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Physiological response to a virtual reality simulation for preoperative stress inoculation

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Abstract.

This paper describes the development of a novel immersive virtual reality (VR) simulation designed to reduce preoperative state anxiety in patients undergoing breast cancer surgery. A custom interactive VR simulation allows participants to experience the setting of an operating room and the key preoperative stages, all the way through the administration of general anesthesia. Interactivity is provided through a self-avatar with which the various simulated medical personnel interact directly. We evaluate the capacity of the simulation to induce an emotional response as measured by the participants' galvanic skin response (GSR). To our knowledge, this is the first fully interactive simulation of an oncology surgery induction procedure for stress inoculation, and the first preoperative VR study to measure emotional impact using GSR. Out of a larger trial, we analyzed 6 participants who had been randomized to the simulation group and for whom baseline and intra-simulation GSR data had been successfully acquired. Three-minute samples were compared for statistical difference with a 95% confidence interval on the mean. 5 out of 6 showed a statistically significant and visually noticeable increase in GSR, and participants reported a high sense of spatial presence. Early results are encouraging, showing that the described simulation can induce a physiological response consistent with the participants' subjective evaluation of presence. While this was a limited experiment, it provides a basis for a larger trial to be conducted in the future.

Keywords.

Interactive simulation, virtual reality, preoperative anxiety, physiological monitoring

1. Introduction and background

This paper describes the technical development of a novel immersive virtual reality (VR) simulation designed to reduce preoperative state anxiety (PSA) – anxiety and distress prior to a surgical intervention – in patients undergoing breast cancer surgery. We evaluate the capacity of an interactive simulation to induce an emotional response as measured by the participants' galvanic skin response (GSR). A previous paper on this initiative studied the feasibility and utility of the system with data from a case series [1] derived from a larger feasibility trial [2]. This complementary paper describes in detail the design of the simulation, especially as it pertains to factors influencing presence and immersion, and measures the impact of the intervention on quantifiable physiological responses of a subset of the participants (who were randomized to the treatment VR group) in the feasibility trial.

Preoperative state anxiety has been associated with a range of poor postoperative health outcomes [3, 4]. A few studies have measured the impact of VR-based preoperative stress inoculation (i.e., pre-emptive exposure to stressful environments) with mixed results. Most systems use 360° videos [5-7] to simulate the surgery process, even though interactivity increases presence [8] and is considered more beneficial in the treatment of phobias [9]. To our knowledge, only one previous investigation utilized a patient perspective interactive VR for surgery simulation in a pediatric setting [10]. The researchers reported no significant decrease in pre-operative anxiety but reported less use of post-operative pain management drugs in the VR treatment group.

2. Design of the Simulation

A custom VR simulation was designed to allow participants to experience the setting of an operating room and the key preoperative steps designed in accordance with operating room appearance and procedures at a large provincial tertiary care center in central Canada. The steps included: lying down on the operating table, having medical sensors attached to the self-avatar, a safety briefing, placing the oxygen mask, and ending with the administration of general anesthesia. While engaged in the simulation, the participant sits and reclines on a real-world surface whose position coincides with that of the virtual operating table. Further elements regarding the simulation are detailed in the feasibility protocol [2].

An iterative and collaborative development process incorporated the input of various subject matter experts. The simulation was built using Unity 2020.1.8 and delivered through an Oculus Rift S off-the-shelf headset. Using a VR headset tethered to a PC enables clinicians or research staff to monitor the user's activities (**Figure 1**). A few design elements were hypothesized as key for increasing the user's emotional response and sense of embodiment in the simulation.

2.1. Interactivity of the Self-avatar and User Agency

The user is represented by a female self-avatar miming their real-life upper-body movement. The position of the self-avatar's lower half is kept fixed with the legs hidden under a virtual blanket. On top of increasing the feeling of presence [11], using a self-avatar enables virtual characters in the simulation to interact with the user. Natural transitions triggered by user actions give the user a greater sense of control during the simulation. For instance, after having a chance to look around the operating room, the next stage of the simulation does not proceed until the participant physically lies down on the operating table. In cases where a patient would not have agency in the surgery process, transitions are triggered by the operator.

Figure 1 Clinician view of the surgery, including first person POV and additional top and side views

3.2 Multi-sensory Scene Representative of Operating Room Conditions

Development team observations of pre-operative procedures, reference photos and videos, and input from medical experts guided the creation of a representative virtual operating room. To enhance immersion [12], attention was paid to multi-sensory aspects of the simulation including realistic sounds like monitor beeps and clink of surgical instruments as well as bright lighting.

2.2. Realism of the Virtual Medical Staff and Devices

Efforts were put on the appearance and behavior of the medical personnel avatars since unnatural motions or expressions can easily break the user's immersion [13]. Characters located closer to the user and character interactions with the user were prioritized as these would be most obvious. For example, it was important to optimize the animations of the nurse placing sensors on the user. To give primary characters a more natural appearance, eyes were animated to include gaze direction, blinking and eye saccades. Multiple devices were attached to the self-avatar including an intravenous port, a wristband, a blood pressure cuff, oxygen mask, wires and a photoplethysmography (PPG) sensor, since these devices can induce claustrophobia and fear of pain [14].

3. Method

A post-experiment analysis of biometric data acquired as part of a larger feasibility trial in which 12 participants were exposed to the VR simulation was undertaken [2]. Participants received the VR simulation 1-2 weeks prior to their scheduled breast cancer surgery. Control participants (n=11) were not analyzed for the purposes of the current study as they did not undergo VR exposure. GSR was selected as the physiological measure of choice, based on earlier research on phobia exposure therapy linking GSR with a sense of presence and with desensitization process' effectiveness [15, 16]. GSR was measured (using Mindfield® eSense Skin Response) before the VR experiment to provide a baseline, and then during the simulation itself.

Of the 12 participants in the intervention group, 6 yielded usable GSR data. For the other 6 participants (age range 46-64 (mean = 56)), GSR data was not acquired due to communication issues between the sensor and the recording app, or poor sensor contact with the skin; these participants were excluded from the analysis. All participants in the analyzed subset self-reported as female and had a previous surgical procedure. Three-minute samples for both the baseline and the intra-simulation measurements were compared with a 95% confidence interval on the mean. In addition, a t-test statistical test was used to compare both samples. Data was also smoothed with a median filter with a 60 s window for visualization purposes.

The iGroup Presence Questionnaire [17] assessed the presence associated with the VR intervention, defined as "the sense of being in the virtual environment" along three subscales: involvement (range -12 to 12), spatial presence (range -15 to 15) and realism (range -12 to 12).

4. Results

Results of the analysis are shown in **Table 1**, and time series for each of the participants are presented in **Figure 2**. 5 out of 6 participants showed a statistically significant increase in GSR ($p < 1e^{-10}$) with a large enough difference to be considered physiologically significative (>1 μS). Participant D showed only a small (<0.1 μS) increase in mean GSR: there is a statistically significant difference on the mean but given the noise on the measurements and the absence of a visually detectable step in the smoothed data, we estimated that this was most likely not clinically relevant.

Table 1. Confidence intervals on the mean, and p-values for individual t-tests between the baseline and the intra-simulation samples. Non-overlapping of the intervals indicates statistical significance.

Participant id	95% C.I. on the mean, baseline (μS)	95% C.I. on the mean, intra-simulation (μS)	Δ mean (μS)	*p*
A	[2.82 2.85]	[5.39 5.53]	2.63	$< 1e^{-10}$
B	[2.95 2.97]	[4.50 4.56]	1.57	$< 1e^{-10}$
C	[0.87 0.90]	[1.87 1.92]	1.01	$< 1e^{-10}$
D	[1.78 1.80]	[1.85 1.87]	0.07	$< 1e^{-10}$
E	[4.21 4.33]	[5.40 5.56]	1.21	$< 1e^{-10}$
F	[3.24 3.32]	[4.46 4.55]	1.22	$< 1e^{-10}$

Responses to the Presence Questionnaire indicate moderate involvement (mean = 1) and moderate realism (mean = 1) scores, but high spatial presence (mean = 8).

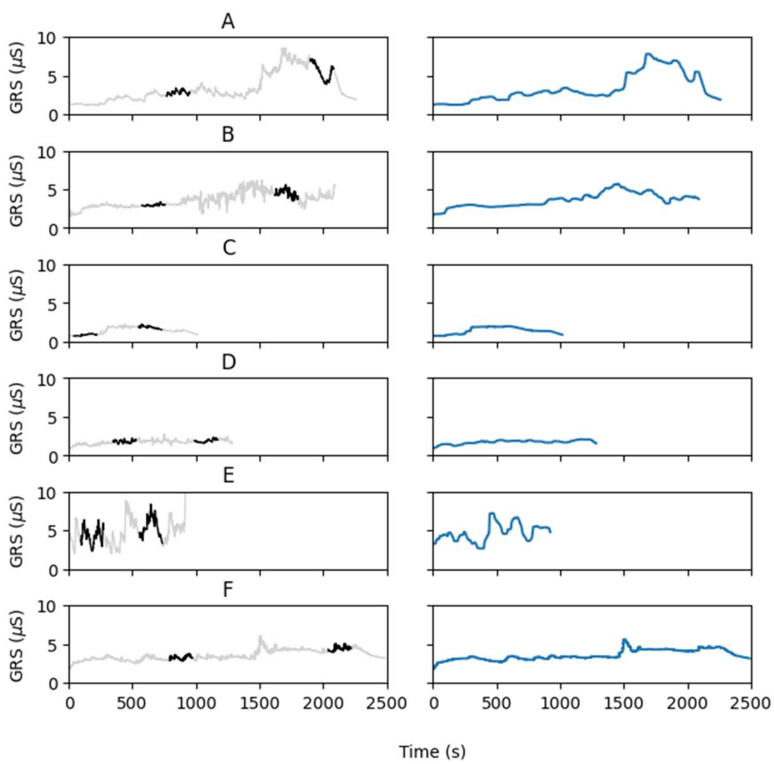

Figure 2 Time series for the 6 participants studied. Samples used for analysis are shown in black. The right column shows the smoothed data.

5. Discussion and Conclusion

This study describes key design elements of a VR simulation created to reduce preoperative state anxiety in patients undergoing breast cancer surgery. It also presents preliminary evidence that immersion in this simulation induces a measurable physiological response for most participants.

Three key design elements that could contribute to an engaging and embodying virtual experience are highlighted: interactivity and user agency, multi-sensory stimulation, and well-designed virtual characters and medical devices. While the impact of these factors has already been documented for a variety of virtual conditions, this is one of the first fully interactive simulations of an oncology surgery induction procedure for stress inoculation, and the first preoperative VR study to measure the emotional impact using GSR. Subjective evaluation of involvement, realism and spatial presence indicate areas of improvement for the next version of the simulation.

Analysis of the physiological data reveals that the simulation appears to increase the mean GSR level for most participants. A limitation of the paper is the manual GSR acquisition process which led to data loss, and the lack of automatic synchronization with the VR data. Manual recording of the simulation start time was imprecise, so we were limited to only analyzing samples of the signals to account for that imprecision. The lack of an active control group is another significant limitation; an active control group was initially planned but had to be eliminated due to recruitment challenges (2).

This study allowed us to observe some indicators of the simulation's effectiveness in eliciting genuine emotional reactions. While not definitive proof of efficacy, it facilitated the identification of potential improvements in the experiment design, the simulation and the GSR acquisition processes to improve the next arm of the study.

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