# Repeat after Me: Using Mixed Reality Humans to Influence Best Communication Practices

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Figure 1: Anesthesia Resident working with Mixed Reality Team (from left to right: MRH Nurse, MRH Surgeon, MRH Anesthesiologist

**ABSTRACT**

In the past few years, advances have been made on how mixed reality humans (MRHs) can be used for interpersonal communication skills training for medical teams; however, little research has looked at how MRHs can influence communication skills during training. One way to influence communication skills is to leverage MRHs as models of communication behavior. We created a mixed reality medical team training exercise designed to impact communication behaviors that are critical for patient safety. We recruited anesthesia residents to go through an operating room training exercise with MRHs to assess and influence residents' closed loop communication behaviors during medication administration. We manipulated the behavior of the MRHs to determine if the MRHs could influence the residents' closed loop communication behavior. Our results showed that residents' closed loop communications behaviors were influenced by MRHs. Additionally, we found there was a statistically significant difference between groups based on which MRH behavior residents observed. Because the MRHs significantly impacted how residents communicated in simulation, this work expands the boundaries for how VR can be used and demonstrates that MRHs could be used as tools to address complex communication dynamics in a team setting.

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## 1 INTRODUCTION

Recent research on medical team training with mixed reality humans (MRHs) has investigated how medical professionals speak up to MRHs [20], how medical professionals gaze at MRHs [18], and how the presence of other medical professionals affects behavior with MRHs [19]. Little research has investigated how MRHs can influence communication skills during training [11].

Leveraging psychology and VR theories such as Social Learning Theory [4] and the Threshold Model of Social Influence in Virtual Environments [7], MRHs could serve as models of communication behavior. We created a mixed reality medical team training simulation designed to influence a communication skill critical for patient safety: closed loop communication during medication administration. Closed loop communication is a standardized communication protocol designed to verify information exchange and ensure both parties involved in the information exchange are in agreement [8]. For example, the following is an example of closed loop communication being used to administer an antibiotic: Ceftriaxone. High risk medications are commonly administered in the OR where a number of medication administration safety measures used in most other hospital settings cannot be applied; therefore careful closed loop communication is all the more important:

**Dr. Girard:** "Dr. Jones, could you please give Mr. Smith one gram of Ceftriaxone IV right now?"
**Dr. Jones:** "Okay, so I'm going to give Mr. Smith one gram of Ceftriaxone IV right now, correct?"
**Dr. Girard:** "Yes, that's correct."

Unfortunately, the reality of the communication culture among healthcare teams is that when medications are requested to be administered, the following typically happens:

**Dr. Girard:** "Dr. Jones, could you please give Mr. Smith one gram of Ceftriaxone IV right now?"
**Dr. Jones:** "Okay"

Not employing best practices such as closed loop communication can lead to adverse drug events. According to the Agency for Healthcare Research and Quality, approximately 5% of hospitalized patient are affected by an adverse drug event [2]. Those errors are even more common in patients undergoing surgery where as much as 5% of every medication administration involves an error or adverse drug event [17].

Previous research has found that, even during in-situ team training, use of closed loop communication in healthcare teams is limited [15]. One reason for this lack of closed loop communication is due to the leadership style of healthcare teams which typically adopt a more authoritative style in which a single person (the surgeon) leads the team. The authors found that closed loop communication use increased among teams whose leadership styles were more egalitarian as opposed to authoritarian [15].

This lack of closed loop communication could cause medical errors possibly leading to patient injury or death. To address this need for changing healthcare professionals' behavior, we addressed the following question: would observing an MRH modeling closed loop communication behaviors impact how participants communicated in a mixed reality simulation? To address this question, we recruited anesthesia residents to participate in an operating room training exercise with MRHs to assess and influence residents' closed loop communication behaviors during medication administration. Residents interacted with a MRH surgeon, MRH anesthesiologist, and a MRH nurse. Early in the exercise, the MRH surgeon asked the resident to administer Ceftriaxone to the patient. This moment served as a baseline assessment of the residents' closed loop communication behavior. After the baseline assessment, residents observed the MRH surgeon ask the MRH nurse to give Heparin. Finally, we assessed the residents' closed loop communication behaviors again by having the MRH anesthesiologist ask the resident give the patient Insulin.

Three conditions were created in which we manipulated the behavior of the MRH nurse and MRH surgeon to determine if MRHs could influence the residents' closed loop communication behaviors:

- Good Modeling condition (GM): When asked by the MRH surgeon to give Heparin, the MRH nurse and MRH surgeon use closed loop communication.
- Bad Modeling condition (BM): When asked by the MRH surgeon to give Heparin, neither the MRH nurse nor the MRH surgeon use closed loop communication. This condition also reflects the cultural norm where training was conducted.
- Bad Modeling with Correction condition (BMC): When asked by the MRH surgeon to give Heparin, the MRH nurse initially does not use closed loop communication, but is corrected by the surgeon to repeat back what he requested. After this correction, the MRH surgeon and MRH nurse use closed loop communication.

The main goal of this work was to show that, in simulation, MRHs can be used to address complex communication dynamics like closed loop communication in an OR team setting. We had one main hypothesis (H1): Closed loop communication performance will be different based on the MRH model of behavior observed (BM, GM or BMC).

This paper provides two main contributions to virtual human and virtual reality research. First, we found that MRHs can influence critical communication behavior in a team-based environment. We found a statistically significant difference in closed loop communication performance between groups. Specifically, participants performed significantly better in the BMC group than participants in the BM group. The results provide researchers a better understanding as to how MRHs can be used to teach communication skills. Virtual human researchers may be able to leverage this work to investigate how other critical communication behaviors can be influenced in a training environment. It is possible that MRHs can be used to influence other critical skills required by medical professionals.

Second, this work expands the possibilities for applications of VR. The results are encouraging for applying VR training to other team-oriented domains where critical communication skills are necessary for success. This work expands future directions on how to most effectively use VR training for medical team communication skills training.

## 2 Related Work

The study presented in this paper is based on existing theories that suggest that MRHs can influence real humans. This work also builds upon previous mixed reality medical team training research that has continually shown MRHs can serve as stand-ins for human teammates. Additionally, we build upon existing research that has studied how behaviors can be changed using virtual humans.

### 2.1 Theoretical Foundation

#### 2.1.1 Social Learning Theory

Theorized by Albert Bandura, Social Learning Theory states that behaviors can be learned by observing another person perform those behaviors [4]. Bandura tested this theory in the "Bobo Doll" experiment in which he found that children were more likely to be physically aggressive with a Bobo Doll toy if they previously saw an adult play aggressively with the toy [5].

#### 2.1.2 The Threshold Model of Social Influence in Virtual Environments

Introduced by Blascovich, The Threshold Model describes how behaviors can be influenced in virtual environments [6, 7]. Specifically, the model hypothesizes that if a virtual human is perceived to be more human-like, influence is more likely to occur even if the virtual human's communicative realism is low. This theory also hypothesizes that if a virtual human is perceived to be more computer-like, influence is likely only to occur if the virtual human has high communicative realism.

#### 2.1.3 Closed Loop Communication and the Five *Rights* of Medication Administration

Closed loop communication is a standardized communication protocol designed to verify information exchange and ensure both parties involved in the information exchange are in agreement [8]. Closed loop communication is used in other team-based environments including the aviation industry and military [8]. In medicine, closed loop communication ensures the correct medication and dosage are given to the patient. One way to reduce medication errors with closed loop communication is to use the "Five *Rights* of Medication Administration" [14]. The Five *Rights* are as follows:

1. The right patient
2. The right drug
3. The right dose
4. The right route
5. The right time

In Figure 2, the five *rights* are shown being used with closed loop communication. In this exchange, the five *rights* are as follows: the patient is “Mr. Smith”, the drug is ”Ceftriaxone”, the dose is ”one gram”, the route is ”IV”, and the time is ”right now”.

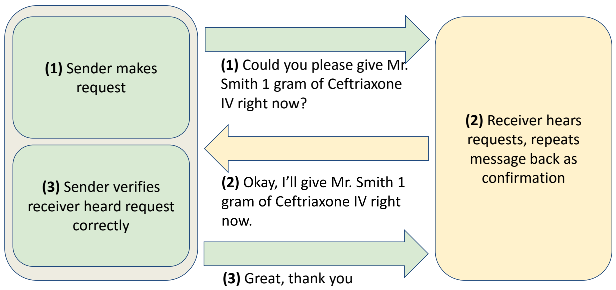


Figure 2: Closed Loop Communication

### 2.2 Behavior Change with Virtual Humans

Fox and Bailenson have looked at how virtual doppelgangers can influence eating habits [13]. They ran a study in which participants observed a virtual doppelganger eating carrots and candy. In one condition, the doppelgangers lost weight when eating carrots but gained weight when eating candy. In the other condition, the doppelgangers did not change weight when it ate. After going through the experiment, participants were seated at a computer to complete a survey. A bowl of candy was next to the computer and participants were told they could eat candy if they wanted. The authors found that when participants reported high presence, men ate more candy, and women restrained from eating the candy in the bowl. The results of this study show that participants can be influenced to change real-world habits such as eating.

Babu et al, looked at using a virtual peer cyclist to influence road-cross behavior in a virtual environment [3]. The study operated on the assumption that peers have strong influences on children; therefore, a virtual peer could also have strong influence on real children. The authors conducted a study in which a virtual cyclist engages in either risky or safe behavior when crossing a virtual road. In the risky peer condition, the virtual peer chose a tight gap to cross the road while a large gap was chosen by the safe peer. The authors recruited 10-12 year old children to participate in this experiment. The results showed that the children who rode with the risky peer were significantly less likely to stop at the last six intersections than participants who rode with the safe peer. This study reinforces the power of social learning theory and the effects it can have on behavior.

Cordar et al. investigated if virtual humans could be used to influence conflict resolution behavior [11]. Surgical technicians participated in a team training exercise in which they observed a virtual nurse attempt to speak up to a virtual surgeon over a patient safety issue. After observing the virtual surgeon and nurse argue, participants were put into a situation in which they needed to speak up to the surgeon about another patient safety issue. In one condition, participants saw the virtual nurse successfully speak up to the surgeon and “stop the line” by calling a manager to intervene. In another condition, they saw the nurse attempt to speak up to the surgeon but ultimately back down. The results showed that participants were significantly more likely to speak up to the virtual surgeon if they first observed a virtual nurse successfully speak up to the virtual surgeon.

### 2.3 Medical Team Training with MRHs

Initial research on MRHs for medical team training investigated how to increase social presence with MRHs. Chuah et al. conducted research on the concept of “physicality.” [10] Physicality is the degree to which a virtual human occupies the physical space. Physicality is positively correlated with social presence.The authors found that adding physical components like scrub pants, creating a “see-through” display, and displaying the virtual human life-size on a television in portrait mode increased physicality which also increased the social presence of the virtual humans.

Robb et al. investigated conflict behavior with virtual humans [20]. In his study, a virtual surgeon tries making a risky medical decision which could impact the safety of the patient. Robb found that real OR nurses exhibited conflict resolution behavior which aligned with an existing behavioral framework describing conflict behavior amongst humans.

White et al. investigated how MRHs can be used to train nurses on information exchange during post-anesthesia care unit (PACU) handoffs [21]. The authors found that nurses did not properly provide critical information to the MRHs during the handoff. This work highlighted the importance of team training and that MRHs could potentially aid in training medical professionals.

## 3 Methods

### 3.1 Overview

The main goal of this work was to show that, in simulation, MRHs can be used to address complex communication dynamics like closed loop communication in a OR team setting. We believed, based on theories in both VR and psychology, that MRHs could influence closed loop communication behavior. In order to achieve this goal, we addressed the following question: would observing an MRH modeling closed loop communication behaviors impact how participants communicated in a mixed reality simulation? To study this question, we recruited anesthesia residents to participate in an exercise with MRHs to assess and influence residents’ closed loop communication behaviors during medication administration. Residents interacted with a MRH surgeon, MRH anesthesiologist, and a MRH nurse. At two moments in the exercise, participants are tasked with administering a medication to the patient. The first moment serves as a baseline assessment of closed loop communication behavior. In between the first and second moment, participants observe the MRH surgeon and MRH nurse administer a medication to the patient. The second moment serves as an assessment of whether the MRHs influenced closed loop communication behavior.

We created three conditions (discussed in more detail in section 3.5) which manipulated the behavior of the MRH surgeon and MRH nurse. Our main hypothesis (H1) was the following: Closed loop communication performance will be different based on the MRH model of behavior observed.

### 3.2 Technology

The MRHs used in this study are known as Animatronic Digital Avatars (or ANDI units) [9]. ANDI units are life-size virtual humans presented on a 40” TV screen rotated in portrait mode (see Figure 3). ANDI units have physical scrub pants stuffed with polyester stuffing which hang behind the TV. On the display, a static image is textured onto a cylindrical mesh and placed behind the 3D model of the virtual human. This static image is a picture of what is behind the TV screen. This technique gives the illusion of a “see-through” display. A Microsoft Kinect v2 is mounted on top of the

TV and is used to track the user's head position. The Kinect allows for head-coupled perspective rendering. The MRH can also use this tracked head position to look at the participants. All of these components aid in increasing social presence and is due to the relationship between physicality and social presence [10].

ANDI units were physically placed in a decommissioned operating room with the participants. We also positioned the ANDI units based on their role on the team. For example, the MRH nurse was positioned at the feet of the patient which is typically where a nurse stands during a surgery, and the MRH anesthesiologist was positioned at the patient's head where there is an anesthesia machine.

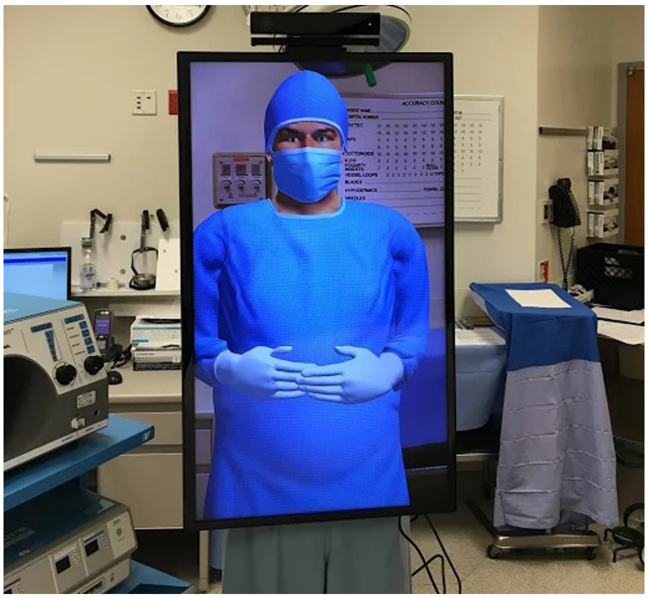

Figure 3: Close Up of ANDI Unit

Our MRHs are controlled using a Wizard of Oz (WOZ) approach. Behind a curtain in the operating room, a single operator controlled every action for all of the MRHs (see Figure 4). We chose a WOZ approach for controlling the MRHs' actions in order to overcome potential issues with speech recognition that could either result in sub-par training or affect the study's results. Participants were always given a headset and told that the headset allowed the MRHs to hear and understand them. Participants were never aware that someone was controlling what the MRHs said or did. The WOZ computer had a touchscreen display that allowed for the WOZ operator to quietly and quickly select actions for the MRHs.

### 3.3 Participants

At the University of Florida (UF) health system, 53 anesthesia residents participated in this study. 53 anesthesia residents represents a significant portion of the entire anesthesia resident population at UF Health. Of those participating, 38 participants were male and 15 participants were female. Resident ages ranged from 26 to 40 with an average age of 30.8 and standard deviation of 3.01. 41 participants reported their race as White, 8 reported as African American, and 4 as Asian.

One participant was in the first year of residency, 19 were in the second year of residency, 17 were in the third year of residency, and 16 were in the fourth (final) year of residency.

While participation in the training was not explicitly required, anesthesia residents were strongly encouraged by the anesthesia department to participate in the exercise. Residents who consented to participate in the study component of the training exercise received a $10 Starbucks gift card. Participants were scheduled for the exercise through email and told they would be participating in an exercise aimed at improving perioperative teams. Participants were not made aware of the learning objectives of the exercise until a debriefing session after the training was completed.

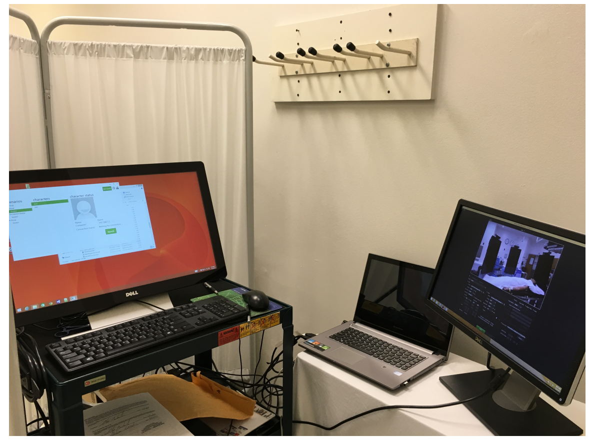

Figure 4: WOZ Computer

Training took place in a single session during the anesthesia residents' didactic time which is between 6:30 and 7:00 AM. This constraint meant the entire study, including surveys and debriefing interview, had to take no more than thirty minutes. Due to the design of the study, only one anesthesia resident could participate in the exercise at a time.

### 3.4 Training Exercise

The training exercise was conducted in a decommissioned operating room. The room was configured to look like an operating room by including a patient bed with a patient mannequin, an anesthesia machine, and a looping video of the patient's vital signs.

We designed the training exercise in conjunction with the UF Health anesthesiology department. We created an exercise to assess and influence anesthesia residents' ability to used closed loop communication. The exercise was designed based on the need to reduce medication errors.

The exercise was composed of two stages where important medications are given to the patient. The two stages were the Pre-Induction Briefing (prior to the patient being induced for surgery) and the Closing (after the surgery has been performed). The medications were Ceftriaxone, Heparin, and Insulin. The medications given during the exercise were chosen because medication administration errors had occurred previously at this hospital.

In both stages, anesthesia residents worked with a MRH nurse, MRH surgeon, and MRH faculty anesthesiologist (see Figure 1).

During the Pre-Induction Briefing Stage, participants work with the team as the MRH surgeon goes over the Surgical Safety Checklist [16]. After confirming the patient has no allergies, the MRH surgeon asks the anesthesia resident: "Okay, for antibiotics: Since incision will be within the hour, resident, could you give Mr. Smith Ceftriaxone one gram IV slowly right now?" This moment serves as a baseline assessment of the residents' closed loop communication skills. Shortly after giving the Ceftriaxone, the MRH surgeon asks the MRH nurse to give the patient Heparin: "Okay. Nancy, Could you give Mr. Smith Heparin 5000 units SubQ [subcutaneous] right now?" This moment serves as the main manipulation in which we change the behavior of both the MRH surgeon and MRH nurse to later assess if the MRHs' behavior affects the anesthesia residents' closed loop communication behaviors. Since we did not have a way for the MRH nurse to physically interact with the patient, the MRH nurse walks off the screen temporarily and returns after administering the Heparin. More details on this manipulation will be discussed in the next section.

During the Closing stage, the surgery has been completed successfully. The MRH surgeon lets the team know he is going to go visit patient's family. After asking if anyone has any issues with him leaving, the MRH surgeon leaves by walking off screen. At this point, the patient is going to be moved to the Post-Anesthesia Care Unit (PACU). Before doing so, the MRH faculty anesthesiologist requests the resident to give the patient Insulin: "Okay, so Mr. Smith is going to the PACU. It looks like his blood sugar is high: It's 250. Could you please give Mr. Smith five units of Insulin IV right now?" This moment serves as the second assessment point in which we see if the MRH's closed loop communication behavior influenced the residents' closed loop communication behavior. Figure 5 shows a anesthesia resident in the process of giving Insulin to the patient. At that point, the faculty anesthesiologist has already requested for the resident to give Insulin to the patient.

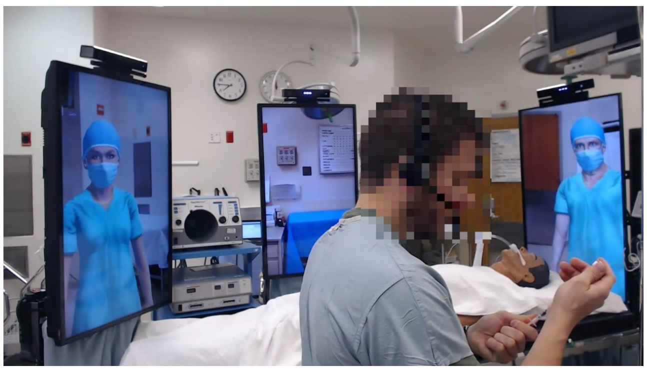

Figure 5: Participant drawing Insulin from vial to administer to patient

Participants were able to physically deliver fake medications to the patient mannequin lying on the bed. An IV was placed on the mannequin which allowed residents to administer medications to the mannequin similar to how medications would be administered to a real patient. The IV was configured so the medications would drain into an empty IV bag placed into the stomach of the mannequin. The setup for the IV can be seen in Figures 6 and 7.

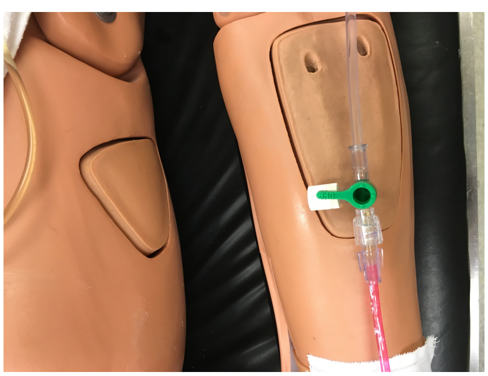

Figure 6: IV Setup to allow for medication administration

### 3.5 Conditions

Three conditions were created for this training exercise which manipulated the behavior of the MRH surgeon and MRH nurse during the administration of Heparin in the Pre-Induction Briefing Stage. The goal was to investigate if the observed model of behavior would

Figure 7: IV Drainage Bag

influence the residents' closed loop communication behavior. Our hypothesis, H1, is closed loop communication performance will be different based on the MRH model of behavior observed.

The three conditions are as follows:

- **Good Modeling:** The MRH surgeon asks the MRH nurse to give Heparin, and the MRH nurse and MRH surgeon properly close the loop:

  **Dr. Howard:** Okay. Nancy, Could you give Mr. Smith Heparin 5000 units SubQ right now?
  **Nancy:** So you want me to give 5000 units of Heparin SubQ right now?
  **Dr. Howard:** Yes, that's correct
  **Nancy:** Okay, given.

- **Bad Modeling:** The MRH surgeon asks the MRH nurse to give Heparin, and the MRH nurse and MRH surgeon do not properly closed the loop:

  **Dr. Howard:** Okay. Nancy, Could you give Mr. Smith Heparin 5000 units SubQ right now?
  **Nancy:** Okay
  **Nancy:** Okay, given

- **Bad Modeling with Correction:** The MRH surgeon asks the MRH nurse to give Heparin, but the MRH nurse does not confirm what the MRH surgeon asked her to administer.

  **Dr. Howard:** Okay. Nancy, Could you give Mr. Smith Heparin 5000 units SubQ right now?
  **Nancy:** Okay
  **Dr. Howard:** Nancy, I need you to repeat back what I said so I know you heard me correctly. We don't want to mess up.
  **Nancy:** Sorry, you're right. So you want me to give him 5000 units of Heparin IV right now?
  **Dr. Howard:** No, not IV, I said SubQ.
  **Nancy:** Sorry, I misspoke. I meant to say SubQ. So you want me to give 5000 units of Heparin SubQ right now?
  **Dr. Howard:** Yes, that's right.
  **Nancy:** Okay, given

In all conditions, the nurse is shown walking off the screen to administer the Heparin before walking back on screen to say "Okay, given." "SubQ" stands for subcutaneous which means the medication is injected under the skin. Other than the variations in MRH behavior, all other components remained the same throughout the training exercise for all conditions (see Figure 8).

The three conditions show varying degrees of closed loop communication behavior. In the Good Modeling condition (GM), participants are simply shown an ideal use of closed loop communication when medications are administered. In the Bad Modeling condition (BM), participants are shown what is essentially the norm of closed loop communication usage, i.e. that it is not frequently used. Finally, in the Bad Modeling with Correction condition (BMC), participants first see the norm (no closed loop communication), but are then shown ideal closed loop communication behavior.

The duration of the three modeling moments (from when the MRH surgeon asks to administer to right before MRH nurse walks off screen to administer Heparin) is as follows:

- **Bad Modeling** - 7 seconds
- **Good Modeling** - 10 seconds
- **Bad Modeling with Correction** - 30 seconds

Eighteen participants participated in the GM condition, seventeen participants participated in the BM condition, and eighteen participants participated in the BMC condition.

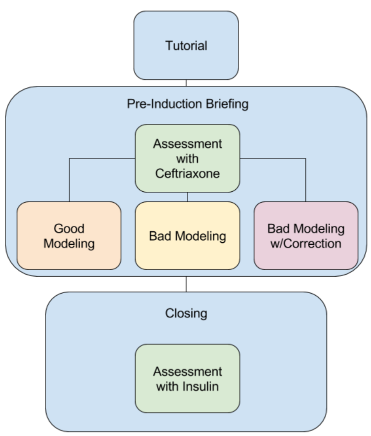


Figure 8: Study Flow

## 4 Results

Closed loop communication performance was analyzed at two points: during the Pre-Induction Briefing stage before observing the MRH nurse administer Heparin (the modeling moment), and during the Closing stage after the modeling moment. The first closed loop moment serves as a baseline of the participants' closed loop communication behaviors and the second moment is used to analyze differences in performance based on the MRH model of behavior observed.

Eight participants' closed loop communication data were removed from the results. Eight participants either did not administer the Ceftriaxone or Insulin. These participants typically had a medical reason for not wanting to give the medications. For example, with the Ceftriaxone, some participants expressed concerns of patient nausea. For Insulin, some participants did not want to give Insulin to a patient who was Insulin naive, i.e. had never been given Insulin. As a result, these eight participants have incomplete data. After removing these data points, fifteen participants each participated in the three conditions (45 total data points).

### 4.1 Metrics

We scored closed loop communication behavior using the Five *Rights* mentioned in section 2.1.3. Although there are Five *Rights*, we chose not to include "the right patient" as part of the metric because given the operating room setting, a mistake with giving a medication to the wrong patient could not occur.

Participants were able to get a maximum score of 4 (all four *rights* used). Upon scoring the data, we noticed that some participants would use closed loop communication after the medication was already administered. We felt that this was not the ideal closed loop communication behavior as a mistake could have already been made if the drug was already administered. Because of this distinction, if any of the *rights* was said after administering the medication, participants were given half a point, otherwise they received one point for any *right* said before administering the medication.

For example, if a participant said "Okay, I will give five units of Insulin IV right now," their response would be given a score of 4 because the four *rights* were used. If the participant had said, "Okay, I just gave five units of Insulin IV" they would be given a score of 1.5 because although three *rights* were used, they were all said after the Insulin was administered. It was possible for participants to get 1 point for some *rights* and half a point for other *rights* if for example, the participants said: "Okay, five units of Insulin", gave the medication, and said "Okay five units of Insulin given IV." This would receive a score of 2.5 because they said two of the *rights* before administration and one *right* after administration.

### 4.2 Effect of MRH Behavior on Closed Loop Communication Performance

We hypothesized that there would be a difference in closed loop communication performance behavior based on the observed MRH model of closed loop communication behavior. A one-way ANCOVA was conducted to determine if there was a statistically significant difference between the observed MRH model of closed loop communication on their closed loop communication performance with Insulin controlling for their baseline closed loop communication performance when administering Ceftriaxone. We found a significant effect of the model observed on their closed loop communication performance after controlling for their baseline closed loop communication, $F(2,41) = 4.180$, $p = 0.022$. Post-hoc analysis shows (with Bonferonni adjustment) specifically that participants in the BMC condition performed significantly better than participants in the BM condition (p-value = 0.021). Adjusted means for closed loop communication performance with Insulin are shown in Figure 9. Unadjusted means for both closed loop communication with Ceftriaxone and Insulin are shown in Table 1.

Table 1: Unadjusted Means of Closed Loop Performance

| Condition | Closed Loop Mean (Ceftriaxone) | Closed Loop Mean (Insulin) |
|---|---|---|
| **BM** | 1.87 (S.D 1.47) | 1.8 (S.D 1.13) |
| **GM** | 1.53 (S.D 1.36) | 2.4 (S.D 1.28) |
| **BMC** | 1.73 (S.D 1.38) | 2.77 (S.D 0.42) |

While not statistically significant, participants in the GM condition performed better than participants in the BM condition. For the BMC and GM conditions, there is no statistically significant difference in performance between these groups. Participants in the BMC condition on average said one *right* more that participants in the BM condition.

When looking at the mean before and after observing the model of closed loop communication, participants in both the GM and

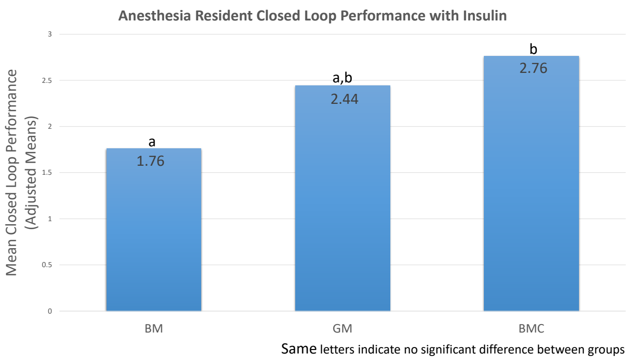


Figure 9: Comparing Closed Loop Performance After Observing MRH Model of Closed Loop Behavior

BMC demonstrated an improvement in closed loop communication whereas participants in the BM condition demonstrated no improvement. This suggests that seeing the MRHs use closed loop communication influenced the participants' use closed loop communication whereas when seeing MRHs exhibit behavior that reflects the norm (not using closed loop communication), behavior was not influenced.

Looking at participants who said the *rights* before administering Insulin (see Figure 10), it is clear that participants in the BMC condition consistently used closed loop communication. Of the 15 participants in the BMC condition, 73.3% used three out of four *rights*. Note that no participant in the BMC condition used closed loop communication *after* administering the Insulin (see Figure 11).

For the GM condition, 26.7% of participants said all four *rights before* administering Insulin. The main difference between the GM and BMC condition is that participants in the BMC condition consistently used closed loop communication *before* administering the Insulin whereas a third of participants in the GM condition said only one or two *rights after* administering the Insulin.

For the BM condition, one participant did use all four *rights* before administering Insulin; however, two participants said zero of the four *rights*. In the BM condition, 46.7% of participants said two *rights before* administering Insulin, and 20% of participants said only one or two *rights after* administering Insulin

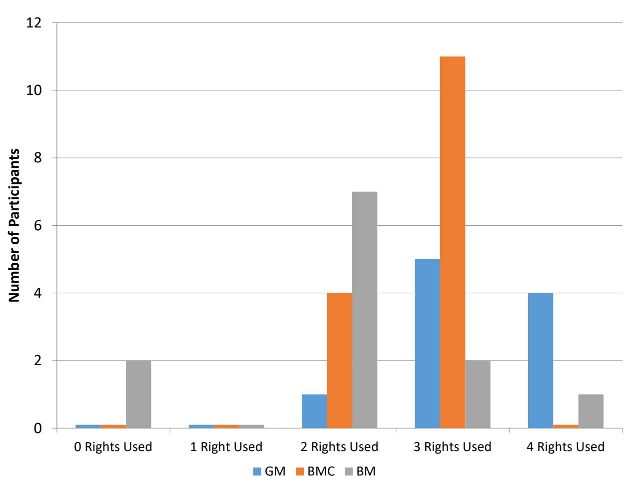


Figure 10: Number of *Rights* Said Before Administering Insulin

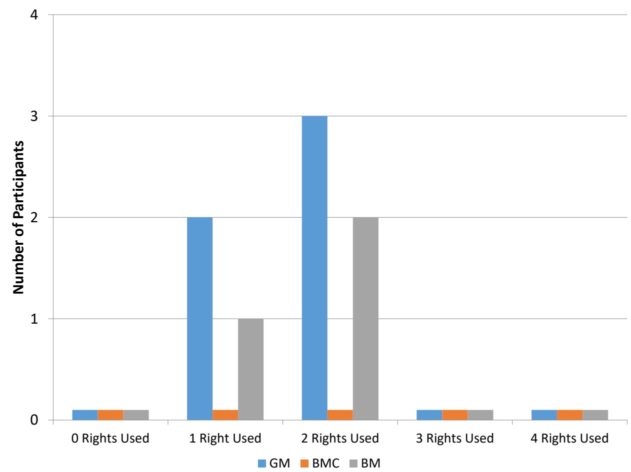


Figure 11: Number of *Rights* Said After Administering Insulin

### 4.3 Percentage of Each Right Used Before Insulin Administration

When looking at the *rights* used *before* administering the Insulin (see Figure 12), the most used *right* was confirming the drug, dose was the second most used *right*, route was the third most used *right*, and time was used the least. With the exception of "time," participants in the BMC condition had a greater number of participates for each *right*.

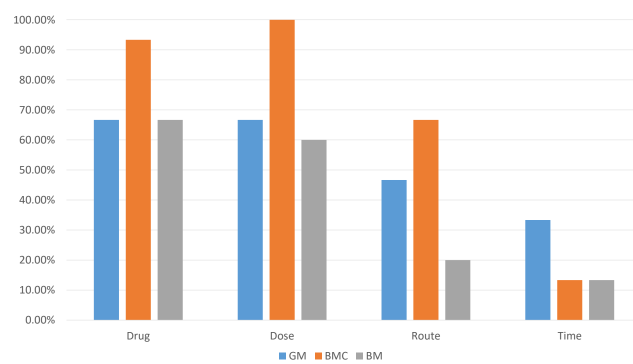


Figure 12: Percentage of Participants Who Used Each *Right* Before Insulin Administration

## 5 Discussion

The first contribution to this paper is that the results of this study show, in simulation, MRHs can influence communication skills that are critical to patient safety. Participants that observed MRHs model closed loop communication (GM, BMC) used more of the Five *Rights* than participants who observed MRHs fail to use closed loop communication (BM). This means that the MRHs were successfully able to change the way in which participants communicate when administering medications. This study improves upon previous work in which MRHs were found to influence conflict resolution skills [11]. The previous work, while using MRHs to change behavior, did not have a baseline assessment of the behavior the authors wanted to change. In the results presented in this work, we were able to control for the participants' baseline closed loop communication by assessing their closed loop behavior prior to observing the MRH model. Every aspect of the training exercise was exactly the same for all participants with the exception of the closed loop communication model observed during the Pre-Induction Briefing stage.

The BMC condition had the best closed loop communication performance. The difference between BMC's and BM's mean closed loop performance suggests that on average, participants in the BMC condition used one more *right* than participants in the BM condition. While a difference in one *right* may not seem significant, not confirming even one critical piece of information about the medication being administered could mean the difference between life and death for the patient.

The reason the BMC condition had the best closed loop performance is most likely because in this condition, the MRH surgeon and MRH nurse create a situation highlighting the importance of closed loop communication. The MRH surgeon wants the MRH nurse to repeat back what he said to avoid making a mistake. Upon repeating back what she thought she heard, the MRH nurse actually makes a mistake and says the wrong route, IV instead of SubQ. Because the MRH surgeon encouraged her to complete the second step of closed loop communication, the MRH surgeon was able to catch the MRH nurse's mistake. While the GM condition performed better than the BM condition, the difference between the scores was not statistically significant. Although the MRH nurse and surgeon exhibited ideal closed loop communication behavior in this condition, the manipulation may not have been noticeable enough for all participants. We think this is further shown in Figure 10 as there were 33.33 percent of the 15 participants in the GM condition who used closed loop communication after administering the Insulin.

When looking at the percentage of participants who used each *right* before administering the Insulin, participants in the BMC condition performed better for each *right* with the exception of "time." While over 50% of participants in the BM and GM conditions confirmed the "drug" and "dose" before administering the medication, these *rights* are critical to confirm as making mistakes can increase the chance of patient morbidity.

An interesting finding from this study is the lack of change in closed loop communication performance for participants in the Bad Modeling condition. The lack of change establishes that the Bad Modeling condition effectively served as a control condition. Because the only difference between the conditions was the behavior of the MRH nurse and MRH surgeon during the administration of Heparin, the lower closed loop communication performance in the Bad Modeling condition strengthens the finding that the MRHs in the other conditions (BMC and GM) influenced the participants closed loop communication behavior.

The second contribution of this paper is that this work expands the possibilities for how VR can be used. Specifically, this paper demonstrates that MRHs could be used as tools to address complex communication dynamics in a team setting. While this work does not generalize to other domains with teams such as military or aviation, the results are still encouraging for other team-based environments to pursue team training in VR to improve communication skills. For medical team training, this work provides strong evidence on the advantages of MRHs as virtual teammates. Future work could continue to leverage MRHs as models of communication behavior and influence other critical skills required by healthcare professionals.

## 6 LIMITATIONS

The main limitation of this work is that we do not know the long-term effects of the closed loop behavior change. We did not follow up with participants, nor do we know if they use closed loop communication in a live OR setting. For this paper, we can only claim participants' closed loop communication behaviors were influenced during simulation. Unfortunately, it is logistically challenging to observe healthcare professionals in a real OR. For future work, when studying behavior change during simulation, we plan to observe healthcare professionals before and after training interventions to assess if knowledge transfer occurs outside of training.

Another limitation is whether closed loop communication was used more with Insulin than with Ceftriaxone due to the risk factors associated with Insulin. According to the participants, Insulin poses higher risks to patient safety if a mistake is made. For adults, Ceftriaxone typically comes in one dose amount so it is difficult to make mistakes. Despite any perceived differences in risk levels of medications, we believe this did not affect the results because participants in the BM condition did not improve in their closed loop communication behavior from the Pre-Induction Briefing stage to the Closing stage (see Table 1). If participants were using closed loop communication because the medication posed a greater risk of injury, we would expect an increase in the five *rights* used by group that saw no modeling of closed loop communication (the BM condition).

We used a Wizard of Oz (WOZ) technique to control the MRHs' behavior which meant the MRHs were not computer controlled. Fox et al. conducted a meta-analysis on research involving avatars (human-controlled virtual humans) or agents (computer-controlled virtual humans) [12]. The authors found that if a VH was actually controlled by a human (despite participants being told the VH was computer controlled) social influence effects were stronger. The reason for this is primarily driven by the Threshold Model of Social Influence mentioned above. Participants may perceive cues from the MRHs that make them feel more like they are interacting with a human, despite not being told a human is controlling the MRH. Social Presence questionnaires gathered during this study do show that the MRHs elicit a sense of social presence; however, if the MRHs were actually agents, it is possible that the sense of social presence would decrease and social influence might not occur.

Finally, the demographics of our data limit generalization of the results. Participants were predominantly male (71.4 percent) and were predominantly white (77.3 percent). According to the Association of American Medical Colleges, the percentages of males in our study is slightly larger than national percentage of 64.4% [1]. Our data still reflects that the majority of anesthesia residents are male. The MRHs were all white and their genders reflected the norm for their role: the surgeon and anesthesiologist were male, and the nurse was female. We don't know whether the gender or race of the MRHs might change influence in closed loop communication behavior during simulation.

## 7 CONCLUSION

The results presented in this paper found that in simulation, anesthesia residents' communication behaviors are influenced by interacting with MRHs modeling specific communication patterns. This is critical because MRHs can model ideal communication patterns or suboptimal communication that are corrected by other MRHs, and result in a change in residents' communication patterns. The results are encouraging as we were able to control for participants baseline closed loop communication behavior.

This work highlights the strength of MRHs because they can influence real healthcare professionals' critical communication skills and behave consistently for all participants. If MRHs can influence behavior in humans, medical team training researchers may be able to leverage MRHs to provide more easily accessible training that does not require the logistical challenge of scheduling multiple teammates. Additionally, due to the standardization of MRH behavior, MRHs may serve as better stand-ins for human teammates in some instances, especially if behavior change is a goal of the training exercise. Virtual human researchers may be able to leverage this work to investigate how other critical communication behaviors can be influenced in a training environment.

Finally, this work expands on application of VR. Specifically, we've shown that critical team communication skills can be trained using VR. The results are encouraging for applying VR training to other team-oriented domains where critical communication skills are necessary for success. For medical team training, this work expands future directions on how to most effectively use VR training for team communication skills training.

## 8 Future Work

Research on social influence of communication skills in medical team training with MRHs is still in its infancy. Other important critical skills should also be studied to determine if MRHs can be used to influence those skills. While this paper showed that MRHs can influence closed loop communication skills, we do not know what other skills MRHs are capable of influencing.

Finally, future work needs to assess if the behavior improvements gained during the simulation transfers into the real world OR setting. Determining whether knowledge transfer occurs would require observing healthcare professionals in the operating room and measuring their behaviors before and after training.


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