

Virtual Human + Tangible Interface = Mixed Reality Human An Initial Exploration with a Virtual Breast Exam Patient

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ABSTRACT

Virtual human (VH) experiences are receiving increased attention for training real-world interpersonal scenarios. Communication in interpersonal scenarios consists of not only speech and gestures, but also relies heavily on haptic interaction – *interpersonal touch*. By adding haptic interaction to VH experiences, the bandwidth of human-VH communication can be increased to approach that of human-human communication.

To afford haptic interaction, a new species of embodied agent is proposed – *mixed reality humans* (MRHs). A MRH is a virtual human embodied by a tangible interface that shares the same registered space. The tangible interface affords the haptic interaction that is critical to effective simulation of interpersonal scenarios. We applied MRHs to simulate a virtual patient requiring a breast cancer screening (medical interview and physical exam). The design of the MRH patient is presented. This paper also presents the results of a pilot study in which eight ($n = 8$) physician-assistant students performed a clinical breast exam on the MRH patient. *Results show that when afforded haptic interaction with a MRH patient, users demonstrated interpersonal touch and social engagement similarly to interacting with a human patient.*

KEYWORDS: Tangible interfaces, virtual humans, mixed reality

INDEX TERMS: I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism – *Virtual Reality*. I.3.6 [Computer Graphics]: Methodology and Techniques – *Interaction techniques*.

1 INTRODUCTION

Virtual human (VH) experiences are increasingly being used for training real-human interpersonal scenarios, for example, military leadership [13] and doctor-patient interviews [15]. These human-VH interactions simulate a human-human interaction by providing two-way verbal and gestural communication. Prior research using these systems has shown that the efficacy of a VH experience would be significantly enhanced by integrating the haptic component of interpersonal communication [15]. This would, in effect, increase the bandwidth of human-VH communication.

We expand on current VH experiences by affording haptic interaction with the VH. This paper proposes a new species of embodied agent that affords haptic interaction by combining virtual and real spaces – *mixed reality humans*.

A mixed reality human (MRH) is a virtual human with a physical embodiment in the form of a tangible interface. By merging virtual and real spaces, MRHs afford haptic interaction between human and VH (Figure 1).

Mixed reality humans allow for:

1. Interpersonal touch between the human and VH. Interpersonal touch is a critical component of non-verbal communication which affects how people perceive those they communicate with, increases information flow, and aids in conveying empathy [11, 7]. Affording haptic interaction with a VH will allow VH experiences to more accurately and effectively simulate interpersonal communication.
2. VH experiences to train interpersonal scenarios which *require* interpersonal touch. Without affording touch, the domain of current VH experiences is limited. By affording haptic interaction, VH experiences can simulate a wider range of real-human interpersonal scenarios, such as medical physical exams.

This paper presents the design of a MRH breast exam patient and the results of a pilot study in which physician-assistant students performed a clinical breast exam of the MRH patient. Students' interaction with the MRH patient was compared to prior interactions with VH and human patients.

Study results show that MRHs allow for interaction more similar to human-human interaction: *participants demonstrated increased social engagement over a human-VH interaction, and participants' use of interpersonal touch was similar to that of a human-human interaction.*

A discussion of design issues for MRHs is motivated by study results.

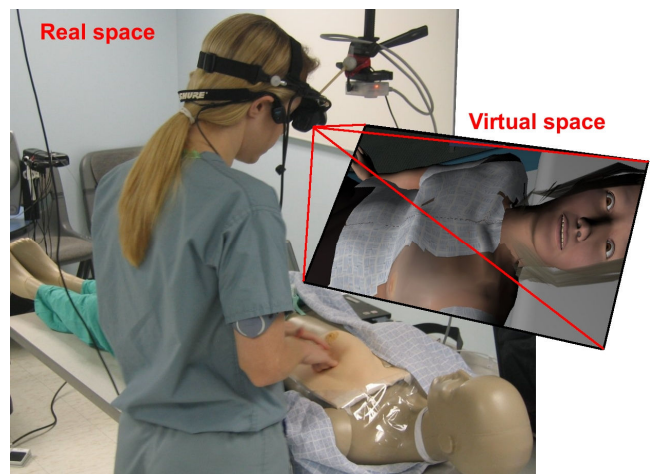


Figure 1. A *mixed reality human* merges virtual and real spaces. The user views a VH while touching her physical embodiment, including tangible interfaces (here, the breast and gown).

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1.1 Motivation: Effective Communication Requires Touch

Interpersonal touch is a critical component of communication in interpersonal scenarios. Interpersonal touch is the most commonly used method of comforting [9] and allows social

norms to be enforced (e.g. handshakes). In clinical and professional situations, interpersonal touch has been shown to cause people to evaluate more favorably those with whom they interact [11]. In medicine, touch improves doctor-patient communication by increasing patient verbalization, disclosure of information, and attitudes towards the medical professional [11]. Patients obtain increased reassurance through doctors' non-verbal cues, including touch, than through verbal communication alone [10]. Physical contact plays a critical role in forming a close doctor-patient relationship. Interpersonal touch conveys the idea that the caregiver is doing something for the patient and is an important component of expressing empathy [7].

1.2 Motivation: Touch Affords New VH Experiences

Unlike communication in human-human interpersonal scenarios, communication in current VH experiences is not augmented by touch. Current VH experiences focus on applications in which spoken communication is at the forefront: conversing with VH civilians injured in a military operation, negotiating with a VH doctor to move his clinic [23], question-answer sessions with a virtual assistant to teach proper response to health emergencies [20], and conversing with a VH patient to practice medical interview skills [15]. The goal of these VH experiences is the exchange of information between user and VH. However, this bi-directional exchange of information between human and VH is not augmented by touch, *making it dissimilar from human-human interactions*. By incorporating touch into a human-VH interaction, communication can be made more similar to that of a human-human interaction, and VH experiences can be applied to interpersonal scenarios that *require* interpersonal touch.

An interpersonal scenario in which interpersonal touch is both required and is an integral communication element (e.g. to comfort and express empathy) is a medical physical exam. Physical exams require complex haptic interaction: e.g. a breast exam includes palpating soft tissue for hard masses and feeling subtle changes in skin texture that may indicate an underlying mass. Soft tissue simulation and feeling of subtle changes in surface texture are difficult problems for active-haptic technologies. Physical medical simulators, e.g. the breast simulator of Figure 2, simulate this interaction realistically using passive haptics. Harnessing these simulators as tangible interfaces allows for VH experiences to be applied to medical physical exams of MRH patients.

1.3 Mixed Reality Humans

A *mixed reality human* (MRH) is a virtual human who is physically embodied by tangible interfaces. As mixed reality implies the synthesis of virtual and real spaces, the MRH inhabits both virtual (what the user sees) and real (what the user feels) spaces (Figure 1).

Virtual Space: The virtual space is inhabited by the MRH's visual component, a virtual human. This VH is a full-body virtual character with facial animation and gestural capabilities including lip-synched speech, eye blinking, following the user's head, breathing, and pointing. To converse with the VH, user speech is processed by a speech recognition module. Keyword matching determines the appropriate pre-recorded response to recognized speech. A high level of immersion is afforded by a VH that is life-size and registered to the MRH's real space component (Figure 1).

Real Space: The real space is inhabited by the MRH's *physical embodiment*. The MRH's physical embodiment represents a part of the MRH's body, e.g. an arm, torso, or full-body. The physical embodiment of the MRH is composed of

1) tangible interfaces that provide bi-directional haptic interaction and 2) other physical correlates to the MRH that provide passive haptic feedback but do not accept input.

A *tangible interface* uses physical objects as interfaces to underlying virtual structures [25]. The MRH's tangible interfaces detect the user's touch through a combination of sensors (e.g. pressure sensors) and computer vision techniques.

We define the *degree of embodiment* as the amount of the MRH's body included in the physical embodiment. The MRH breast exam patient has a full-body embodiment. The patient's left breast and clothes are tangible interfaces which afford haptic input and output; the rest of the physical embodiment is a mannequin that provides passive haptic feedback (Figure 1).

By combining tangible interfaces with a virtual human, the MRH affords high bandwidth (visual, verbal, and haptic) interpersonal communication. Synthesizing these communication modalities allows for interaction not afforded by virtual humans or tangible interfaces alone.

2 PREVIOUS WORK

Active and passive haptic interfaces have allowed for human-human and human-VH collaboration in virtual environments. Physical simulators are widely used in medical education to allow students to practice hands-on procedures. Passive-haptic tangible interfaces and physical simulators are integrated by MRHs to allow haptic communication between human and virtual human.

2.1 Haptic Collaboration in Virtual Environments

A passive-haptic "lazy susan" increased remote users' sense of being co-located around a virtual table [26]. Remote users collaborated in a shared Unified Modeling Language editor using active-haptic cursors provided by a PHANTOM Omni [21]. Remote users collaborating to move a ring along a curved wire in a virtual world reported a higher sense of togetherness when active-haptic feedback was given than when only visual feedback was given [6]. An active-haptic interface allowed a user to play catch with a virtual human [14]. The passive-haptic interface of a real checkers set allowed a human to play a game of checkers with a VH [5].

2.2 Towards Touching Virtual Humans

Bailenson and Yee proposed the concept of virtual interpersonal touch [2], touching a VH using an active-haptic interface. A study found that participants who used a Phantom Omni force-feedback device to clean virtual dirt off of a VH's body touched female VHs with less force than male VHs. However, the VH did not communicate with the user or react to the touch. This was not an interpersonal touch between a human and VH, as the cleaning was not a type of social touch and there was no communication between the human and VH. MRHs use passive haptics to afford bi-directional communication and interpersonal touch between human and VH.

2.3 Physical Simulators for Medical Education

Physical simulators combine realistic haptic input with visual and auditory output in order to simulate medical procedures such as laparoscopic surgery, pelvic exams, and intubation.

Model-based simulators use purely physical objects, providing visual and passive haptic feedback. A drawback of model-based simulators is the lack of real-time feedback concerning performance, i.e. if a surgical error is made the simulator gives no feedback to this effect.

Computer-based simulators use real-world input devices, such as endoscopes, and provide 3D graphical and auditory feedback to simulate procedures such as lower gastrointestinal endoscopy.

Hybrid simulators such as the Human Patient Simulator combine complex physical models, such as articulated mannequins, with computer-based techniques. Physical models provide realistic simulation of soft tissue and real surgical tools, while computer-based simulation allows the mannequin patient to react realistically (with changes in vital signs and speech) to, e.g., being anaesthetized or intubated [18].



Figure 2. The physical breast simulator affords realistic soft-tissue haptic interaction and is used as a tangible interface to the MRH breast exam patient.

The drawback of physical simulators is that learning of technique is isolated from the clinical context of patient interaction. Because physical simulators do not afford bi-directional communication between doctor and patient, the experience is not similar to clinical practice. For example, physical simulators can not change their visual appearance to express fear or pain, can not move or gesture in response to the user's input, and can not be comforted by the user. To simulate a more realistic patient experience, model-based simulators have been combined with standardized patients (actors trained to simulate a medical condition) [19]. However, using a trained human actor limits the availability of the simulation and the ability to simulate abnormal medical conditions. MRHs combine the advantages of physical simulators and standardized patients, providing haptic, verbal, and gestural communication similar to that of a real-human doctor-patient interaction.

3 THE MRH BREAST EXAM PATIENT

3.1 Driving Application: Medical Education

Medical students currently practice clinical exam skills through a simulated doctor-patient interview, the OSCE (Objective Structured Clinical Exam). This human-human interaction consists of an interview and physical exam of a standardized patient (SP), a human actor trained to simulate a medical condition. While SPs have been validated for simulating clinical exams, drawbacks include limited availability and difficulty in simulating abnormal medical conditions.

We have developed a VH experience, the VOSCE (Virtual OSCE), which simulates the OSCE by allowing students to conduct a medical interview of a VH patient [15]. Users interact with the VH patient through natural speech and gestures. This natural, transparent interface is needed to effectively simulate, and allow the VH experience to be compared to, a human-human interaction. Over 220 medical, physician-assistant, nursing, and pharmacy students have experienced the human-VH interaction of the VOSCE. Students' performance in the VOSCE and OSCE

were found to be correlated, validating the VH experience for evaluating medical students' interview skills [16]. However, the VOSCE can not simulate physical exams, as it does not provide haptic interaction.

Replacing the VH patient with a *MRH patient* will allow medical students to perform a full clinical exam including a physical exam. Simulation of a clinical breast exam is an appropriate platform to explore MRHs. The breast exam is a scenario in which interpersonal touch is both *required*, for the physical exam, and *compelled*, to comfort the patient. The MRH breast exam patient, Edna (Figure 1), combines a physical breast simulator (Figure 2) with a VH breast mass patient (Figure 3). The physical breast simulator is used in the Medical College of Georgia's curriculum to teach breast examination technique. The VH breast mass patient has previously been interviewed by forty-eight 3rd-year medical and physician-assistant students. By merging these two technologies, the MRH allows for verbal and haptic interaction not afforded by either technology individually.

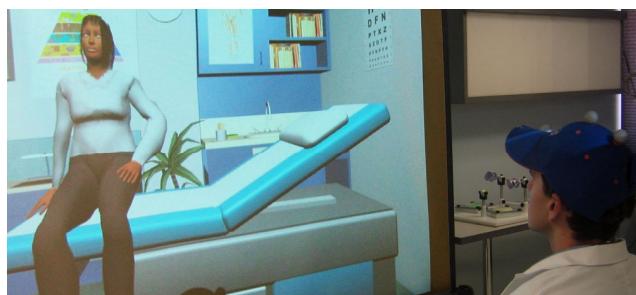


Figure 3. Human-VH interaction: a 3rd-year medical student interviews a VH patient with a breast mass.

3.2 Breast Exam Simulation Requirements

A clinical breast exam has two components: medical interview and physical exam.

The **medical interview** is a 10-minute conversation in which the healthcare professional and patient exchange information. Each of the communication partners possesses unique goals for this interaction.

The goals of the healthcare professional are to gather key facts of the patient's condition (e.g. principal complaint: the patient has found a hard mass in her left breast; family history: her sister had breast cancer) and to develop rapport with the patient. These goals are achieved through asking questions of, and expressing empathy to, the patient. When interacting with a human patient, interpersonal touch is critical for allowing the healthcare professional to develop rapport and express empathy [7,10,11]. Previous user studies in the VOSCE revealed that healthcare professionals had difficulty building rapport with the VH patient due to the lack of interpersonal touch [15].

The patient has two goals: to receive information about her condition, and to be comforted. She accomplishes these goals by expressing her fear, anxiety, and pain through facial expressions and speech, and by prompting the healthcare professional with questions such as "*could this be cancer?*" (empathetic challenges).

The MRH synthesizes verbal communication and interpersonal touch, allowing both conversation participants to better accomplish their goals: Touch allows the healthcare professional to better empathize and build rapport [11]. Touch also allows the patient to be better comforted [9, 10].

The **physical exam** consists of a visual inspection of the patient's breasts and palpation (touching). The healthcare professional visually inspects each of the patient's breasts, exposing only one breast at a time to minimize patient discomfort and embarrassment. This is afforded by allowing users to manipulate a gown worn by the MRH patient.

Palpation is the portion of the examination that requires haptic interaction. This requires realistic feeling skin, soft tissue, and breast masses. Visual and verbal communication is also important during palpation. The patient should respond with facial expressions (e.g. grimacing) and speech to any part of the palpation that is painful. During palpation the medical professional must be able to ask questions such as 'is this area tender?' and, upon finding a mass, 'is this the mass that you found?' Haptic and verbal interaction requirements are afforded by the physical and virtual components of the MRH breast exam patient.

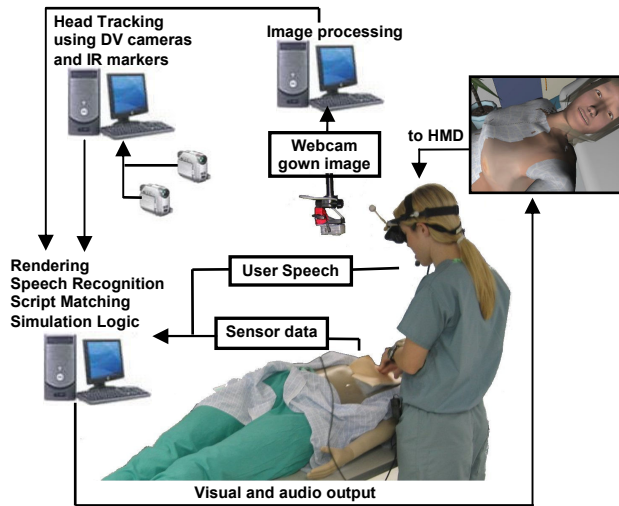


Figure 4. System design: users interact with the MRH patient through natural speech, gestures, and touch.

3.3 System Design

The system design is shown in Figure 4. The user wears a headband with attached head mounted display (HMD) and wireless microphone. Head orientation and position are tracked using a combination of infrared-marker based tracking and accelerometers in the HMD. Users are able to interact with the MRH through a combination of verbal, gestural, and haptic input. *The innovations of the MRH design are to use instrumented haptic devices, such as a physical breast simulator, and computer-vision tracking of passive physical objects, such as the patient's gown, to provide haptic interaction and interpersonal touch between human and VH.*

Verbal: The user interacts verbally with the MRH patient using natural speech. A wireless microphone transmits the user's speech to a PC which performs speech recognition using a commercial product, Dragon Naturally Speaking Pro 9. Recognized speech is matched to a database of question-answer pairs using a keyword-based approach. The database for the breast exam has 118 pairs of semantic queries and corresponding responses. The many syntactical ways of expressing each query are handled using a list of common synonyms. The MRH responds to matched user speech with speech pre-recorded by a human patient.

Gestural: An optional glove with infrared-reflective markers allows for detection of simple gestures such as pointing. The pose of a chair placed in the environment is tracked to determine the user's body lean and differentiate between sitting and standing.

Haptic: The MRH patient's left breast is a physical simulator (Figure 2) which provides the feel of breast skin, tissue, and underlying breast masses, and contains twelve pressure sensors to detect the user's touch. This tangible interface provides passive haptic feedback and affords haptic input to the MRH.

In addition to the physical simulator, the MRH patient, *Edna*, has a full-body physical embodiment, in the form of a plastic mannequin. The mannequin is not a tangible interface as it does not provide input to the system. However, it provides haptic information that aids the user in locating Edna's breasts, and allows for interpersonal touch (e.g. a comforting touch on the shoulder).

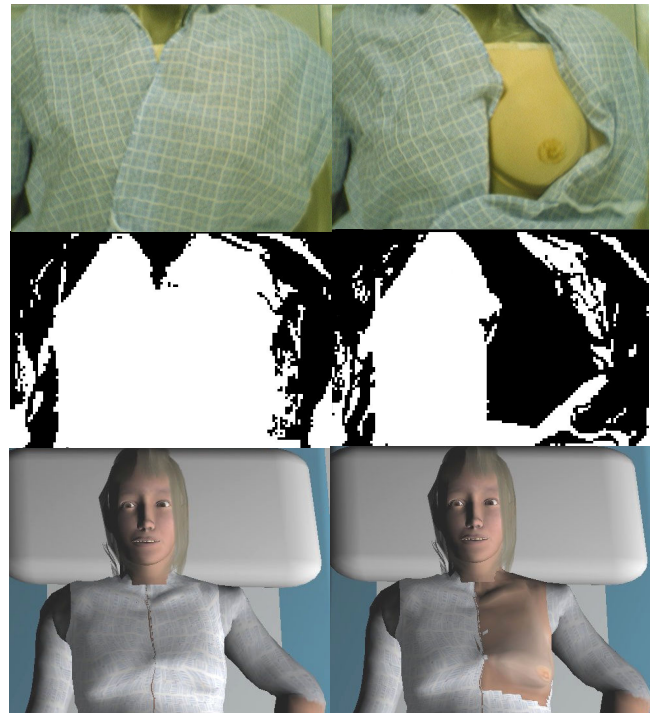


Figure 5. Haptic input is transformed to haptic and visual output by tracking the opening and closing of the MRH patient's gown.

Edna wears a hospital gown which opens in the front. The physical correlate to this gown is worn by the mannequin. The gown is an integral part of the breast exam: both breasts must be visually and physically examined, but to maintain patient comfort, only one breast should be exposed at a time. The gown is tracked using computer vision techniques, providing haptic and visual feedback from manipulation of the gown. Opening and closing of the gown is tracked using a down-looking webcam mounted above the MRH patient (Figure 4). The gown is segmented from the webcam image using a Gaussian-model background subtraction approach (see [22] for a review). To reduce noise in the segmentation caused by shadows cast by the user, the binary foreground image is passed through a variation of a smoothing filter. This classifies an image region as foreground if the region contains a number of foreground pixels greater than a predefined threshold, and classifies the region as background otherwise. The resulting binary foreground image is ANDed with the gown texture's alpha channel. The result is displayed at 30Hz

(webcam's maximum frame rate) on the MRH patient using a dynamic texture (Figure 5).

3.3.1 Synthesizing Interaction Modalities

The MRH system synthesizes bi-directional verbal, gestural, and haptic interaction modalities. An XML database contains pairs of pressure sensor inputs (triggers) and responses (MRH gestures and speech). This allows the MRH to appear aware of where in her breast any masses or painful areas are located. The MRH's verbal and gestural responses are triggered based on the amount of pressure applied at each pressure sensor. These responses may be absolute, i.e., the response is triggered when certain pressure conditions are met, or may be conditional based on recent or coinciding user speech.

For the pilot study, the MRH breast exam patient was able to:

- Respond verbally and visually to touch on a tender area of her breast: "ouch" or "that hurts." The patient's facial expression became one of discomfort during any touching of the breast, and one of pain if the user pressed in an area that was designated as painful.
- Respond to a combination of palpations and user speech concerning pain. Questions semantically similar to "does it hurt here?" would receive a "yes it's a little tender" or "no" response from the MRH depending on where the user was palpating.
- Respond to a combination of palpations and user speech concerning the location of the mass. If the user asked "is this the mass you found?" or "is this it?" the MRH would respond with "yes, does it feel like cancer?" if the user had palpated the mass present in the breast simulator.
- Respond to the user finding the mass. If the user expressed that he or she found the mass, e.g. "ok, I found a mass here," (where "here" is disambiguated by where on the breast the user had previously touched) the patient posed an empathetic challenge to the user: "do you think it is cancer?"

MRHs synthesize haptic, verbal, and gestural interaction modalities allowing for these novel human-VH interactions.

3.4 Evaluation Methods for MRHs

To determine validity and effectiveness of a MRH experience, it should be evaluated similarly as, and compared to, the human-human interaction it simulates. Real and virtual experiences for training interpersonal skills focus on evaluating the user's behavior, which has external and internal components. Effective evaluation methods for a MRH interaction must thus focus on the user's internal (e.g. anxiety, embarrassment) and external behavior (e.g. expression of interest, rapport, empathy). As *physiological* and *behavioral* measures are used to evaluate these behaviors in human-human interactions [1], these are expected to be effective methods of evaluating human-MRH interactions.

Physiological measures indicate internal changes in the user's state. Physiological measures are objective and quantitative, allowing for valid comparisons between different types of interactions (e.g. human-human, human-MRH). We have previously used physiological measures of heart rate, blood pressure, and galvanic skin response (i.e. sweating) to characterize human-VH interaction in the VOSCE [17].

Behavioral measures such as interpersonal distance and posture have previously been used to evaluate VH experiences [4, 8]. For evaluating the haptic affordances of MRHs, the most important behavioral measure is the use of interpersonal touch. For applications such as medical exams which *require* touch, this

measure focuses on interpersonal touches which are not required by the examination, such as touches used to comfort.

4 PILOT STUDY

4.1 Study Design

Eight ($n = 8$) 2nd year physician-assistant students at the Medical College of Georgia conducted a clinical breast exam of the MRH breast exam patient. Only one of the students had previous experience performing a clinical breast exam on a human patient, although all had conducted medical interviews of human patients (between 1 and 6, an avg. of 2.4).

The *interaction research* goal of this study was to use physiological, behavioral, and subjective measures to assess users' internal and external behavioral responses to the MRH. The *education research* goal was to ascertain whether performing a clinical breast exam on a MRH patient could increase students' confidence in performing a clinical breast exam on a human patient.

A pre-study questionnaire assessed participants' subjective levels of anxiety when performing interviews and physical exams of human patients. This took between 5-10 minutes and served as time to collect a baseline for the physiological measures. The participant's heart rate (HR) and systolic blood pressure (BP) were measured after this baseline period and again after the clinical examination of the MRH. During the exam, the participant's galvanic skin response (GSR) was measured unobtrusively at 32Hz using the BodyMedia Sensewear armband. We previously used this device to monitor human-VH interactions, and it performed reliably with noise on the order of 1×10^{-4} micro-Siemens. Students briefly saw the MRH's physical embodiment while being fitted for the HMD used to view the virtual scene, but were not allowed to touch the embodiment prior to the start of the patient interaction. A post-study questionnaire assessed participants' subjective anxiety and embarrassment during the MRH interaction as well as subjective ratings of co-presence [3] and the MRH's realism.

4.2 Results

Results of physiological, subjective, and behavioral measures are presented. The results of the pilot study, *Study MRH*, are compared to results of a previous study of human-VH interaction. In the previous user study, *Study VH*, twenty-seven 3rd-year medical students performed a medical interview (with no physical exam) of a VH patient with a breast mass (a discussion of *Study VH* is given in [17]).

4.2.1 Reaction to an Expression of Pain

Participants' GSR peaked in response to causing the MRH pain during palpation, and participants subsequently responded empathetically to the patient (Figure 6).

When participants touched a pre-defined (but unknown to participants) section of the MRH patient's breast, the patient exclaimed "ouch!" or said "that hurts." Participants' GSR was extracted for 12 seconds after the first occurrence of either response. The average GSR signal, shown in Figure 6, is characteristic of the orienting response, an indication of surprise [1]. Although they had already conversed with the MRH for an average of 8 minutes, participants were surprised by the MRH patient's expression of pain. This surprise was not due to the intensity of the stimulus: the "ouch" or "that hurts" was not louder than the MRH patient's other verbal responses. Participants were surprised that they were able to cause a

simulated patient pain, and that the patient was able to express her pain.

Out of the seven participants who elicited the pain response, five responded empathetically: two apologized (“*I’m sorry*”) and three others responded with other empathetic sentiment (e.g. “*I’ll try to be gentle*”). Non-empathetic responses from the other two participants were confirmatory (e.g. “*oh, that hurts?*”). 100% of participants responded to the MRH’s expression of pain.

Participants’ surprise and empathetic reactions to causing the MRH pain indicates an increased level of social engagement over human-VH interactions. In *Study VH*, the VH patient issued an empathetic challenge “*could this be cancer?*” after four minutes of conversation. More than 70% of participants did *not* respond empathetically (i.e. were not sufficiently engaged in the experience to respond with empathy as they had been trained to do), and 20% ignored the VH’s question (i.e. did not afford the VH the social respect to even answer her question). Providing a physical embodiment of the VH increased users’ social engagement. Future direct comparison of MRH and VH interactions will determine the role of touch in eliciting and amplifying these physiological and external behavioral responses.

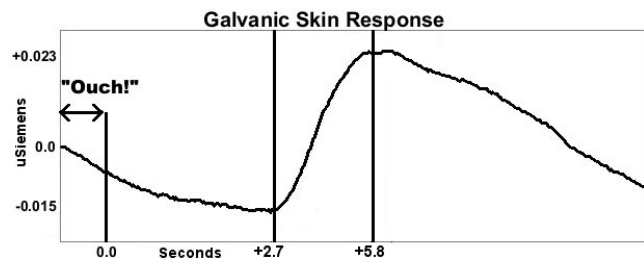


Figure 6. Participants’ galvanic skin response (GSR) peaked when the MRH patient verbally expressed pain – “*ouch!*” or “*that hurts.*”

4.2.2 Participant Anxiety and Embarrassment

Changes in heart rate and blood pressure are measures of anxiety and embarrassment. Increased anxiety is characterized by an increase in either HR or BP; conversely a decrease in HR or BP indicates decreased anxiety [1]. Embarrassment is characterized by an initial increase in HR which is followed by a return to baseline levels, concurrent with a sustained increase in BP [12].

In *Study VH* it was found that anxiety decreased during interaction with the female VH patient, and that male participants exhibited embarrassment.

In *Study MRH*, participants’ HR decreased (avg. of -2.0 bpm) during interaction with the MRH, while BP remained nearly constant (avg. of +0.4 mmHg). These results show that, on average, participants’ anxiety decreased and participants did not become embarrassed during the MRH interaction. Results of both studies suggest that users are initially anxious about interacting with a virtual or mixed reality human, but that this anxiety subsides as they converse with the VH or MRH.

BP was significantly positively correlated with reported anxiety during the MRH medical interview and physical exam (interview: $r = 0.88$, $p < 0.005$; exam: $r = 0.83$, $p < 0.01$). This result demonstrates that, as previously shown for human-human and human-VH interactions, physiological measures can detect user anxiety in a human-MRH interaction.

4.2.3 Subjective Ratings of the MRH Experience

In both *Study MRH* and *Study VH*, an effect of gender was found on ratings of co-presence. In *Study MRH*, females ($n = 5$)

reported significantly lower co-presence than did males ($n = 3$) – females (2.9 ± 0.4) < males (3.9 ± 0.4), $p < 0.01$. The same result was observed in *Study VH* – females (2.2 ± 1.3) < males (3.8 ± 1.0), $p < 0.01$. (*Study VH* population was 15 males, 12 females).

Future studies will explore if this result is due to cross-gender interaction or instrument bias. Ratings of co-presence did not differ significantly between *Study VH* and *Study MRH* – unexpectedly, co-presence did not increase as touch was afforded.

However, the rating of how realistically the MRH patient simulated a real patient was significantly lower ($p < 0.05$) than the rating of *Study VH*’s VH breast mass patient. On a scale of 1-10, the VH patient was rated a 6.0 ± 1.4 and the MRH patient was rated a 4.5 ± 4.6 . This implies that the addition of touch to a human-VH interaction increases users’ expectation for the VH to act more like a human.

4.2.4 Assuming Unrestricted Affordance of Touch

Without being informed otherwise, participants treated the MRH patient as though she had all of the abilities and affordances of a human patient. All participants attempted to perform a full breast exam, which includes palpating the armpit area. Five participants even lifted the mannequin arm in order to reach this area. This was despite the fact that the MRH patient’s armpit consisted of the hard plastic mannequin.

The limitations of the MRH were expected to be clear (to the touch); the only part of the physical embodiment that was palpable was the left breast. The participants’ assumption that a full exam could be performed may be due to two factors: 1) participants assumed that because the MRH had a full-body physical embodiment, the MRH would react to manipulation of the entire physical embodiment, 2) participants had no prior experience with simulators, only human patients, and had not learned that interfaces to simulations typically impose restrictions on interaction. Both factors emphasize the need to more clearly and transparently reveal the limitations of the physical interface of the MRH (i.e. without the experimenter verbally informing participants – this breaks presence and causes false-positive physiological responses).

4.2.5 Use of Interpersonal Touch

Participants used interpersonal touch with the MRH patient similarly to interpersonal touch observed in prior real patient encounters. Participants’ use of interpersonal touch other than that required for the physical exam (such as comforting touches on the shoulder; touches of the breast were not included) was compared, through video review, to use of interpersonal touch in 76 prior medical student interactions with human patients.

The number of touches was similar between the MRH and SP interactions. In the MRH experience, participants used an average of 1.4 ± 0.9 touches compared to an SP average of 1.8 ± 1.8 touches. The 95% confidence interval (CI) of [-0.2, +1.1] overlaps a conservatively chosen zone of indifference (ZI) of [-1,+1] touches. This is consistent with the hypothesis that the amount of touches in the MRH and SP interactions are equivalent; however, a larger population is required to demonstrate statistical equivalence (statistical equivalence is demonstrated if the CI lies entirely within the ZI). However, this result suggests that participants’ use of interpersonal touch was similar to that of a human-human interaction. Larger user studies may confirm this.

In the previous 220 human-VH interactions observed in the VOSCE, no touch was afforded. *As soon as touch was afforded by the physical interface of the MRH, users began employing interpersonal touch as they would with a real patient.* Providing a

simple plastic mannequin allowed the physician-assistant students to satisfy their need (and training) to touch a real person.

5 FUTURE DESIGN QUESTIONS FOR MRHS

The study results presented here have allowed us to identify areas of MRH design that will be investigated to create more effective experiences. Each design issue is presented along with possible solutions which will be investigated in future user studies.

5.1 Visual Fidelity

The reactions of pilot study participants motivate an increase in visual realism of the MRH. Participants identified two areas: 1) allowing the user to see her arms and hands (e.g. “*should I be able to see my hands?*”, “*I really wanted to be able to see my hands?*”) and 2) more realistic appearance and movement of the patient’s breasts. Although these are partially due to the nature of the physical exam, we believe that participants’ increased desire for visual fidelity (over earlier VH patient studies [15,16,17]) is driven by an increase in participants’ scrutiny of the system once touch is afforded.

Seeing one’s hands when using a tangible interface has previously been identified as important to the user’s sense of presence. Increased presence in an augmented reality experience over that of an identical VR experience was attributed to users’ inability to see their arms and hands in the VR condition [24]. A see-through HMD would allow users to see their hands during future interactions with MRHs.

Simulation of human tissue requires both visual and behavioral realism. For the breast exam, detailed imperfections in the skin such as dimpling or visible bumps must be simulated. When the patient changes poses, e.g. from sitting to laying, the breast tissue must move realistically, accounting for any masses that would cause abnormal movement. Palpation should cause the MRH’s breast to deform similarly to human breast tissue. These require either real-time soft tissue simulation or a large library of precise animations. As the physical breast simulator accurately simulates soft tissue, we propose using a see-through HMD to merge video of the physical simulator with the visualization of the VH during palpation. However, to increase visual fidelity during the visual inspection stage, higher fidelity computer graphics and animation are required.

5.2 Physical Embodiment and Dynamic Avatars

Mixed reality humans merge virtual and real spaces by registering a physical embodiment to a VH. This seemingly imposes the restriction that the VH remains in a static pose throughout the interaction to maintain the registration between real and virtual. Indeed, for the pilot study we kept the VH in a static pose, except for facial expressions, head turning, and breathing animations.

However, our approach of registering a physical embodiment to the VH’s appearance does not limit the VH to static poses except when the user needs to touch the MRH. For example, future iterations of the MRH breast exam patient will have a fully dynamic VH which will sit up and gesture during the patient interview and visual inspection steps, then lie down when instructed that palpation will begin (becoming registered to the physical embodiment).

5.3 Hiding Implementation Details

Allowing the user to view implementation details of the system may cause breaks in presence and cause the user to treat the human-MRH interaction dissimilarly to a human-human interaction. Additionally, if users are able to see the physical embodiment, should it match the MRH in appearance? For example, if the MRH is African-American, the experience may be less believable and effective if the physical embodiment has white skin color.

Hiding implementation details is trivial when using a user-contained display such as a HMD, but becomes an issue when using displays such as projectors.

5.4 Optimal Degree of Embodiment

The MRH breast exam patient has a full-body physical embodiment. A full-body embodiment afforded participants the ability to employ comforting interpersonal touches of the MRH and allowed experimenters to compare the use of interpersonal touch in MRH and human patient scenarios. However, although participants briefly saw the physical embodiment before beginning the experience (when being fitted with the HMD), having a full-body embodiment confused participants as to the affordances of the physical embodiment (Section 4.2.4). Reducing the physical embodiment to tangible interfaces only may be sufficient for outcomes of increasing user confidence and decreasing user anxiety in conducting physical exams (the medical education goals of the pilot study). However, a full-body embodiment appears advantageous to encourage use of interpersonal touch.

5.5 Display Type and Implications for Design

One issue for MRH design is determining what types of displays promote user engagement and interaction similar to a real-human interpersonal scenario. We have investigated both HMD and projector displays to allow medical personnel to experience the MRH breast exam scenario. The pilot study presented here ($n = 8$) used an HMD to display the MRH experience. An earlier exploration of the MRH by medical students and doctors ($n = 3$) used a life-sized projected display (fish-tank VR). Advantages and drawbacks of each of these displays are presented along with the impact of each display on the design issues presented above.

HMD: Viewing the virtual world through a HMD provides an immersive experience. Visual inspection of the MRH patient is better afforded by the HMD, as users can move freely in 3-space around the MRH and move closer to the MRH than can be afforded by a fish-tank projected display. However, as shown in the pilot study, when viewing the MRH through the HMD, the affordances of the physical embodiment are not clear to users.

Projector: Life-size projection of the MRH allows the user to view the physical embodiment separately from the virtual human. This clearly defines affordances of the physical embodiment, e.g. users can see that the breast exam patient’s armpit can not be palpated. However, implementation details are not hidden. Allowing users to view the physical embodiment may impact the optimal degree of embodiment: e.g. if only the chest of the breast exam patient were present, it may decrease the believability of the experience (vs. having a full body present). Initial testing with the projector has identified a drawback: users did not look at the projected display (only looked at the physical embodiment) once they began the physical exam. This caused them to miss important visual cues, e.g. the patient grimacing in pain.

6 CONCLUSION AND FUTURE WORK

A new species of embodied agent was proposed in order to increase the communication bandwidth between humans and VHs. *Mixed reality humans* possess a physical embodiment, including tangible interfaces, and afford haptic interaction with a VH.

Eight 2nd-year physician-assistant students performed a clinical breast exam of a MRH patient. Affording touch of the MRH patient allowed participants to fulfill their need to communicate through interpersonal touch and increased participants' social engagement over previous human-VH interactions.

Future work will address design considerations of MRHs (Section 5) and additional applications of MRHs. We have received interest from medical professionals to create MRH experiences to teach pelvic and prostate clinical exams. Future user studies will directly compare human-MRH and human-human interactions to ascertain similarities in types of, frequency, and effects of interpersonal touch and physiological reactions.

By affording haptic interaction, MRHs can simulate interpersonal communication similarly to human-human communication. MRHs will expand the domain of VH experiences to encompass interpersonal scenarios that require touch.

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