems/xpd-series/xpd2hs/

3.3.2 Procedure. Once participants arrived, they were asked to affirm their consent to participate in the experiment by signing an informed consent form. Afterwards, the experimenter verbally explained the study details and made sure that the participants understood the tasks. The experimenter explained the different noise levels participants would experience as experimental conditions. Participants entered the projected immersive interaction space with the experimenter, who then introduced participants to the experiment's two virtual humans, described each virtual human's role, and instructed participants how to interact with them.

The first virtual human was introduced to participants as the Sender in the handoff scenario. Participants were told the Sender would describe a wounded patient and list the patient's injury, the cause of the injury, any symptoms the patient is exhibiting, and any treatments applied to the injury. Participants were instructed to record as much of the patient's information as possible. Participants were given a notebook and pen to assist with this task.

The second virtual human was introduced to participants as the handoff Receiver. Participants were told they would need to communicate all the information they captured from the Sender to the Receiver. Participants could reference any notes that they took when receiving the information. Participants were told that they could have as much time as they needed to communicate all the handoff details to the Receiver. Neither virtual human was programmed to respond to participants, so all speech was one-sided during the experimental trials.

Before the experiment, we included one practice trial so that the participants could try out the procedure and interaction with the virtual human. For this practice trial, we set the environmental noise to Low. Once participants were familiar with the environment and tasks, we started the experimental trials in random order.

After completing all conditions, they proceeded to complete a post-questionnaire in a computer form, assessing their demographics and prior VR experience, and we asked their general perception and preference of the environmental noise conditions as well. The questionnaire also included an open-ended prompt asking participants to write any questions they would have asked the Sender if given the chance. Finally, the experiment ended with a monetary compensation.

3.4 Measures and Hypotheses

In this section, we describe the measures that we used for the experiment as well as our hypotheses that we modeled based on our research questions in Section 1. We collected the measures described below for each experimental trial.

3.4.1 User Experience. It is important to understand the participants' subjective experience to determine how well the simulation causes a realistic experience. We applied the following user experience measures in our experimental study:

- **NASA Task Load Index:** Participants filled out the NASA Task Load Index (TLX) [18] to assess their cognitive load with sub-scales of *mental demand*, *physical demand*, *temporal demand*, *effort*, *performance*, and *frustration*. Each sub-scale question was presented on a 7-point scale from 1 to 7.

- **Self-reported stress:** We asked participants to report their subjective stress level on a 7-point scale (from 1 = Not at all stressed to 7 = Extremely stressed).

3.4.2 Performance. We measured participants' self-assessed and actual handoff performance. Self-assessed performance relates to participants' confidence in their handoff, and their actual performance captures how well they actually did. It is important to understand how environmental noise affects both of these interconnected performance measures.

- **Self-assessed performance:** In a questionnaire, participants were asked to enter how much (in percentage) of the original handoff they believe they *understood* from the SENDER, as well as what percentage of the original handoff they believe they *communicated* to the RECEIVER.
- **Actual performance:** We transcribed participants' handoff speech and scored each transcript against a rubric for the experimental scenario. The rubric was developed by our healthcare SME and frequent participant of medical handoffs. The rubric was based on the IBID handoff tool [17], and scores were calculated for each of the tool's domains (Identification/Info, Background, Illness Severity, Duties).

3.4.3 Behavior. We recorded the following social behavioral measures: the distance participants were from the virtual humans, and their speech loudness when sending the handoff. Participants' distances to the virtual humans provide insight into how they experienced the noise level; people stand closer when communicating in high noise environments. Participants' speech loudness is also linked to this experience, as they may speak louder to compensate for higher noise levels.

- **Distance to virtual humans:** The Vive tracker attached to the cap worn by participants logged their position every frame. This data was used to calculate how close participants stood to the virtual SENDER and RECEIVER.
- **Speech audio loudness:** We analyzed participants' audio recordings to determine the average relative loudness of their speech in each condition. We used the Python SoundFile library[6] to compute the audio signal (value between -1 and 1) for each frame of participants' .wav speech files, which were trimmed to include only the portion of recording when they were sending their handoff. To arrive at an average audio level for each recording, we then computed the root mean square (RMS) across all audio frames in a file and converted them to decibels relative to full scale (dB FS), which is a standard unit of amplitude measurement for digital audio. The maximum dB FS level read by a digital audio system is 0, and any audio louder than that level is clipped (i.e., not read) by the system. Decibels use a logarithmic scale that converts 50% decreases in audio loudness to a decrease in 6 dB FS. In other words, audio measured at -20 dB FS is four times as loud as audio measured at -32 dB FS.

3.4.4 Open-ended Responses. To understand how participants perceived the handoff when they received the information from the virtual human sending the handoff, we gave them the opportunity to type any questions or comments they would have communicated to the SENDER. This could include clarification questions, requests for additional information, or general comments. We performed qualitative content analysis on these responses.

3.4.5 Hypotheses. Based on related work highlighting the relevance of chaotic environs to handoffs [39], and research on communication noise and disruptions causing stress [1, 8, 9], reducing performance [23], and eliciting realistic behaviors [1], we established the following general hypotheses:

H1 Higher noise levels will cause poorer participant experience in the form of higher task load and higher reported stress when receiving and sending the handoff.

H2 Higher noise levels will cause reduced self-assessed and actual handoff performance.

H3 Higher noise levels will cause participants to move nearer to the SENDER when receiving the handoff and nearer to the RECEIVER when sending the handoff, as well as speak louder when sending the handoff.

4 RESULTS

We analyzed the quantitative responses with repeated-measures ANOVAs and Tukey multiple comparisons with Bonferroni correction at the 5% significance level. We tested the assumptions of the parametric statistical tests. We confirmed the normality with Shapiro-Wilk tests at the 5% level and QQ plots. Degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity when Mauchly's test indicated that the assumption of sphericity had been violated. We only report the significant effects.

4.1 User Experience

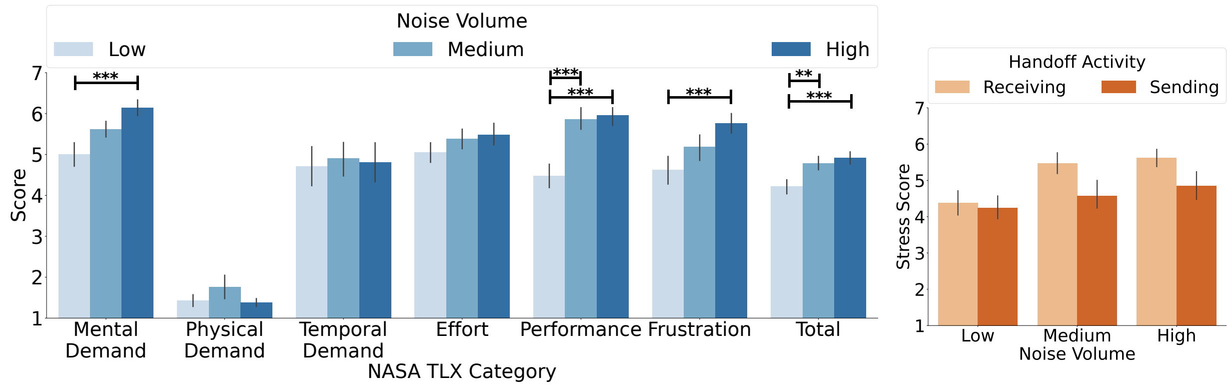
The results for user experience are shown in Figure 2. The x-axis of Figure 2(a) shows the NASA-TLX category. The y-axis of Figure 2(a) shows the reported NASA-TLX score. The hue of Figure 2(a) shows the NOISE VOLUME. The x-axis of Figure 2(b) shows the NOISE VOLUME. The y-axis of Figure 2(b) shows the reported stress level. The hue of Figure 2(b) shows the HANDOFF ACTIVITY. The error bars indicate the standard error.

We found a significant main effect of NOISE VOLUME on participants' reported stress level, $F(2, 20) = 5.10$, $\mathbf{p = 0.01}$, $\eta_p^2 = 0.11$. Post-hoc tests revealed a significant difference in *stress* between the LOW ($M = 4.31, SD = 1.46$) and HIGH ($M = 5.24, SD = 1.57$) NOISE VOLUME conditions; $\mathbf{p = 0.01}$.

We found a significant effect of HANDOFF ACTIVITY on reported stress, $F(1, 20) = 6.57$, $\mathbf{p = 0.02}$, $\eta_p^2 = 0.07$. Post-hoc tests revealed a significant difference in *stress* between the receiving HANDOFF ACTIVITY ($M = 5.16$, $SD = 1.38$) and the sending HANDOFF ACTIVITY ($M = 4.56$, $SD = 1.73$); $\mathbf{p = 0.02}$. In other words, participants reported significantly higher stress levels when receiving the handoff than when sending the handoff.

We found a significant main effect of NOISE VOLUME on the overall task load measured by the NASA-TLX, $F(2, 20) = 16.1$, $\mathbf{p < 0.001}$, $\eta_p^2 = 0.48$. Post-hoc tests revealed a significant difference in the overall TLX scores between the LOW ($M = 4.21$, $SD = 0.81$) and the MEDIUM ($M = 4.79$, $SD = 0.79$) conditions, $\mathbf{p = 0.002}$; as well as between the LOW and HIGH ($M = 4.92$,

[6]https://github.com/bastibe/python-soundfile



(a) NASA Task Load Index

(b) Self-Reported Stress

Figure 2: Experimental results for *User Experience*: (a) NASA Task Load Index and (b) self-reported stress levels. Lower is better.

SD = 0.70) conditions, $\mathbf{p} < \mathbf{0.001}$. More specifically, there were significant main effects of Noise Volume on the sub-scales of *mental demand*, $F(2, 20) = 12.0$, $\mathbf{p} < \mathbf{0.001}$, $\eta_p^2 = 0.38$, *performance*, $F(2, 20) = 13.2$, $\mathbf{p} < \mathbf{0.001}$, $\eta_p^2 = 0.40$, and *frustration*, $F(2, 20) = 7.2$, $\mathbf{p} < \mathbf{0.001}$, $\eta_p^2 = 0.26$. For the *mental demand* sub-scale, post-hoc tests revealed a significant difference between the Low (M = 5.00, SD = 1.30) and High (M = 6.14, SD = 0.85) conditions, $\mathbf{p} < \mathbf{0.001}$. For the *performance* sub-scale, post-hoc tests revealed a significant difference between the Low (M = 4.48, SD = 1.29) and Medium (M = 5.86, SD = 1.24) conditions, $\mathbf{p} < \mathbf{0.001}$; as well as between the Low and High (M = 5.95, SD = 1.02) conditions, $\mathbf{p} < \mathbf{0.001}$. For the *frustration* sub-scale, post-hoc tests revealed a significant difference between the Low (M = 4.62, SD = 1.60) and High (M = 5.76, SD = 1.18) conditions, $\mathbf{p} < \mathbf{0.001}$. The post-hoc tests are shown in Figure 2(a). There were no significant effects for the *physical demand temporal demand*, or *effort* sub-scales.

4.2 Performance

The results for handoff performance are shown in Figure 3. The x-axis in Figure 3(a) shows the Handoff Activity. The x-axis in Figure 3(b) shows the IBID domain. The y-axes show participants' performance as percentages on the handoff rubric (Sec. 3.4.2). The colors of the bars indicate the Noise Volume. The error bars indicate the standard error.

Self-assessed performance was the percentage of the handoff content participants reported *understanding* from the Sender in the receiving Handoff Activity or as the percentage of the handoff content participants reported *communicating* to the Receiver in the sending Handoff Activity. We found a significant main effect of Noise Volume on participants' *self-assessed performance*, $F(2, 20) = 23.51$, $\mathbf{p} < \mathbf{0.001}$, $\eta_p^2 = 0.43$. Post-hoc comparisons revealed significant differences in *self-assessed performance* between Low (M = 54.24, SD = 23.24) and Medium (M = 30.45, SD = 21.70); $\mathbf{p} < \mathbf{0.001}$. Post-hoc comparisons also revealed significant differences in *self-assessed performance* between Low (M = 54.24, SD = 23.24) and High (M = 24.87, SD = 16.97); $\mathbf{p} < \mathbf{0.001}$.

We found a significant main effect of Handoff Activity on *self-assessed performance*, $F(1, 20) = 10.12$, $\mathbf{p} = \mathbf{0.005}$, $\eta_p^2 = 0.03$. Post-hoc comparisons revealed a significant difference in *self-assessed performance* between the receiving Handoff Activity (M = 39.81, SD = 25.55) and the sending Handoff Activity (M = 33.22, SD = 22.72); $\mathbf{p} = \mathbf{0.005}$. In other words, the percentage of the original handoff participants reported communicating was lower than the percentage of the of the handoff they understood.

Participants' actual performance was recorded as the percentage of how many items they correctly communicated in each domain of the IBID tool (i.e., Identification/Info, Background, Illness Severity, Duties) [17]. We also computed a total IBID score as the participants' percentage of all items correctly communicated. One participant's audio was not recorded properly and thus could not be transcribed and scored properly, so that participant was excluded from this analysis.

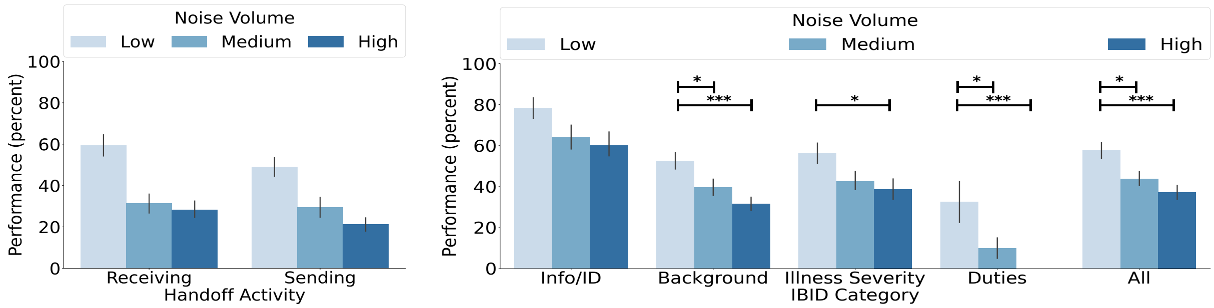
We found a significant main effect of Noise Volume on Identification/Info scores, $F(2, 19) = 3.35$, $\mathbf{p} = \mathbf{0.046}$, $\eta_p^2 = 0.15$. Post-hoc comparisons revealed no significant pairwise differences.

We found a significant main effect of Noise Volume on Background scores, $F(2, 19) = 8.92$, $\mathbf{p} < \mathbf{0.001}$, $\eta_p^2 = 0.32$. Post-hoc comparisons revealed a significant differences between the Low (M = 0.53, SD = 0.19) and Medium (M = 0.40, SD = 0.18) Noise Volume conditions, $\mathbf{p} = \mathbf{0.043}$; and between the Low and High (M = 0.32, SD = 0.16) conditions, $\mathbf{p} < \mathbf{0.001}$.

We found a significant main effect of Noise Volume on Illness scores, $F(2, 19) = 5.19$, $\mathbf{p} = \mathbf{0.010}$, $\eta_p^2 = 0.21$. Post-hoc comparisons revealed a significant differences between the Low (M = 0.56, SD = 0.26) and High (M = 0.39, SD = 0.22) Noise Volume conditions, $\mathbf{p} = \mathbf{0.012}$.

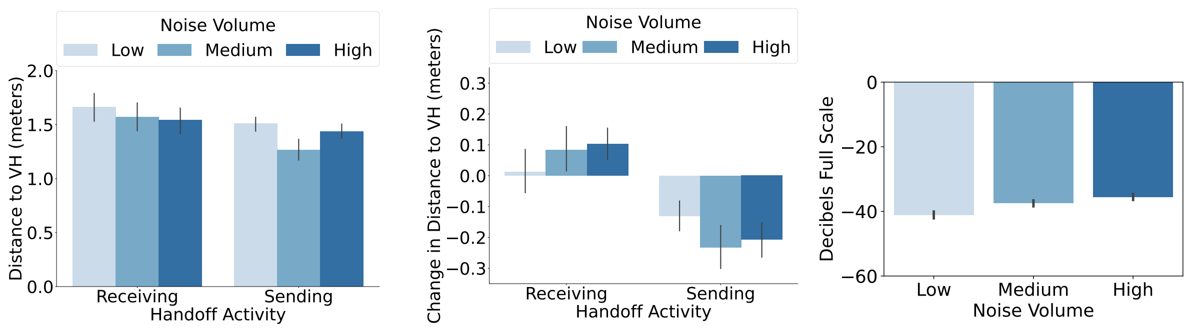
We found a significant main effect of Noise Volume on Duties scores, $F(1.29, 19) = 7.73$, $\mathbf{p} = \mathbf{0.007}$, $\eta_p^2 = 0.29$. Post-hoc comparisons revealed a significant differences between the Low (M = 0.33, SD = 0.41) and Medium (M = 0.10, SD = 0.21) Noise Volume conditions, $\mathbf{p} = \mathbf{0.034}$; and between the Low and High (M = 0.00, SD = 0.00) conditions, $\mathbf{p} = \mathbf{0.001}$.

We found a significant main effect of Noise Volume on all IBID scores averaged, $F(2, 19) = 10.0$, $\mathbf{p} < \mathbf{0.001}$, $\eta_p^2 = 0.35$. Post-hoc comparisons revealed a significant differences between the Low



(a) Self-Assessed Performance (b) Actual Performance

Figure 3: Results of the experiment for (a) self-assessed and (b) actual performance. Higher is better.



(a) Distance to Virtual Human at the End of Each Handoff Activity (b) Change in Distance to Virtual Human During Each Handoff Activity (c) Speech Audio Loudness (Higher is Louder)

Figure 4: Results of the experiment for participants' proxemics and speech behavior during the handoffs.

(M = 0.58, SD = 0.19) and Medium (M = 0.44, SD = 0.16) Noise Volume conditions, **p = 0.014**; and between the Low and High (M = 0.37, SD = 0.16) conditions, **p < 0.001**.

4.3 Behavior

The results for handoff behaviors are shown in Figure 4. The x-axes show the Noise Volume. In Figure 4(a) and Figure 4(b), the y-axes show the distance in meters between the participant and the virtual human projected in the MR simulation. In Figure 4(c), the y-axis shows the decibels relative to full scale (dB FS), where 0 dB FS is the maximum possible digital audio level. The colors of the bars indicate the Noise Volume condition. The error bars indicate the standard error.

We performed a paired samples t-test to compare the distance participants stood to the virtual humans at different points in time. We recorded *distance to virtual human* as the distance between the participant and the relevant virtual human in each handoff phase. In the *receiving* phase, *distance to virtual human* was the distance between the participant and the Sender at the end of the Sender's speech. In the *sending* phase, *distance to virtual human* was the distance between the participant and the Receiver at the end of the participant's speech. There was a significant difference in *distance to virtual human* between the *receiving* phase (M = 1.59 m, SD = 0.56 m) and the *sending* phase (M = 1.40 m, SD = 0.37 m); t(59) = −2.6, **p = 0.012**. In other words, participants stood closer to the virtual human at the end of receiving the handoff compared to sending the handoff.

When sending the handoff, we found a significant main effect of Noise Volume on *distance to virtual human*, $F(2, 19) = 4.23$, **p = 0.022**, $\eta_p^2 = 0.182$. Post-hoc comparisons revealed a significant difference between the Low (M = 1.51, SD = 0.29) and Medium (M = 1.27, SD = 0.31) Noise Volume conditions, **p = 0.022**.

We found a significant difference in the change in participants' distance to the Sender over the course of receiving the handoff (M = −0.19 m, SD = 0.27 m) and the change in participants' distance to the Receiver over the course of sending the handoff (M = 0.07 m, SD = 0.30 m); t(59) = −4.57, **p < 0.001**. In other words, participants moved closer to the Sender while receiving the handoff compared to moving farther from the Receiver while sending the handoff.

We found a significant main effect of Noise Volume on the loudness of participants' speech when sending the handoff, $F(2, 19) = 58.59$, **p < 0.001**, $\eta_p^2 = 0.755$. Post-hoc comparisons revealed significant differences between the Low (M = −41.10, SD = 4.60) and Medium (M = −37.48, SD = 4.65) Noise Volume conditions, **p < 0.001**; between the Low and High (M = −35.61, SD = 4.30) conditions, **p < 0.001**; and between the Medium and High conditions, **p = 0.003**.

4.4 Qualitative Results

Participants' responses to the open-ended question, "Would you have asked any questions after hearing the handoff to clarify what you heard or understood? If yes, what would you have asked?" (Sec. 3.4) were analyzed using the thematic analysis approach [6]. After reading the responses to get familiarized with the data, one author coded the data and discussed the codes with the first author after every iteration. Afterwards the codes were grouped into two conceptual themes. To focus our efforts on our primary question, we only analyzed the responses that were in the scope of the original question, which is an accepted approach in thematic analysis [6].

The thematic analysis of our participants' open-ended responses revealed two themes pertaining to their experience of how ambient noise influenced their information understanding and their perceived difficulty. Table 1 presents our codebook and the number of codes per condition. In some cases, a response by a participant contributed to more than one code or to one code multiple times. All of our participants at least mentioned one point that contributed to our observations of differences or similarities in information understanding across conditions and helped us to identify less common occurrences that may be valuable to include when it comes to assessment of novice learners' performance.

Information understanding is sometimes affected by ambient noise. For all conditions, we observed that many of our participants asked for specific topics *within* the handoff to be repeated or clarified (e.g., P1: "where was the wound? ...is she responsive?"). However, explaining this pattern is difficult, as our measures could not distinguish between the specific question referring to the only thing the participants heard or the only thing they did not hear. Also, we noticed a few instances where participants asked for information that was not given in the handoff, which may be indicative of their engagement or curiosity such as the response below:

> P22: "Yes, I would ask again of where the 22 year old was located. Since I heard she was wounded but wasn't sure if he wanted me to tell my partner where to find her to help with her wounds."

As our participants were novice learners we expected that even the Low condition may introduce some difficulty for them, which is supported by the five instances of participants asking for a full/part redo in the Low condition. However, we observed a consistent increase in such requests in Medium and High conditions (nine instances), which suggests that after a certain level of ambient noise the difficulty in information understanding reached a ceiling effect (e.g., P5: "Yes, I would ask him to repeat everything he said").

Additionally, we observed a few instances mostly in the Low condition where participants wanted to read back what they recorded to the Sender, indicating their desire to ensure that they did not miss anything (e.g., P7: "...I would also repeat what I heard to ensure that I wasn't missing anything"). This observation emphasizes mutual understanding between handoff participants, which has been shown to be important for improving handoff quality [27].

Last, we noted two instances of participants asking questions as a result of mishearing parts of the handoff, which suggests the importance of training scenarios where participants can get used to fast-paced and high-stakes handoff situations.

Table 1: Codebook for thematic analysis of open-ended verbal responses in the experiment.

Themes	Code: Definition	Off	Medium	High
Information understanding is sometimes affected by ambient noise	**Within:** number of responses about the repeat or clarification of specific details that were given during the handoff (e.g., vital signs, treatment)	12	9	14
	Additional: number of responses about related details that were not given during the handoff (e.g., progression of symptoms)	2	1	2
	Redo: asking for the whole handoff or topic (un)specific parts of the handoff to be repeated (e.g., repeat everything, repeat treatment and symptoms)	5	9	9
	Read back: asking for the opportunity to read back the handoff to the Sender	4	1	1
	Misheard: asking for information that resulted from mishearing the handoff	0	2	0
Articulation of perceived difficulty was slightly more in the presence of ambient noise	**Difficulty:** any explicit mention of experiencing difficulty (e.g., struggling to hear, barely understand)	0	2	4

Articulation of perceived difficulty was slightly more in the presence of ambient noise. We noted six instances across four participants who explicitly noted experiencing difficulty in understanding the handoff in conditions were ambient noise was added to the experience. For instance one of our participants mentioned:

> P8: "I could barely understand anything because of the background noise so I would've needed everything to be repeated"

While this was not a common occurrence, for novice learners it can be valuable to understand the exact reason why their performance may be lower (e.g., not hearing vs. not remembering) to appropriately support their learning experience.

5 DISCUSSION

Our experiment revealed several effects related to participants' handoff experience and noise levels. First, we found that the volume of noise in the virtual environment impacts participants' handoff experience in terms of stress and task load. We also found that Noise Volume affects participants' self-assessed and actual handoff performance. Last, we found that participants allowed different interpersonal distance between themselves and the virtual humans depending on Noise Volume.

5.1 Noise Volume Impacts Handoff Experience

Noise Volume significantly affected participants' reported stress levels, and there was a significant difference in their stress levels between the Low and High conditions. That participants reported more stress with louder helicopter noise suggests the helicopter noise had a realistic effect on the handoff experience. Additionally, participants experienced more stress when receiving the handoff than when sending the handoff. This suggests that the helicopter noise affected participants more when they were trying to gather information from the handoff Sender. A limitation of our study is that we measured stress levels with a single question rather than a more complete questionnaire (e.g., [29]). Participants also experienced higher task load throughout the receiving and sending of the handoff (as measured by the NASA TLX questionnaire) when the helicopter noise volume was at Medium or High levels. They experienced different scores specifically in the *mental demand*, *performance*, and *frustration* sub-scales of the NASA TLX.

Participants also reported wanting the Sender to repeat parts of or the entire handoff, or wanting to read back what they gathered from the handoff to the Sender to make sure they captured important details. However, they could not interact with the Sender, which may have prevented them from feeling as though they could reach a mutual understanding with the handoff Sender and establish a common ground [7, 27]. Additionally, the handoff task's configuration of the Sender offloading the entire handoff to the Receiver could have contributed to the stressful scenario. Indeed, a typical strategy for communication grounding when receiving a large amount of information to be recalled verbatim is to break up the information into installments [7]. While emergency situations present fewer opportunities to clarify information during the handoff [4, 34, 40], future MR handoff simulators should provide some level of interactivity between participants and virtual humans to support a more realistic experience.

5.2 Noise Volume Affects Handoff Performance

Noise Volume also affected participants' self-assessed and actual performance. Participants reported what percentage of the handoff they both understood from the Sender and communicated to the Receiver. Higher noise levels decreased participants' scores in both of these performance measures, which are expected and realistic results. Interestingly, doubling the volume of the helicopter noise did not significantly affect participants' handoff experience; there were no significant differences in stress, task load, or performance between the Medium and High Noise Volume conditions. In other words, the introduction of noise (regardless of its volume) that obfuscated the Sender's speech was sufficient to cause stress and performance degradation in handoff participants, and the loudest noise did not exacerbate these effects.

5.3 Interpersonal Distance and Voice Level Depend on Noise Volume and Handoff Role

When helicopter noise was added to the virtual environment, participants complained about the Sender not coming close enough to them and not speaking loud enough when the participants were receiving the handoffs. This caused participants to move closer to the Sender when receiving the handoff. Interestingly, when it was the participants' turn to send the handoff, they remained farther away from the Receiver and even moved farther away over the course of their handoff. This behavior may be explained by the different levels of stress participants reported when sending and receiving the handoffs: they felt more stress when receiving the handoff because they experienced difficulty hearing or recording all the handoff details, which resulted in moving closer to the Sender. Sending the handoff to the Receiver did not cause as much stress, so participants did not feel the need to compensate for the handoff difficulty by moving closer. An alternative explanation for this behavior is that participants moved away from the noise source and not necessarily the Receiver when sending the handoff, and they did not feel like moving closer to the Receiver would help the Receiver hear the handoff better. Future studies might examine how more realistic interactivity with the Receiver would affect this behavior. Additionally, when sending the handoff, participants spoke louder depending on the Noise Volume, suggesting that participants felt a realistic need to compensate for louder environmental noise with their speech but not necessarily with their proximity to the Receiver. Handoff training not only serves to ensure that practitioners perform better in communicating handoff information (the "what"), but also in reducing their cognitive load and adopting behaviors that make it easier for receivers to capture the information (the "how"). Our MR handoff simulation caused expected results in both of these dimensions, which suggests it may be a useful tool in training and studying handoff communication in emergency settings.

6 CONCLUSION

In this paper, we presented an MR simulation of a patient handoff that simulated different levels of environmental noise. Errors in handoff communication can result in poor patient outcomes, so it is important to train handoff participants effectively. Emergency situations introduce additional duress to handoff communication, such as chaotic environs (e.g., increased environmental noise). To test how environmental noise affected participants' handoff experience, performance, and behaviors, we conducted a human-subjects experimental design study ($N = 21$) using our MR simulation. We found that increased environmental noise increased participants' stress and task load, and decreased their self-assessed and actual performance. The noise also caused participants to stand closer to the handoff sender than the receiver, and speak louder when sending their handoff. We discussed how our results are valuable for understanding patient handoffs, as well as implications for the development of other MR handoff simulations.

ACKNOWLEDGMENTS

This material includes work supported in part by the UCF Florida High Tech Corridor Council (FHTCC) Matching Grants Research Program (MGRP); the Office of Naval Research under Award Numbers N00014-21-1-2578 and N00014-21-1-2882 (Dr. Peter Squire, Code 34); the National Science Foundation under Award Number 1800961 (Dr. Ephraim P. Glinert, IIS); and the AdventHealth Endowed Chair in Healthcare Simulation (Prof. Welch).

REFERENCES

[1] Mohammed Alghamdi, Holger Regenbrecht, Simon Hoermann, and Nicola Swain. 2017. Mild stress stimuli built into a non-immersive virtual environment can elicit actual stress responses. *Behaviour & Information Technology* 36, 9 (2017), 913–934.

[2] Darcy Alimenti, Sarah Buydos, Lindsay Cunliffe, and Alexandra Hunt. 2019. Improving perceptions of patient safety through standardizing handoffs from the emergency department to the inpatient setting: a systematic review. *Journal of the American Association of Nurse Practitioners* 31, 6 (2019), 354–363.

[3] Mindi Anderson, Frank Guido-Sanz, Steve Talbert, Christopher W Blackwell, Marci Dial, Ryan P McMahan, and Desiree A Díaz. 2022. Augmented Reality (AR) as a Prebrief for Acute Care Simulation. *Clinical Simulation in Nursing* 69 (2022), 40–48.

[4] Shannon Bakon and Tracey Millichamp. 2017. Optimising the emergency to ward handover process: A mixed methods study. *Australasian Emergency Nursing Journal* 20, 4 (2017), 147–152.

[5] Peter Bauer, Werner Lienhart, and Samuel Jost. 2021. Accuracy Investigation of the Pose Determination of a VR System. *Sensors* 21 (2021), 1–17.

[6] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative research in psychology* 3, 2 (2006), 77–101.

[7] Herbert H Clark and Susan E Brennan. 1991. Grounding in Communication. (1991).

[8] Rory Clifford, Hendrik Engelbrecht, Sungchul Jung, Hamish Oliver, Mark Billinghurst, Robert W Lindeman, and Simon Hoermann. 2021. Aerial firefighter radio communication performance in a virtual training system: radio communication disruptions simulated in VR for *Air Attack Supervision*. *The Visual Computer* 37, 1 (2021), 63–76.

[9] Rory MS Clifford, Simon Hoermann, Nicolas Marcadet, Hamish Oliver, Mark Billinghurst, and Robert W Lindeman. 2018. Evaluating the effects of realistic communication disruptions in VR training for aerial firefighting. In *2018 10th International Conference on Virtual Worlds and Games for Serious Applications (VS-Games)*. IEEE, 1–8.

[10] Rory MS Clifford, Timothy McKenzie, Stephan Lukosch, Robert W Lindeman, and Simon Hoermann. 2020. The Effects of Multi-sensory Aerial Firefighting Training in Virtual Reality on Situational Awareness, Workload, and Presence. In *2020 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*. IEEE, 93–100.

[11] Salam Daher, Jason Hochreiter, Nahal Norouzi, Laura Gonzalez, Gerd Bruder, and Greg Welch. 2018. Physical-virtual agents for healthcare simulation. In *Proceedings of the 18th International Conference on Intelligent Virtual Agents*. 99–106.

[12] Stacey Eberhardt. 2014. Improve handoff communication with SBAR. *Nursing* 44, 11 (2014), 17–20.

[13] Franz Faul, Edgar Erdfelder, Albert-Georg Lang, and Axel Buchner. 2007. G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior research methods* 39, 2 (2007), 175–191.

[14] Teresa Ferrández-Antón, Guillermo Ferreira-Padilla, Rafael Del-Pino-Casado, Pilar Ferrández-Antón, Jose Baleriola-Júlvez, and Jose Ramón Martínez-Riera. 2020. Communication skills training in undergraduate nursing programs in Spain. *Nurse Education in Practice* 42, 102653 (2020).

[15] Mar Gonzalez-Franco, Eyal Ofek, Ye Pan, Angus Antley, Anthony Steed, Bernhard Spanlang, Antonella Maselli, Domna Banakou, Nuria Pelechano, Sergio Orts-Escolano, et al. 2020. The rocketbox library and the utility of freely available rigged avatars. *Frontiers in virtual reality* (2020), 20.

[16] Craig Goolsby, Ryan Vest, and Tress Goodwin. 2014. New wide area virtual environment (wave) medical education. *Military medicine* 179, 1 (2014), 38–41.

[17] Frank Guido-Sanz, Mindi Anderson, Steven Talbert, Desiree A Diaz, Gregory Welch, and Alyssa Tanaka. 2022. Using Simulation to Test Validity and Reliability of I-BIDS: A New Handoff Tool. *Simulation & Gaming* (2022), 10468781221098567.

[18] Sandra G Hart and Lowell E Staveland. 1988. Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In *Advances in psychology*. Vol. 52. Elsevier, 139–183.

[19] Health and Safety Executive (HSE). 2022. Human factors: Shift handover. *https://www.hse.gov.uk/humanfactors/topics/shift-handover.htm* (2022).

[20] Joint Commission. 2018. Hospital: 2018 National patient safety goals. *https://www.jointcommission.org/* (2018).

[21] Heath G Jones, Nathaniel T Greene, Michael R Chen, Cierrah M Azcona, Brandon J Archer, and Efrem R Reeves. 2018. The Danger Zone for Noise Hazards Around the Black Hawk Helicopter. *Aerospace Medicine and Human Performance* 89, 6 (2018), 547–551.

[22] Niranjan S. Kulkarni. 2010. *A systemic framework for modeling information handoffs in human-centric processes*. Ph. D. Dissertation. Binghamton University-State University of New York.

[23] Colleen G Le Prell and Odile H Clavier. 2017. Effects of noise on speech recognition: Challenges for communication by service members. *Hearing research* 349 (2017), 76–89.

[24] Da-Hye Lee and Eun-Ju Lim. 2021. Effect of a simulation-based handover education program for nursing students: A quasi-experimental design. *International Journal of Environmental Research and Public Health* 18, 11 (2021), 5821.

[25] Christopher Lewis, Daniel Enriquez, Lucas Calabrese, Yifan Zhang, Steven J Anbro, Ramona A Houmanfar, Laura H Crosswell, Michelle J Rebaleati, Luka A Starmer, et al. 2022. Virtual Reality Multiplayer Interaction and Medical Patient Handoff Training and Assessment. In *ITNG 2022 19th International Conference on Information Technology-New Generations*. Springer, 17–23.

[26] Sok Ying Liaw, Sim Win Ooi, Khairul Dzakirin Bin Rusli, Tang Ching Lau, Wilson Wai San Tam, and Wei Ling Chua. 2020. Nurse-physician communication team training in virtual reality versus live simulations: randomized controlled trial on team communication and teamwork attitudes. *Journal of medical Internet research* 22, 4 (2020), e17279.

[27] Tanja Manser, Simon Foster, Stefan Gisin, Dalit Jaeckel, and Wolfgang Ummenhofer. 2010. Assessing the quality of patient handoffs at care transitions. *Quality and Safety in Health Care* 19, 6 (2010), e44–e44.

[28] Stuart Marshall, Julia Harrison, and Brendan Flanagan. 2009. The teaching of a structured tool improves the clarity and content of interprofessional clinical communication. *BMJ Quality & Safety* 18, 2 (2009), 137–140.

[29] Gerald Matthews, James Szalma, April Rose Panganiban, Catherine Neubauer, and Joel S Warm. 2013. Profiling Task Stress with the Dundee Stress State Questionnaire. *Psychology of stress: New research* 1 (2013), 49–90.

[30] Lee Ann Riesenberg. 2012. Shift-to-shift handoff research: Where do we go from here? , 4–8 pages.

[31] Grazielle Rezende da Silva dos Santos, Fabiana de Mello Barros, Priscilla Valladares Broca, and Rafael Celestino da Silva. 2019. Communication noise during the nursing team handover in the intensive care unit. *Texto & Contexto-Enfermagem* 28 (2019).

[32] Ryan Schubert, Gerd Bruder, Alyssa Tanaka, Francisco Guido-Sanz, and Gregory F. Welch. 2021. Mixed Reality Technology Capabilities for Combat-Casualty Handoff Training. In *International Conference on Human-Computer Interaction*, Jessie Y. C. Chen and Gino Fragomeni (Eds.), Vol. 12770. 695–711.

[33] Mike Shertz. 2018. MIST report: A simple way to convey information. *https://www.crisis-medicine.com/mist-report-a-simple-way-to-convey-information* (2018).

[34] Christopher J Smith, Russell J Buzalko, Nathan Anderson, Joel Michalski, Jordan Warchol, Stephen Ducey, and Chad E Branecki. 2018. Evaluation of a novel handoff communication strategy for patients admitted from the emergency department. *Western Journal of Emergency Medicine* 19, 2 (2018), 372.

[35] Robin Stacey. 2000. Marketing medical simulation—what industry needs from the clinical community. *Minimally Invasive Therapy & Allied Technologies* 9, 5 (2000), 357–360.

[36] Amy J. Starmer, Nancy D. Spector, Rajendu Srivastava, April D. Allen, Christopher P. Landrigan, Theodore C. Sectish, and I-PASS Study Group. 2012. I-PASS, a mnemonic to standardize verbal handoffs. *Pediatrics* 129, 2 (2012), 201–204.

[37] Jacob Stuart, Karen Aul, Michael D. Bumbach, Anita Stephen, and Benjamin Lok. 2021. Building a Handoff Communication Virtual Experience for Nursing Students Using Virtual Humans. *CIN: Computers, Informatics, Nursing* 39, 12 (2021), 1017–1026.

[38] Alyssa Tanaka, Brian Stensrud, Greg Welch, Fransisco Guido-Sanz, Lee Sciarini, and Henry Phillips. 2019. The Development and Implementation of Speech Understanding for Medical Handoff Training. In *Proceedings of Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC)*.

[39] Ruth Tortosa-Alted, Estrella Martínez-Segura, Marta Berenguer-Poblet, and Sílvia Reverté-Villarroya. 2021. Handover of Critical Patients in Urgent Care and Emergency Settings: A Systematic Review of Validated Assessment Tools. *Journal of Clinical Medicine* 10, 24 (2021), 5736.

[40] Brigit VanGraafeiland, Cynthia Foronda, Sarah Vanderwagen, Laura Allan, Meghan Bernier, Jennifer Fishe, Elizabeth A Hunt, and Justin M Jeffers. 2019. Improving the handover and transport of critically ill pediatric patients. *Journal of clinical nursing* 28, 1-2 (2019), 56–65.

[41] Richard M Warren. 1970. Elimination of biases in loudness judgments for tones. *The Journal of the Acoustical Society of America* 48, 6B (1970), 1397–1403.

[42] Casey White, Joon Chuah, Andrew Robb, Benjamin Lok, Samsun Lampotang, David Lizdas, James Martindale, Guillermo Pi, and Adam Wendling. 2015. Using a critical incident scenario with virtual humans to assess educational needs of nurses in a postanesthesia care unit. *Journal of Continuing Education in the Health Professions* 35, 3 (2015), 158–165.