EXPLORATION OF VISUO-HAPTIC INTERACTIONS TO SUPPORT LEARNING LEOPOLD'S MANEUVERS PROCESS IN VIRTUAL REALITY

A Thesis

by

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ABSTRACT

Immersive technologies have been utilized in nursing education and other disciplines as effective learning and teaching tools. Many virtual reality (VR) simulations provide users immersive experiences through audiovisual stimuli. However, these systems do not enable haptic and tangible interactions, preventing them from utilizing higher multisensory stimuli for learning. There is a need in nursing education for more realistic VR experiences that allow direct hand manipulation in the acquisition of assessment skills, especially Leopold's Maneuvers which require palpating the patient's abdomen. To meet this need, a haptic-enabled virtual reality simulation called *Leopold's Maneuvers VR* was developed. This application utilized a set of commercial haptic gloves called *SenseGlove* to allow users to touch and feel the virtual patient's abdomen and fetus in the virtual exam room. To investigate the quality of haptic interactions from *Leopold's Maneuvers VR*, two sets of user studies were conducted. Study 1 was an explorative haptic experience study to investigate the effectiveness and usability of the haptic interactions. Study1 included three tasks to evaluate four different haptic device settings and a subjective post-study questionnaire to measure sense of presence for each device. Four different haptic device settings consisted of VIVE controller, *SenseGlove*, Custom-made Vibration glove, and the combination of Vibration glove and *SenseGlove*. The results show that *SenseGlove* showed the highest performance in task 1 and Vibration glove showed highest performance in task 2 and 3. According to the quantitative analysis, the combination of the *SenseGlove* and the Vibration glove provided the highest presence.

Study 2 was conducted with three of the haptic devices which showed high performance and presence. Study 2 investigated haptic interactions in the Leopold's Maneuvers process using

Leopold’s Maneuvers VR application. Most participants showed improvements in Leopold's Maneuvers knowledge after using the application and expressed positive feedback about using haptic devices in the application. This implies that the application may prove to be an effective educational tool in nursing education. In the future, we would like to improve the application based on the user feedback and conduct user studies with more students.

DEDICATION

This thesis is dedicated to my family, who have provided me with great love, support, and care during this journey. No words can express how grateful I am to them for always being there for me and encouraging me.

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CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supervised by a thesis committee consisting of Professor Jinsil Hwaryoung Seo and Caleb Kicklighter of the Department of Visualization and Professor Elizabeth Wells-Beede of the College of Nursing.

Some of the 3D models were purchased from TurboSquid and some other assets were provided by undergraduate 3D artists at Texas A&M University. The pre- and post-activities questionnaires were created under the guidance of Dr. Jinsil Hwaryoung Seo. The validity of 3D models and contents were done by a 3D graphics expert Caleb Kicklighter and a College of Nursing faculty Dr. Elizabeth Wells-Beede. All other work conducted for the was completed by the student independently.

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NOMENCLATURE

VR	Virtual Reality
HMD	Head-Mounted Display
UI	User Interface
VC	VIVE Controllers
VG	Custom-made Vibration Gloves
SG	*SenseGlove*
SGVG	The combination of *SenseGlove* and custom-made vibration glove
LM	Leopold’s Maneuvers

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1. INTRODUCTION

1.1. Leopold's Maneuvers

Leopold's Maneuvers, shown in Figure 1, is a part of physical examination of pregnant women during the antepartum assessment. It is a systematic method for determining the fetal position and presentation that can assist predict the course of labor. The maneuvers are performed by palpating the pregnant women's abdomen with the healthcare professional's entire palm and fingers. The procedure should be performed properly by the operators unless it may be uncomfortable and painful for the patient.

Figure 1. A nurse conducting Leopold's Maneuvers

1.2. Motivation

The research idea came across while working on this project called, *Antepartum 360* (Figure 2). *Antepartum 360* is a 360 video in a virtual reality (VR) application designed to help nursing students in their antepartum assessment learning. *Antepartum 360* application depicts a nursing faculty's demonstration during a routine office visit, which is accompanied by visuals, such as motion graphics and diagrams, as well as sounds. The application gives the impression that the viewers are in the same room as the faculty and the patient, observing the demonstration. Nevertheless, there are some limitations; they are unable to walk closer or interact with the virtual environment. Thus, we devised a plan to develop a VR simulation using haptic gloves, which would allow students to engage with the virtual environment and direct hand manipulation. *Leopold's Maneuvers VR* is a haptic-enabled VR simulation that teaches Leopold's Maneuvers procedure through visuo-haptic interaction. The application aims to provide students with a more realistic and engaging learning experience.

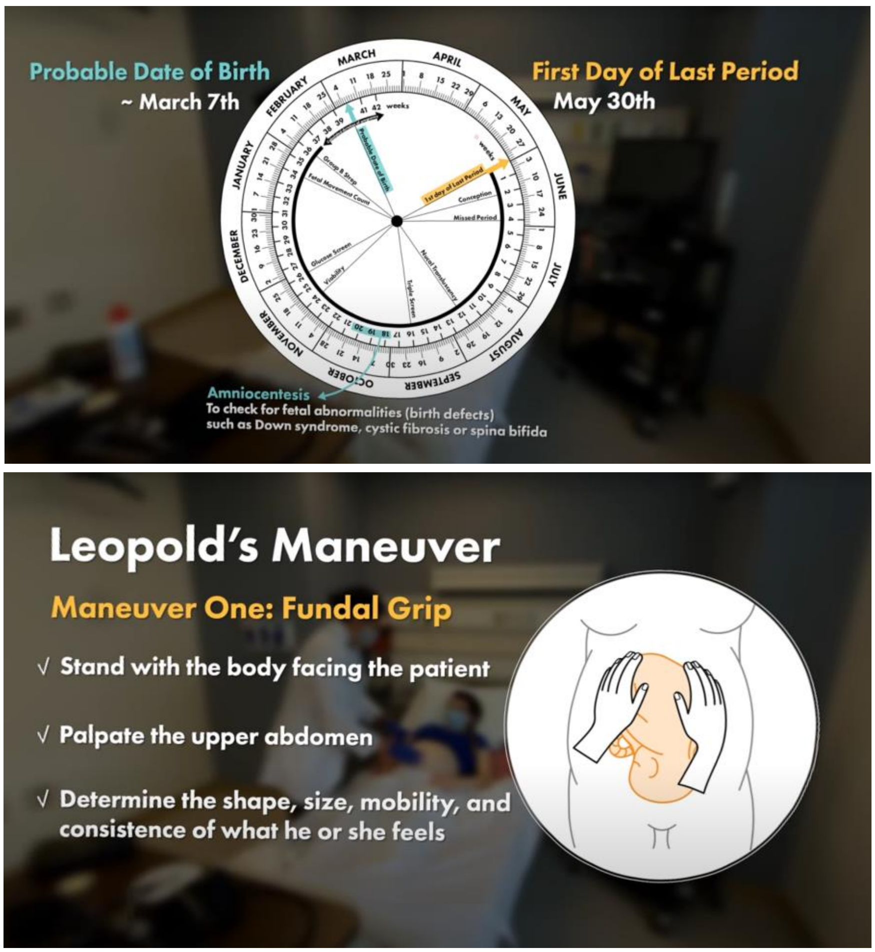

Figure 2. ***Antepartum 360*** **Application**

2. BACKGROUND AND LITERATURE REVIEW

2.1. Challenges in Nursing Education

Leopold's Maneuvers is challenging for physicians since they should assess the fetus's size, location, and direction only based on the abdominal palpation without actually seeing the fetus. To maintain patient safety and reduce the potential of harm, abdomen palpation should be performed by health care professionals who have received sufficient training and education. Generally, this training has been done with a plastic abdominal palpation model and an SP, a paid actor that roleplays as a patient with a particular condition. The palpation model is a three-dimensional demonstration tool that includes a female abdomen with a bony pelvis and a fetus model. It provides a semi-realistic interaction; however, it does not provide students an immediate and interactive feedback of the fetus movement. The integration of SPs into learning experiences is a more effective way since it gives students the opportunity to gain hands-on experience by practicing skills on a real person in a safe and controlled environment with immediate and constructive feedback (Jenkins & Schaivone, 2007; Schlegel & Terhaar, 2009; Vessey & Huss, 2002). However, SPs have limited availability, are time consuming and high cost. They require training, monetary compensation, and adequate safeguarding of their privacy. It can also be challenging to access the right SP: they often need to match specific demographic and/or body-state requirements to simulate the desired training scenario (ie. a SP in the third trimester of pregnancy). An additional challenge presented itself recently with the outbreak of COVID-19, where social distancing reduced the number of opportunities that students could gain first-hand experiences.

2.2. Virtual Reality in Nursing Education

Immersive technologies have been utilized in a wide range of education and training in healthcare. Virtual reality (VR) simulation has become a significant learning and practicing tool for acquiring knowledge and skills since it allows students to easily understand abstract concepts and provides an immersive virtual environment (Kilmon, et al, 2010; Lateef, 2010). *SimX VR* is a medical simulation software developed by clinicians at Stanford and UCSF (SimX, n.d.). The application allows physicians, nurses, and other healthcare professionals to practice skills on customizable simulated patient scenarios. *Oxford Medical Simulation* is a healthcare VR and screen-based simulation designed by Oxford Medical Simulation Team (Oxford Medical Simulation, n.d.). The application provides real-life training scenarios and evidence-based learning environments that are immersive and engaging.

In nursing education, immersive VR is growing rapidly as a practical learning tool due to its potential for improving the training and learning experience. In addition, due to COVID-19, the utilization of VR in nursing education has increased more (Fogg, et al, 2020). VR simulation provides the opportunity gain hands-on training by practicing skills in a safe environment repetitively without the jeopardizing the safety of patient (Chen, et al., 2020), facilitates distance learning (Dutile, Wright, & Beauchesne, 2011), and provides high-quality learning experiences (Founds, Zewe, & Scheuer, 2011) that enhances students' clinical competency (Smith & Hamilton, 2015), decision making, critical thinking skills (Kaddoura, 2010; Nibbelink & Brewer, 2018). Butt, et al. (2018) conducted a study utilizing game-based VR simulation designed to practice skill acquisition. The findings showed that the VR simulation could be an effective way to develop and gain fundamental skills.

Previous research shows that by utilizing VR simulation in nursing education, students can learn essential skills, improve decision making and critical thinking skills. In addition, VR offers a variety of patient scenarios that allow students to practice their skills repeatedly in a safe setting. However, most VR applications focus on visual and sound stimuli, which limit multisensory and embodied learning experiences for students.

2.3. Haptic Feedback in VR

One of the key aspects of the VR experience is the sense of presence. Presence is defined as the subjective feeling of "being there" in the virtual environment (Witmer & Singer, 1998). To enhance the sense of presence, utilizing multisensory stimuli is essential. There has been research explored that visual realism and the use of supplemental auditory cues increase the sense of presence and enhance task performance in a virtual environment (Dinh, et al., 1999). Although the majority of existing VR systems includes auditory or visual feedback to improve sense of presence, there has been a limited amount of research done on the inclusion of haptic feedback in VR.

Haptic Feedback is a unique attribute of the touch of sense which provides an effective interface to an application (MacLean, 2000). In the previous research, the effectiveness of the haptics has been demonstrated through task-based performance. Hoffman (1998) investigated the realism of the virtual environment when tactile feedback was enabled while interacting with virtual objects. The results demonstrated adding tactile feedback to virtual objects provides an effective experience. Insko (2001) conducted studies to investigate the effects of high-environment on the sense of presence and effects of haptics on task-based performance. The findings showed that adding haptics to virtual simulation has increased task performance and believability of the experience. Kreimeier, et al., (2019) evaluated the impact of different types of haptic feedback on presence and performance in a virtual environment. 14 subjects performed three different types of tasks and the findings revealed that vibrotactile feedback provided the highest presence and increased detection rates. Force feedback lowered execution time for the tasks. Ahmed, et al., (2016) investigated effectiveness of force feedback and vibrotactile feedback and the findings showed that force feedback provided the most natural experience and provided a better sense of presence over vibrotactile feedback.

The effectiveness of haptics has been explored in VR training simulations that require touch or the palpation of the patient. Kotranza & Lok (2008) developed a mixed reality simulation with a tangible interface for the MRH breast exam that required palpating the virtual patient. The simulation included virtual human and haptic interactions. The study results showed that enabling physical embodiment enhanced immersion and engagement, increased virtual realism and quality of communication between the virtual patient, and established acceptability and usability of the system. Kron & Schmidt (2003) developed a mixed reality environment for breast examination training. The system incorporated real-time visual feedback and haptic feedback on the operator’s fingertip. The study was conducted to identify the quality of tactile feedback in object identification tasks and the findings demonstrated that inclusion of the vibrotactile feedback and force feedback would provide a high degree of immersion in virtual simulated environments that require palpation.

Previous research has demonstrated that including haptic sensations into the VR environment improves the user's experience, immersion, and sense of presence. However, haptic-enabled VR simulations in nursing education are rare. In order to learn assessment skills in nursing, especially Leopold’s Maneuvers which requires abdominal examination, an immersive VR system that uses direct hand manipulation and offers interactive and immediate feedback is needed.

In this research, we developed a haptic-enabled VR simulation which includes multisensory stimuli such as visual and haptic feedback to provide a more dynamic and engaging user experience. The application offers step-by-step guidance for assessment preparation, demonstration video, and an interactive learning experience. The application allows users to feel the patient's belly and the fetal presence with their own hands. While interacting with the virtual patient, they can see belly deformation on the touched area and feel the fetal presence. The application also provides two alternative viewing modes for the abdomen: normal belly mode and transparent (x-ray) mode. By enabling both visual modes, users can better grasp the fetal movement, presentation, and position better.

The haptic-enabled VR simulation was developed to:

- Provide high-quality simulation to nursing students.
- Identify how haptic-enabled VR simulation impacts nursing students' learning outcomes.
- Evaluate the effectiveness of haptic-enabled VR in nursing education in the areas of knowledge, satisfaction, and confidence.
- Evaluate the acceptability and usability of haptic-enabled VR simulation.

The research questions for this study includes:

- How does haptic feedback affect users' experience in the virtual environment?
- How does haptic-enabled VR simulation impact nursing student's learning outcomes?
- How does haptic-enabled VR simulation impact nursing student's confidence in performing Leopold's Maneuvers?
- Do students find this learning material interesting and meaningful?

The user study was conducted twice. Study 1 was to investigate the effectiveness and usability of the haptic and conducted with 4 haptics settings. Based on the result, 3 haptic settings were selected and then applied to Study 2 which was to investigate the effectiveness of *Leopold's Maneuvers VR* application.

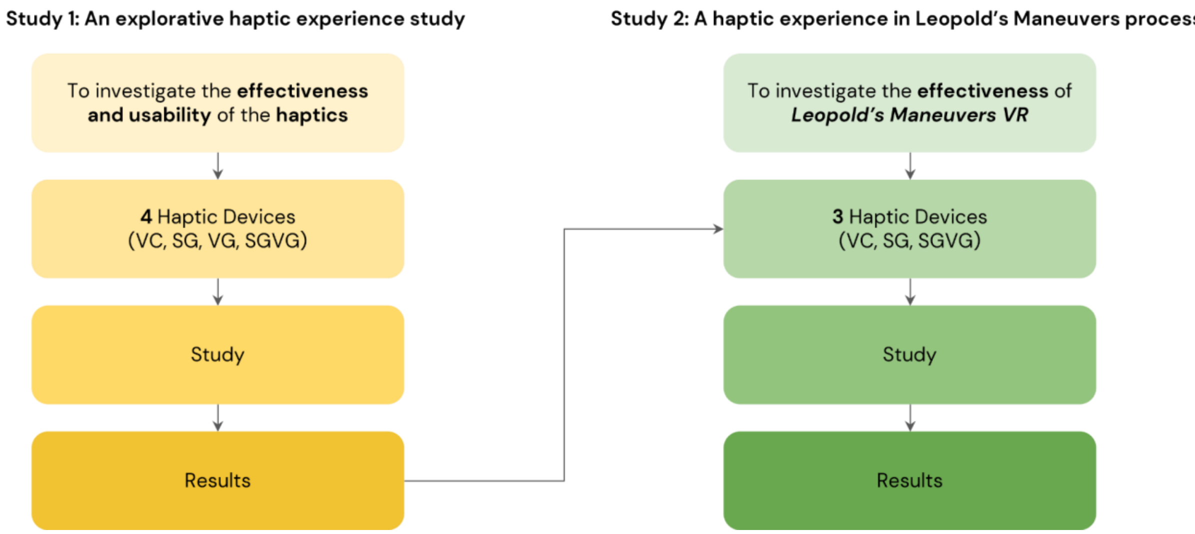

Figure 3. Overview of Study 1 & 2

3. STUDY 1: EXPLORATIVE HAPTIC EXPERIENCE STUDY

3.1. Materials

Study 1 was an explorative haptic experience study to investigate the effectiveness and usability of the haptics. Study 1 consists of two different VR scenes and the scenes were created in the Unity 3D environment. Participants started with Scene A and then moved on to Scene B.

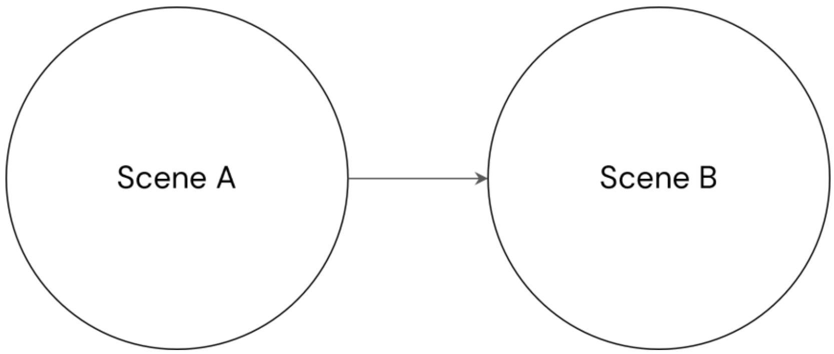

Figure 4. Flow of Study 1

3.1.1. Scene A: Interact with three balls

Scene A was interacting with three balls that had different levels of hardness. Scene A was designed to help participants understand what type of haptic feedback they will receive and to familiarize participants with the haptic devices. The participants can spend as much time as they want interacting with three balls on the table in front of them. When the balls were touched, they deformed and provided haptic sensation in varied ways depending on their hardness.

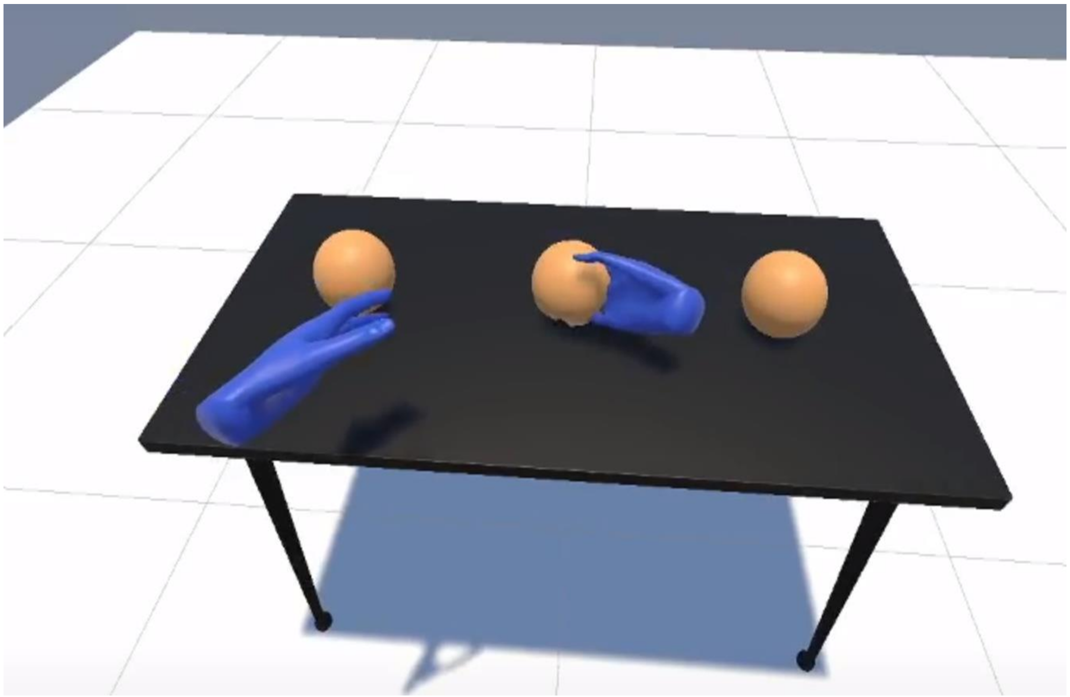

Figure 5. Scene A

3.1.2. Scene B: Object Identification

Scene B was designed to investigate the effect of different haptic feedback types on task-based performance. Objects were hidden inside each box and participants were to guess the objects based on haptic sensation. Participants used only one hand to touch and feel the virtual objects. Scene B featured three tasks.

- Task 1: Guess the sizes of the objects which are small, medium, and large, respectively. The small is similar to a ping pong ball, the medium is similar to a baseball, and the large is similar to a soccer ball.
- Task 2: Guess the shapes of the objects which are sphere, cube, and cylinder, respectively.
- Task 3: Guess the hardness of the objects which are soft, medium-hard, and hard, respectively.

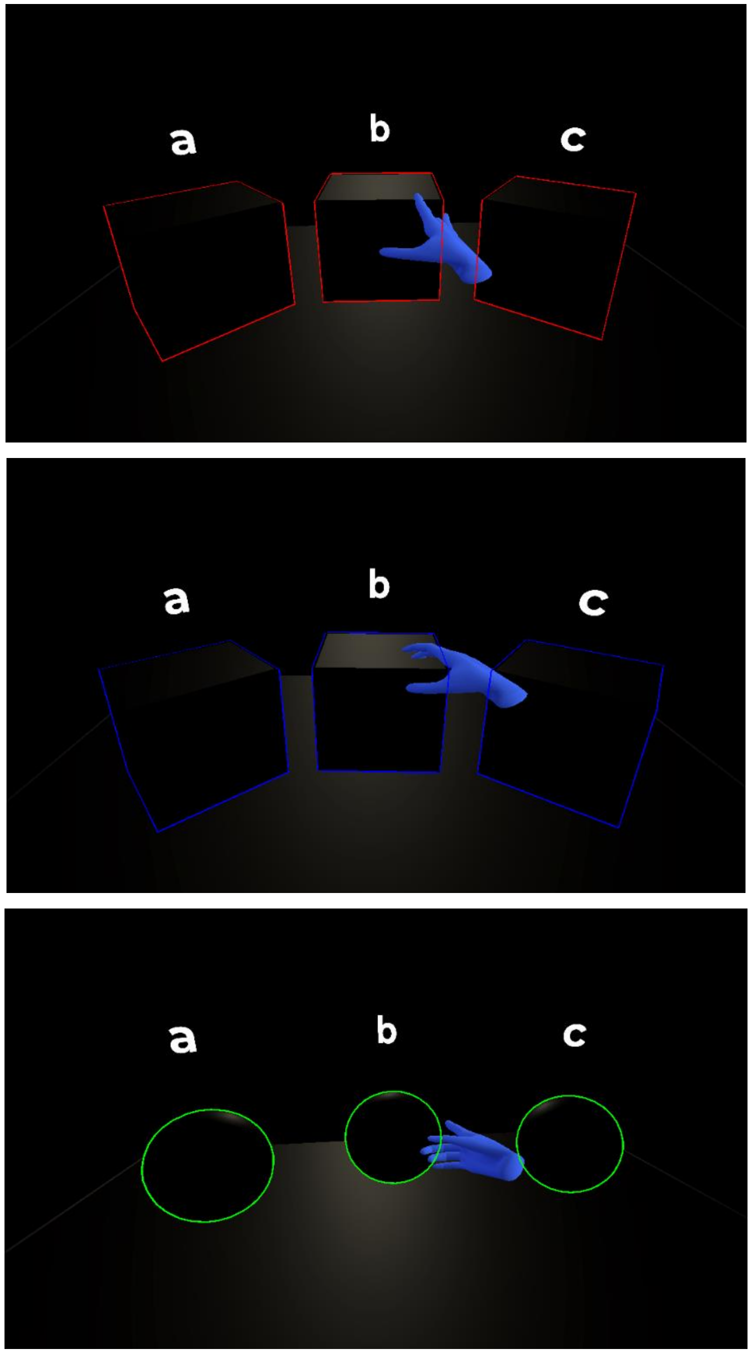

Figure 6. Scene B (Task 1, 2, 3)

3.1.3. Haptic Interaction Design

To evaluate the effectiveness of haptic devices, three types of haptic devices were utilized, VIVE controllers, *SenseGlove*, and Custom-made Vibration Gloves.

Figure 7. Haptic Devices

SenseGlove

SenseGlove, shown in Figure 8, is a pair of haptic gloves that enable users to physically feel and interact with virtual objects for VR training, simulations, modelling, and other research purposes (SenseGlove, n.d.). The gloves provide two types of haptic feedback, force feedback and vibrotactile feedback, and hand motion tracking feature.

Force feedback is provided by an exoskeleton on each finger that generates up to 40 Newtons of resistance, allowing users to feel the virtual object sizes, shape, and stiffness. When the user grips a virtual object, the exoskeletons on each finger apply resistance and pull them back to stop them from moving beyond the shape of the virtual object. The user can also feel the collisions or texture of the virtual objects through vibrotactile feedback which is provided by the vibration actuators on each fingertips and palm of their hand. *SenseGlove*'s per-finger tracking mechanism handles finger tracking. The finger tracking identifies the orientation of the user's hands as well as the bending angle of their fingers. Hand position tracking was done by mounting the VIVE tracker on the *SenseGlove*.

To create a realistic sensation of haptics, we applied varied force-feedback intensity (0-100%) to each material in the Unity environment to establish a distinction between hard and soft materials. 15% of force intensity was applied to the soft material, 60% of force intensity was applied to medium-hard material, and 100% of force intensity was applied to hard material.

Figure 8. ***SenseGlove***

Custom-made Vibration Gloves

We created a pair of vibration gloves to provide vibrotactile feedback on the palm of the user's hand. ESP32 development board and LilyPad Vibe Board were utilized. ESP 32 is a development board that allows Unity to communicate with vibrotactile actuators via WiFi or Bluetooth. LilyPad Vibe Board is a vibration motor that provides up to 5V vibrations. One of the advantages we got from the LilyPad Vibe Board was the ability to sew the motor into the gloves using conductive thread.

To develop an efficient haptic glove, there were three requirements when designing the gloves (Ma, et al., 2015).

- Size: The glove should be able to fit a wide range of hand sizes.
- Weight: The glove should be as light as possible.
- Wearability: The glove should be comfortable to wear and easy to put on.

In order to meet all three requirements, the most crucial factor was the fabric. The fabric should be thin and stretchy enough to lightweight and fit all of the participants comfortably. First haptic glove prototype was a cotton fingerless glove (Figure 9). The glove was lightweight and easy to put on and off, however, the drawbacks were that the material was too thin to hold the vibration motor in place on the palm and the glove was not able to fit to larger hand sizes.

Figure 9. First Prototype

The next prototype was created after fixing all the problems in the first prototype (Figure 10). The second prototype was created with neoprene fabric. The material was stretchy enough to fit a wide range of hand sizes and was lightweight. To ensure that the vibration motors maintain good contact with the palm of the hand, vibration motors were attached to the inside. The velcro straps on the gloves allowed for customized sizes for each hand. The gloves were also easy to put on and off; to wear the gloves, participants would put their thumb through the hole and wrap around their hands.

To provide hand motion tracking, we used *SenseGlove*, and for hand position tracking, we used VIVE tracker. Participants wore *SenseGlove* on top of the vibration glove.

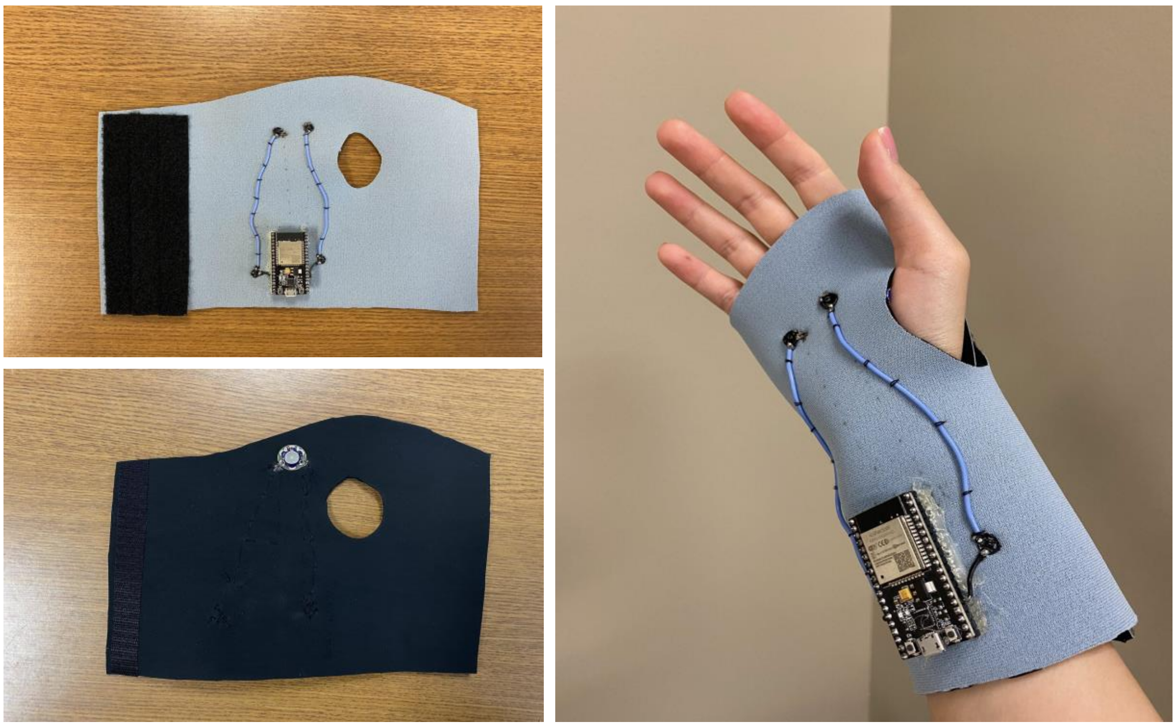

Figure 10. Custom-made Vibration Glove

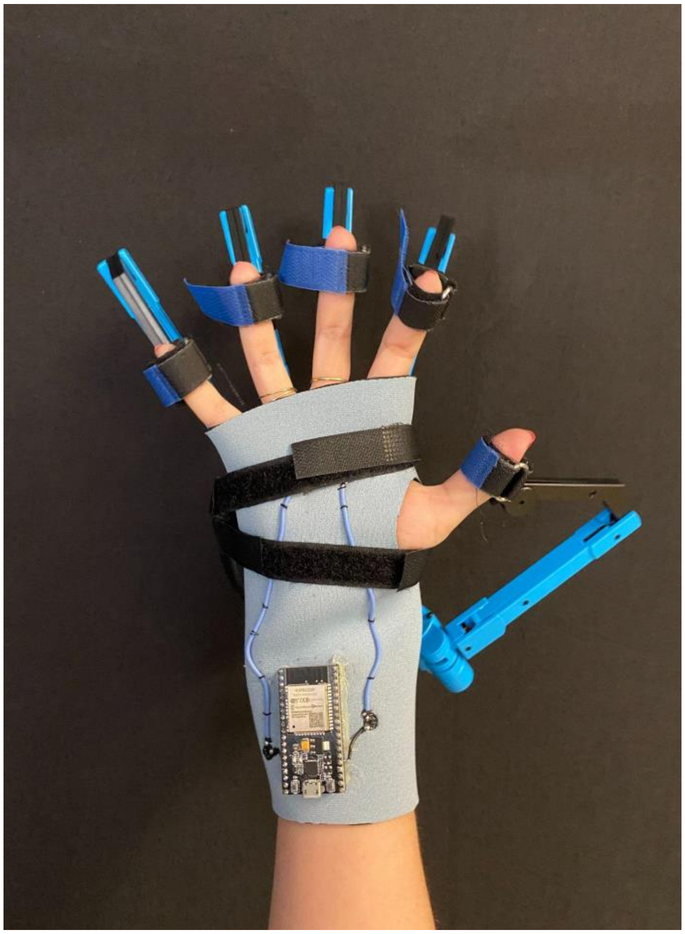

Figure 11. Custom-made Vibration Glove and *SenseGlove*

We applied varied vibro-tactile intensity to each material to differentiate between hard and soft materials. 15% of force intensity was applied to the soft material, 60% of force intensity was applied to medium-hard material, and 95% of force intensity was applied to hard material.

VIVE Controller

VIVE controller is a VR controller that is compatible with HTC VIVE. The controller enables users to interact with the virtual environment wirelessly (VIVE United States, 2018). The controllers have vibration motors that provide vibrotactile feedback when the object is touched. We applied the same vibro-tactile intensity as the custom-made vibration glove. 15% of force intensity was applied to the soft material, 60% of force intensity was applied to medium-hard material, and 95% of force intensity was applied to hard material.

Figure 12. VIVE Controller

3.2. Methods

3.2.1. Institutional Review Board Approval

This study has been approved by institutional Review Board (IRB) and the IRB study number is: IRB2020-1531D. Before taking part in this user study, all participants were asked to provide informed consent before their participation in this user study.

3.2.2. Sample Selection and Recruitment

Twenty-two students from Texas A&M University, both current and alumni, participated in the study. There were no requirements for taking part in the study. The recruitment was done by word-of-mouth. Recruitment messages were sent out via Slack and email providing research details and a link to sign up for a time slot. After signing up, participants received a confirmation email and the event was added to their Google calendar to guarantee the event was not missed.

3.2.3. Study Design

Study 1 is a within-subjects experiment. The independent variable is the 4 different haptic device settings (VIVE Controller (VC), *SenseGlove* (SG), Custom-made Vibration Glove (VG), and combination of *SenseGlove* and Custom-made Vibration Glove (SGVG)), and the dependent variables are the task performance and sense of presence. All of the participants took part in each condition of the independent variable. The researcher randomly assigned participants to four conditions. The following hypotheses were tested, separated into two primary axes:

Sense of Presence (SP)

SP01. The sense of presence is higher when using SG than using VC.

SP02. The sense of presence is higher when using SG than using VG.

SP03. The sense of presence is similar when using VC and VG.

SP04. The sense of presence is highest when using SGVG.

Task Performance (TP)

TP01. The task performance is higher when using SG than using VC.

TP02. The task performance is similar when using VC or VG.

TP03. The task performance is the highest when using SGVG.

3.2.4. Survey Instruments

The research instruments utilized to collect data from participants included presence questionnaire (PQ), and task performance data from the three tasks.

PQ. To quantify the level of presence experienced by participants, a presence questionnaire from Witmer & Singer (1998) was utilized. All the participants filled out PQ after they finished the activities. The questionnaire consisted of 4 items with a 5-point Likert scale.

Task Performance. Participants were given three tasks to complete in order to identify the objects using each haptic device, and their responses to the objects were noted.

3.2.5. Procedure

All participants were given 60 minutes maximum to complete the activities of the user study. The study facilitator sanitized equipment before participants entered the meeting space where the user study took place. The hand sanitizer was also placed in the meeting space to prevent infection from surfaces. Upon arrival, participants were greeted at the meeting space and were given the printed informed consent form. The study facilitator explained the contents of the form and allowed the participants to read the form, ask any questions they had, and sign on it. To secure all participants' identity and the data collected throughout the study, each participant was issued a unique identification (ID) number. After that, the participant was asked to complete a pre-activity questionnaire that was provided on a secured laptop. A set of demographic questions and a set of Likert scale questions were included in the questionnaire.

Following the completion of the questionnaire, the research facilitator gave the participant a quick overview of the haptic devices they will be utilizing throughout the study. Then, the facilitator handed over the haptic device based on their condition orders. Then they were given a disposable face cover mask and a head-mounted display (HMD).

Participants start with Scene A. The study facilitator explains the objective of the scene and the participants can interact with three balls as much time as desired. After that, participants complete task 1, 2, and 3 in order. Scene A and Scene B were done four times with four different haptic devices, with different ordering for each participant. All the participants' responses and reactions were audio recorded and notes were taken.

Figure 13. Study 1 Participant

3.3. Results

3.3.1. Participants

Twenty-two students from Texas A&M University volunteered to take part in the study. Five of them, however, were excluded from data analysis. The data of four participants was unreliable due to technical challenges and one of them did not complete the post-survey and the interview. Seventeen participants were aged 18-24 (47.06 %, n = 8), 25-30 (35.29%, n = 6), 31-35 (11.76 %, n = 2), and 36+ (5.88%, n = 1). Participants were asked about their prior experience with VR and to rate their familiarity with VR on a 7-point Likert scale. The majority of the participants (88.24%, n = 15) had prior VR experience, whereas 11.76 % (n = 2) had none. Participants were also asked to rate their familiarity with VR on a 7-point Likert scale. The participants' familiarity with VR ranged from 1 to 7 (M = 4.65, SD = 2.07). The majority of participants, 64.71 % (n = 11) were very familiar with VR and 35.29% (n = 6) of participants were not familiar at all. Participants were also questioned about their previous experience with haptic technology and to rate their familiarity on a 7-point Likert scale. 58.82% (n = 10) participants had prior experience with haptic technology, while the remaining 41.18% (n = 7) had none. Half of the participants, 52.94% (n = 9) were not familiar at all, 11.76% (n = 2) were familiar, and 35.29% (n = 6) were very familiar. Those who had prior experience with haptics (n = 10) were asked what type of haptic technology they had tried. They selected all that applied.

Variable	**n**	**%**
Age		
18-24	8	47.06
25-30	6	35.29
31-35	2	11.76
36+	1	5.88
VR Experience		
Used VR		
Yes	15	88.24
No	2	11.76
Familiarity with VR (M = 4.65, SD = 2.07)		

Not familiar	6	35.29
Familiar	0	0
Very Familiar	11	64.74
Haptics Experience		
Used Haptics		
Yes	10	58.82
No	7	41.18
Familiarity with Haptics (M= 3.59, SD = 1.27)		
Not familiar	9	52.94
Familiar	2	11.76
Very Familiar	6	35.29
Haptic Devices		
Mobile Phone (Vibration)	8	
Game Controller (Vibration)	7	
Wearables (ex. smart watch)	6	
AR/VR Device (ex. VR controller)	7	

Table 1. Study 1 Participant Demographics

3.3.2. Presence Questionnaire

Participants were asked to rate the questions mentioned below in Table 2 on a 5-point Likert scale and the results are shown in Figure 14. Two sensory factors items were analyzed together as a total.

SP01. The sense of presence is higher when using SG than using VC. The results demonstrate that SG has a higher sensation of presence than VC for all three factors.

SP02. The sense of presence is higher when using SG than using VG. The results demonstrate that SG has a higher sensation of presence than VG for all three factors.

SP03. The sense of presence is similar when using VC and VG. The results demonstrate that they do have the same ratings for control factors, but VG has higher ratings in realism and engagement factors.

SP04. The sense of presence is highest when using SGVG. The results demonstrate that the SGVG has the highest sense of presence among the other three haptic devices.

Question	**Factors**
How engaging was the experience?	Sensory
How completely were all of your senses engaged?	Sensory
How well were you able to manipulate objects in the virtual environment?	Control
How natural did your interactions with the environment seem?	Realism

Table 2. Presence Questionnaire

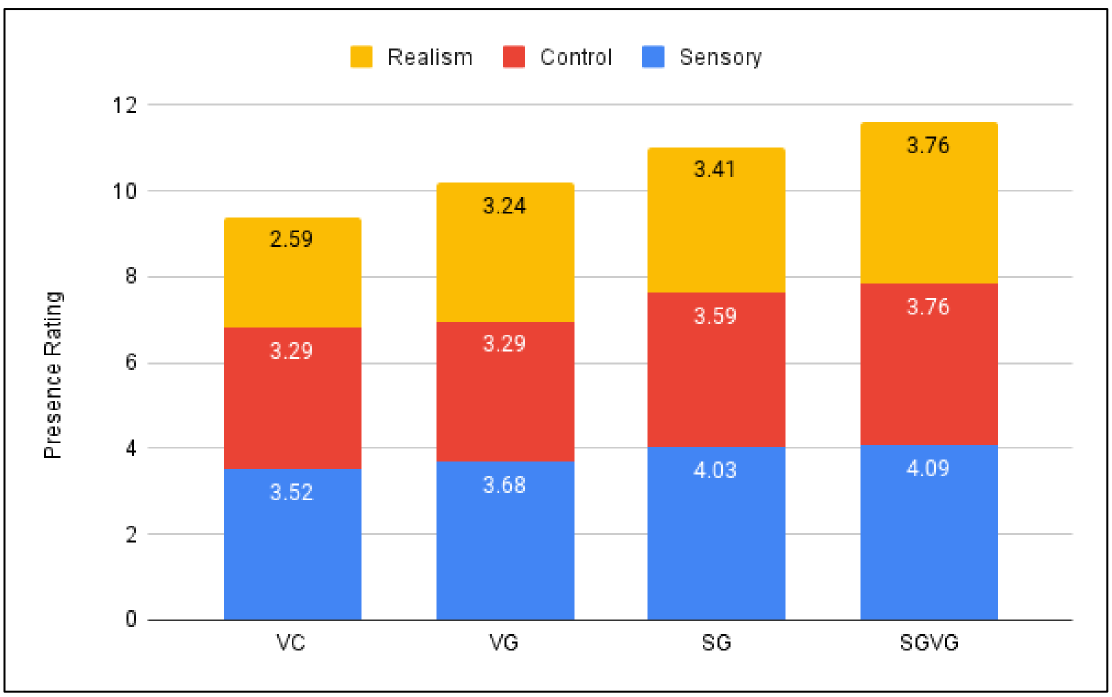

Figure 14. Presence Questionnaire Results

3.3.3. Task Performance

Correct Answer Rate

The percentage of right answers for each type of haptic device was measured in each of three tasks. For task 1, guessing the object sizes, SG had the highest answer rate of 96.08%, followed by SGVG with 86.27%, VC with 84.31%, and VG with 76.47%. For task 2, guessing the object shapes, VC had the highest correct answer rate of 68.83%, followed by SG with 60.78%, SGVG with 58.82%, and VG with 50.98%. For task 3, guessing the object hardness, VC had the highest correct answer rate of 96.09%, followed by SG with 86.27%, SGVG 74.51%, and VG with 72.55%.

During the interview, the majority of participants stated that guessing the shapes of the objects was difficult, and as indicated in Figure 15 below, the correct answer rate for the shape was the lowest.

TP01. The task performance is higher when using SG than using VC. The results show that VC has higher correct answer rates than SG for task 2 and 3, however, SG has a higher correct answer rate than VC for task 1.

TP02. The task performance is similar when using VC or VG. The results show that VC has higher correct answer rates than VG for all three tasks.

TP03. The task performance is the highest when using SGVG. The results show that VC has the highest correct answer rate in task 2 and 3 and SG has the highest correct answer rate in task 1.

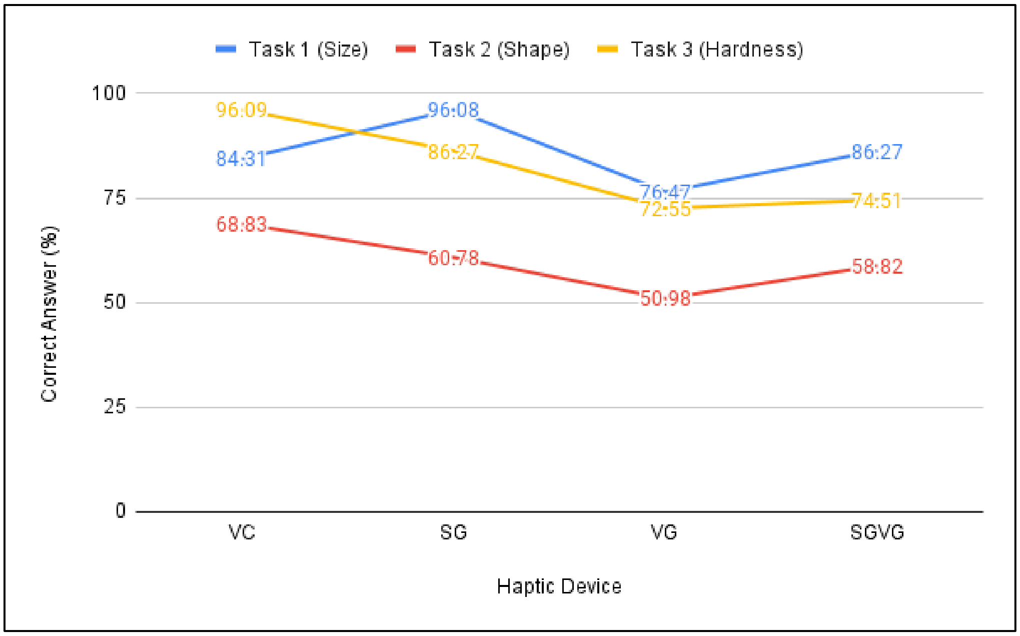

Figure 15. Participants' Average Correct Answer Rate of Each Device

When asked to rate "How helpful was the haptic feedback in recognizing object shapes? (1- Not helpful at all, 5- Very helpful)" on a 5-point Likert scale, VC rated the most helpful device for all three tasks.

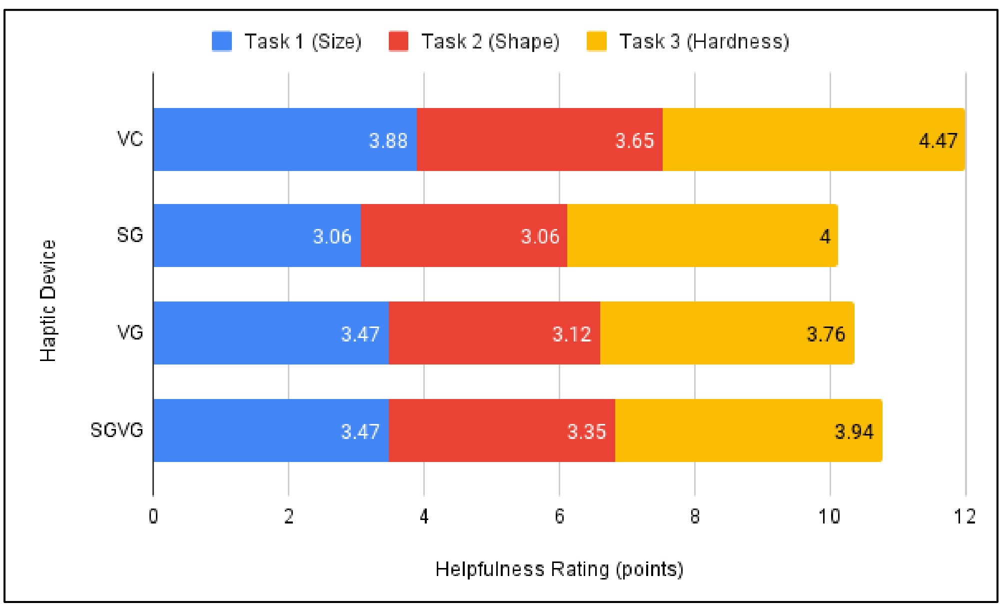

Figure 16. Haptic Feedback Helpfulness Rating (1- Not helpful at all, 5- Very helpful)

When asked to rate "How difficult or easy was it to recognize the shapes (1- Very easy, 5- Very difficult)" on a 5-point Likert scale, overall ratings for task 2, guessing the shapes were the highest among the other tasks, indicating that guessing the shapes was the most difficult task. Using the SG was the most difficult to guess the shapes, followed by VG, SGVG, and VC. Using the SG was the most difficult to guess the sizes, followed by VG and SGVG, and VC. Using the VG was the most difficult to guess the hardness, followed by VC, SGVG, and SG.

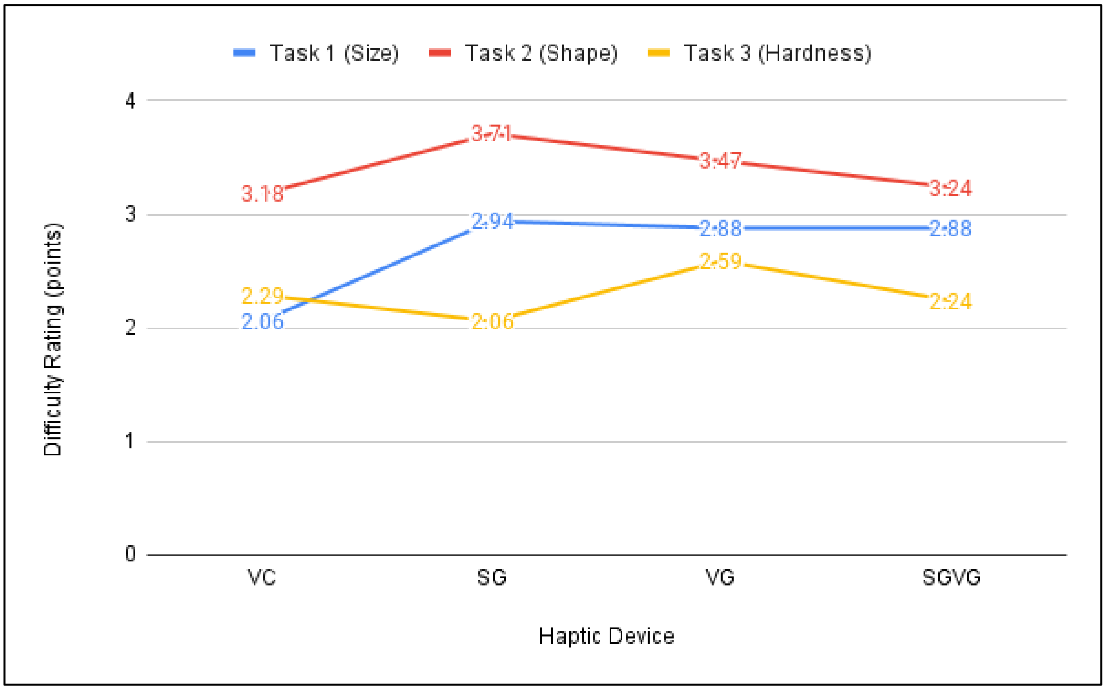

Figure 17. Task Difficulty Rating on Each Device (1- Very easy, 5- Very difficult)

3.3.4. Preference

After the activities, participants were asked to rank their favorite and the least favorite haptic devices during the interview. The favorite device received 21 responses from the 17 participants, while the least liked device had 18 responses. Five participants chose two different types of devices as their favorites. Two of the participants selected two haptic devices as their least favorite devices. One participant did not choose any of the options.

The least preferred haptic device was VG, while the other three devices all had comparable preferences for the most favored haptic device. VC was chosen by 28.57% (n = 6) of respondents, followed by SG by 28.57 % (n = 6), SGVG by 33.33% (n = 7) of respondents, and VG by 9.57%. The majority of participants chose VC as their least preferred haptic device, with the other three devices receiving similar results. VC was chosen by 44.44 percent (n = 8) as their least favorite, followed by 22.22 percent (n = 4) for SG, 16.67 percent (n = 3) for VG, and 16.67 percent (n = 3) for SGVG.

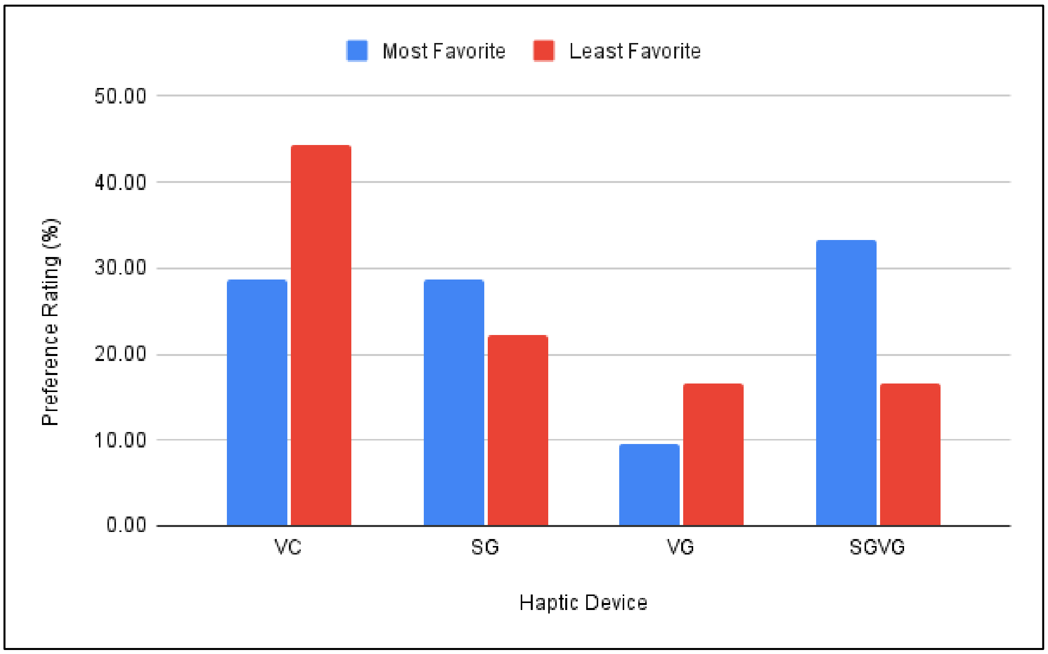

Figure 18. Haptic Device Preference

Participants that selected SGVG or SG as their preferred device selected VC or VG as their least preferred device, and vice versa. The reason for choosing SG or SGVG as their favorite and VG or VC as their least favorites were because SG felt the most natural and immersive because you can move your fingers and the vibration VC provided was too much and felt so unnatural that it just felt like holding their phone or game controller vibrating. Below are some of the verbal comments provided from the participants during the interview:

"SG was probably the most natural feeling because of the resistance. VC it didn't have a very immersive feeling. It felt like I was holding my phone and vibrating. I didn't really feel like I belonged in VR space. And because I was holding the controller but you see a hand so it felt like there was a disconnect between what my hand and the others were gloves. (User ID: P3)"

"SG feels a bit natural when you understand what's going on. (VC) The vibration was a lot. (User ID: P4)"

"SGVG you can move your fingers. If you go for one object only then it's going to be difficult. Like it's difficult to find the results like you're just guessing you don't know. But when you use both of them, you're quite sure that your answer is going to be right. Using VC, it was hard to get the shapes and the sizes. I found it more difficult. (User ID: P6)"

"Using SG, I felt the glove was more immersive. Like it felt more real. The interaction felt more natural. VC was the easiest to use but not natural. (User ID: P7)"

"SGVG was the easiest to tell the difference between all the objects because of the forest feedback, because you know, it made you like to move your hand around like that. Using VC, I felt like it didn't do anything. Like I couldn't tell the difference for anything. Yeah, I mean, the vibration intensity was the only thing that changed, other than that I couldn't tell anything. (User ID: P13)"

“SGVG combination was the most natural experience to me.Adding more senses made me feel more natural. VC it's like playing the game. It is not close to the real experience. (User ID: 16)”

“I've used VR before, so it feels more natural to me. But I especially like actually grabbing the objects. Using VC, it’s like you're holding your phone. (User ID: P17)”

The reason for choosing VC as their favorite and SG or SGVG as their least favorite was because the intensity of the vibration generated by VC made it easier to identify the objects and it is the most familiar haptic device for those using VR. Since SG is heavy and bulky, it made participants’ wrists tired and sore, the clicking sound of the SG was distracting, and the force feedback felt inconsistent. The following are some of the verbal comments provided by the participants during the interview:

“VC was the easiest because it had the least amount of other stuff you had to do. SG is big and bulky. After a while your wrist gets tired. It didn’t feel specific and it was hard to differentiate between medium and hard with the joint resistance (User ID: P1)”

“VC is the most familiar device for people using VR. When using SG you don’t know if that’s natural and the weird sound is that supposed to be? (User ID: P7)”

“VC was the most helpful because it’s just very straightforward. It’s easy to focus on one thing. SG was the most interesting but the most distracting. There was a lot of extra sund. The pressure on my fingers was also interesting but there was a disconnect between your visual feedback and haptic feedback that made me want to fight the glove. It’s a sort of slightly confusing sensation

which may take some time getting used to. Also that (force feedback) didn't feel consistent. (User ID: P9)"

Some of the other comments who picked VG as their most favorite device was:

"It gives you gave you the most smooth interaction (User ID: P14)"

Some of the other opinions for choosing VG as their least favorite was:

"It was kind of hard to detect the vibration. It's weak compared to the others. (User ID: P7)"

"It's really hard to distinguish between the levels of strength of the vibration, or the different objects (User ID: P8)"

4. STUDY 2: A HAPTIC EXPERIENCE IN LEOPOLD'S MANEUVERS PROCESS

As seen in the background section of this thesis, immersive technologies are becoming more popular as a tool in nursing education. VR provides users with a safe and repeated environment that aids in the teaching and learning process. For the project implementation the HTC VIVE head mounted display (HMD) and the *SenseGlove* Development Kit was utilized and developed in a Unity 3D environment. Virtual environment was created using custom designed assets from Autodesk Maya and purchased from TurboSquid. The accuracy of the 3D models was reviewed by a 3D graphics expert and a faculty member from Texas A&M University College of Nursing.

4.1. Materials

4.1.1. Virtual Patient Creation

The 3D model was a free source downloaded from Turbosquid and it was imported into Autodesk Maya 2020 for some modification. The initial model was in a standing pose (Figure 19) and the model we needed was in a relaxed lying down pose. First, rigging was done to make a modification on a model's pose. Rigging is a process of adding a skeleton to a 3D model in order to provide control points for animating it. After the model was rigged, its pose was revised into a lying down pose. Then, its belly was reshaped and resized to resemble the shape and size of a pregnant woman's belly after 36 weeks. After the modification was made to the belly, hair and clothing models were created. The mesh was then simplified in order to reduce the number of vertices in the model. This part was necessary to reduce the render time and improve the interaction with the haptic devices. To lower the poly count, the meshes that were invisible and covered by the clothes and blanket were removed. The finalized model is shown in Figure 20.

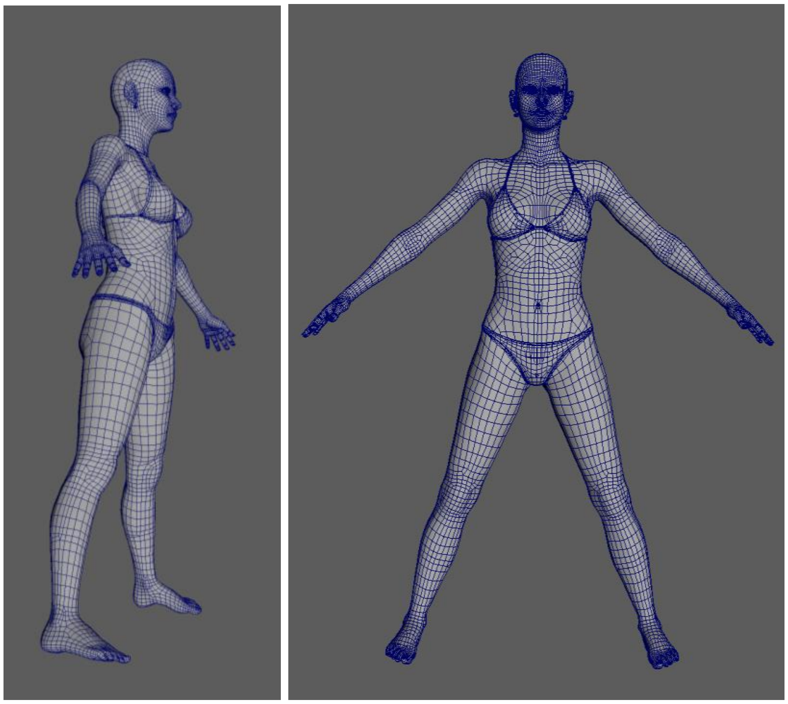

Figure 19. The Original Model

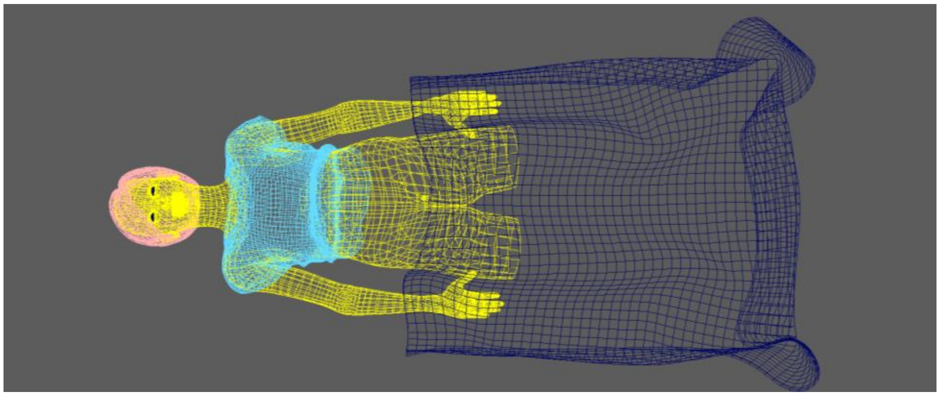

Figure 20. The Revised Model

4.1.2. Virtual Fetus Creation

The 3D fetus model was purchased from Turbosquid. Since the original model had low poly mesh and clean topology, no further modeling was needed. However, we needed to add rigging and animation to the fetus model in order to provide the users a more alive and realistic experience. Rigging and animating was done using Autodesk Maya 2020. Rigging is a process of adding a skeleton to a 3D model in order to provide control points for animating it. After the 3D model was rigged, the skin weight was painted. Painting the weight is an important part of the skinning process since it assigns the right influence each joint has on the mesh (Figure 21). After placing the joints and painting the skin weight, skinning was done to attach the model to the joints. After that, two animations were created. When the fetus is not touched, it shows idle animation (Figure 22), which is a subtle movement, and when the fetus is touched, it triggers a stronger movement (Figure 23). The texturing was done using Unity 3D shader graph.

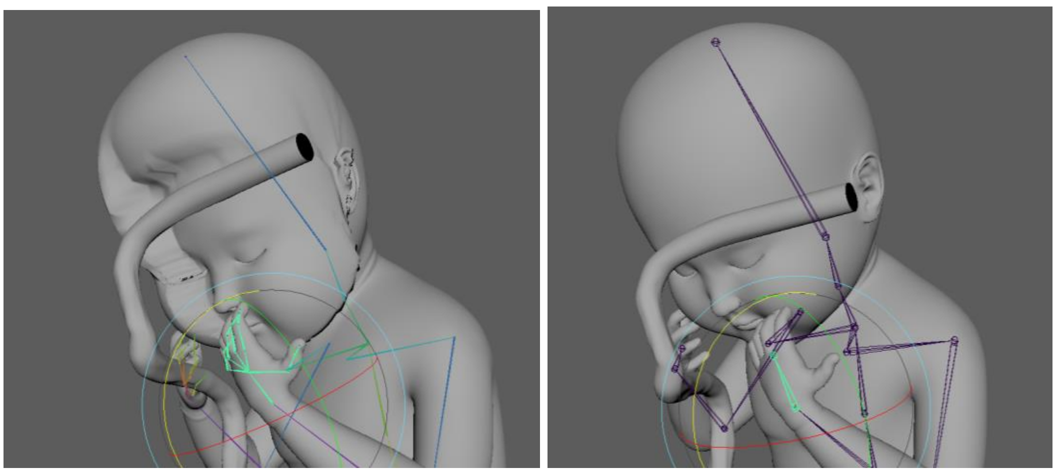

Figure 21. Before and After Weight Painting

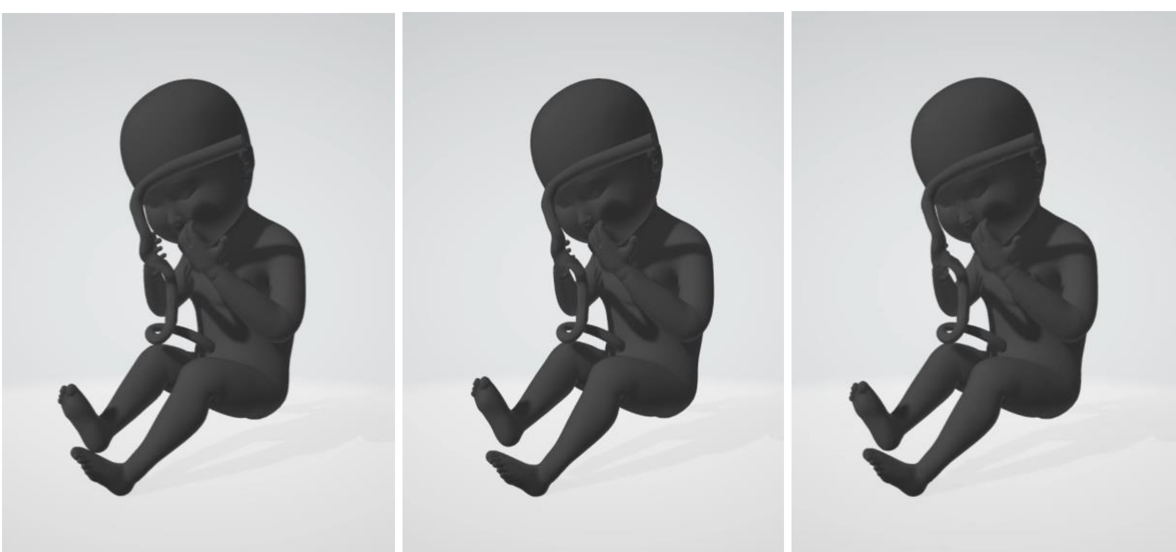

Figure 22. Idle Movement

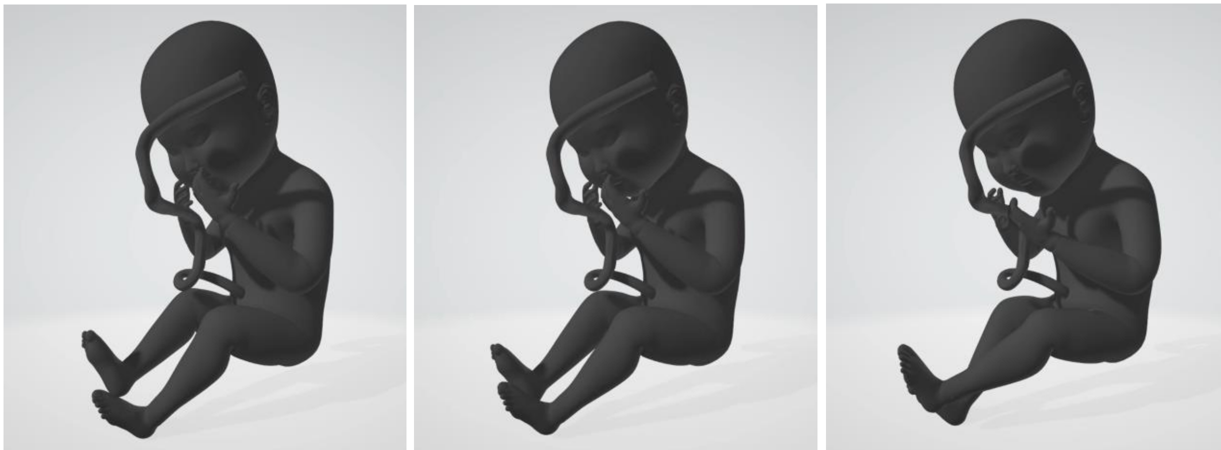

Figure 23. Dynamic Movement

4.1.3. Virtual Examination Room Creation

To provide a high sense of presence in the virtual reality environment, it was important to provide as realistic an environment as possible. The initial step was to collect images of examination rooms for reference. This aided in asset selection, layout selection, and lighting process. The assets were developed by Texas A&M University 3D artists and downloaded from TurboSquid. After assets for the virtual examination rooms were obtained, the texturing was done using Substance Painter. Canva was used to create the flyers that are hung on the wall.

4.1.4. Asset Assembly in Unity

After all of the assets were created, they were assembled using Unity, a cross-platform game engine. First, a scene was created and the fbx files were imported. The files were placed out within the environment and then the texture files and fetus animation files were imported. Imported files were applied to respective fbx files.

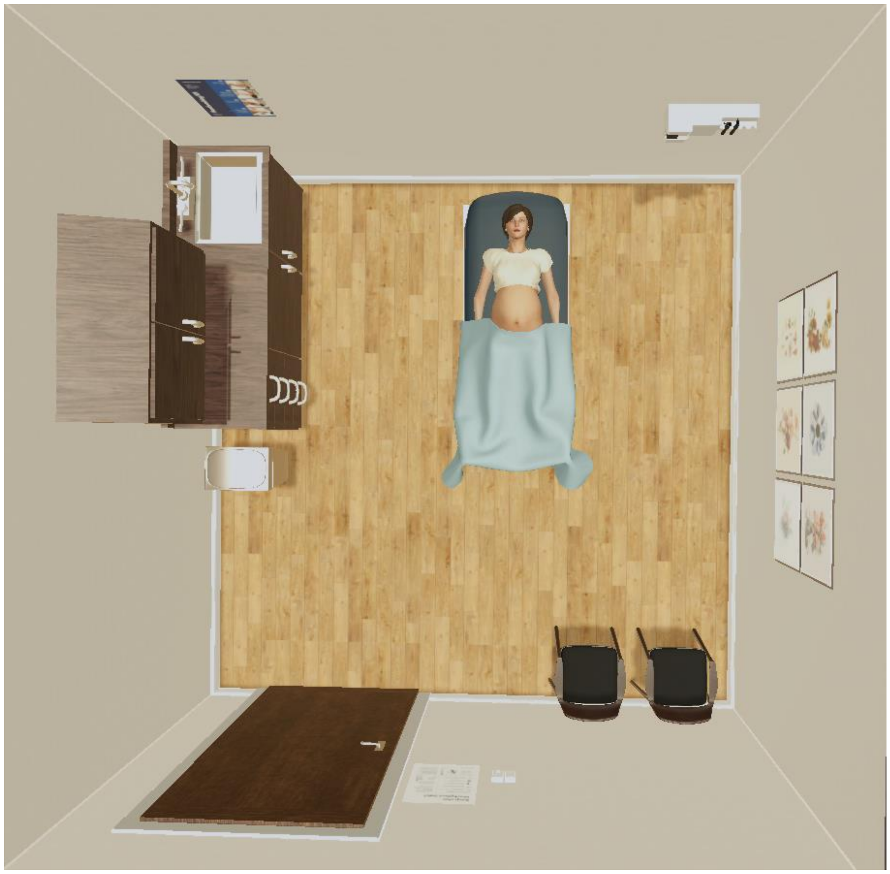

Figure 24. Virtual Examination Room

4.1.5. User Interface Design

The quality of the user experience, such as satisfaction, usability, and acceptability, is influenced by the user interface design in a virtual environment (Schrepp, et al., 2014). *Leopold's Maneuvers VR* application aimed at offering an intuitive and efficient user interface (UI). The interface design went through multiple iterations. Principles that were kept in mind while designing the VR interface were readability of text, ergonomics, and button placement (Purwar, 2019). Generally, reading text in a virtual environment is challenging because of the resolution of the display. We used big and bold text that is legible, kept minimum text, and placed UI elements at an appropriate distance from the user. The inclusion of the audio cues assisted users to look around and help them get started. The audio cue we used was a narration of a nursing faculty throughout the application. The audio cue mainly provides instructions about the information displayed on the panel, but also tells the user what to do. For example, the faculty says something like “Please press the next button to move forward.”

A user starts in a virtual examination room with a pregnant patient on a patient bed on their right side (Figure 25). The application greets the user and explains the controls. Then the users go through the purpose of the Leopold’s Maneuvers and step-by-step preparation steps. The preparation steps consist of washing their hands, provision of privacy, verifying patient information, preparing the patient, and instructing the patient. In these steps, the users actually wash their hands in the virtual examination room, and talk to the patient using the provided script. After all these steps, they start the maneuvers process. While performing the maneuver, the user can palpate a virtual patient’s abdomen, view belly deformation on the touched area, and feel the fetal presence. The application provides two different visual modes (transparent vs. normal, Figure 28) allowing students to easily visualize position, presentation, and location of the fetus in utero. The transparent mode is like an x-ray which allows students to see the fetus movement through the belly. A supplemental video file has additional information about the application.

Figure 25. Third Person Point of View

Figure 26. User Point of View

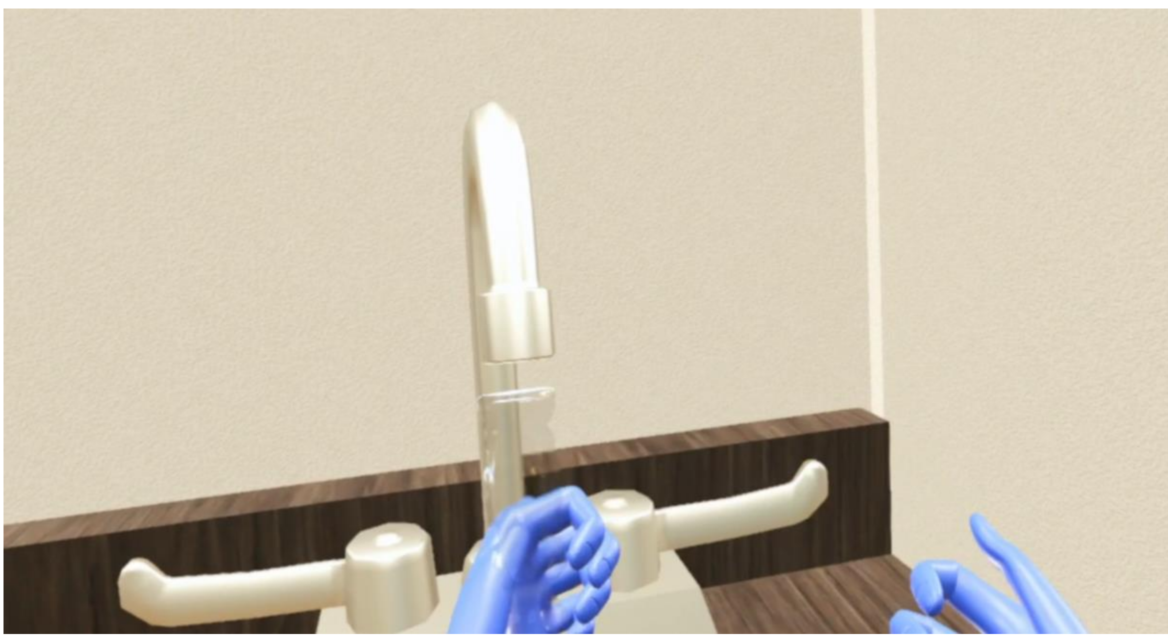

Figure 27. Washing Hands

Figure 28. Two different Visual Modes

4.1.6. Haptic Interaction Design

To evaluate the effectiveness of haptic devices, three types of haptic devices were utilized, VIVE controllers, *SenseGlove*, and Custom-made Vibration Gloves.

Figure 29. Haptic Devices

SenseGlove

By utilizing the *SenseGlove* in *Leopold's Maneuvers VR*, users can physically feel the difference between mother's abdomen and the fetus and interact with VE directly with their hands like they do in real life. *SenseGlove* enables users to feel the shape and stiffness of the fetus and virtual patient's abdomen. To create a realistic sensation of haptics, we applied varied force-feedback intensity (0-100%) to each material in the Unity environment to establish a distinction between hard and soft materials. 50% of force intensity was applied to the belly surface, while 90% of force was applied to the fetus, making it feel "harder".

Custom-made Vibration Gloves

We applied varied vibro-tactile intensity to each material to differentiate between hard and soft materials. 60% of vibration intensity was applied to the belly surface, while 95% of vibration was applied to the fetus. By providing vibration on the palm, the users can feel the virtual objects in a more dynamic and immersive way.

VIVE Controller

We applied the same vibro-tactile intensity as the custom-made vibration gloves. The vibration intensity was set to the same level as the custom-made vibration glove. 60% of vibration intensity was applied to the belly surface, while 95% of vibration was applied to the fetus.

4.2. Methods

4.2.1. Institutional Review Board Approval

This study has been approved by institutional Review Board (IRB) and the IRB study number is: IRB2020-1531D. Before taking part in this user study, all participants were asked to provide informed consent before their participation in this user study.

4.2.2. Sample Selection and Recruitment

Participants who were eligible to participate in this user study were students who were enrolled at Texas A&M University College of Nursing. Any prior experience with Leopold's Maneuvers, VR, or haptic technology was not required. To recruit Texas A&M University College of Nursing students, the first thing we did was get approval from the Dean. After getting the approval, participant recruitment was done. A faculty member from the College of Nursing, who is also a co-investigator in this research, distributed a recruitment email to students from Texas A&M University College of Nursing campus at Bryan and Roundrock. The email highlighted that participating in this user study would have no effect upon their grade and would be entirely voluntary.

4.2.3. Study Design

A within-subject study was conducted to evaluate the effectiveness, acceptability, and usability of a haptic-enabled VR simulation, as well as the satisfaction and confidence of participants. The independent variable is the haptic devices (VIVE Controllers (VC), *SenseGlove* (SG), and the combination of the *SenseGlove* and the Vibration Gloves (SGVG)) and the dependent variables are the Knowledge Test (KT), Presence Questionnaire (PQ), and User Experience Questionnaire (UEQ). Participants took part in each condition of the independent variable. A counterbalanced design was used with (n = 6) students utilizing first the SG, then SGVG, and VC, and (n = 7) students utilizing first SGVG, then SG, and VC in order.

The following hypotheses were tested, separated into 2 primary axes:

Sense of Presence (SP)

SP01. The sense of presence is higher when using SG than using VC.

SP02. The sense of presence is higher when using SGVG than using SG.

Knowledge (K)

K01. *Leopold's Maneuvers VR* will increase the knowledge of Leopold's Maneuvers.

4.2.4. Survey Instruments

The survey instruments utilized to collect data from participants included presence questionnaire (PQ), User Experience Questionnaire(UEQ), and Knowledge Test (KT). The questionnaires were provided on a secured laptop.

PQ. The sense of presence experienced by participants was measured using a presence questionnaire from Witmer & Singer (1998). The questionnaire was completed after the study and participants rated their experience on a 5-point Likert scale. According to Witmer & Singer's theory, the instrument is divided into four factors: Control Factor (CF), Sensory Factor (SF), Distraction Factor (DF), Realism Factor (RF).

UEQ. The questionnaire was designed to assess the acceptability and usability of the system. Participants completed the questionnaire after the activity and rated on a 5-point Likert scale. The questions included investigating the user's perspective in comfortness, flow, clear, useful, and quality of learning.

KT. The test was designed to evaluate participants' understanding of Leopold's Maneuvers. Participants completed the same test which consisted of four multiple-choice questions before and after the study. Each question had four options, with 1 point given for each correct answer and no points for incorrect answers. As a result, the total score ranged from 0 to 4 points. The test was validated by a professor from Texas A&M University College of Nursing, as well as a committee member for the study facilitator. As a measure of learning gain, the difference between the pretest and the posttest was used.

4.2.5. Procedure

All participants were given 60 minutes maximum to complete the activities of the user study. The study facilitator sanitized equipment before participants entered the meeting space where the user study took place. The hand sanitizer was also placed in the meeting space to prevent infection from surfaces. Upon arrival, participants were greeted at the meeting space and were given the printed informed consent form. The study facilitator explained the contents of the form and allowed the participants to read the form, ask any questions they had, and sign on it. To secure all participants' identity and the data collected throughout the study, each participant was issued a unique identification (ID) number. After that, the participant was asked to complete a pre-activity questionnaire that was provided on a secured laptop. The questionnaire included a set of demographic questions, a set of Likert scale questions, and a short quiz with 4 questions to evaluate the students' understanding of Leopold's maneuvers.

Following the completion of the questionnaire, the research facilitator gave the participant a quick overview of the haptic devices they will be utilizing throughout the study. Then, the facilitator handed over the haptic device. Then they were given a disposable face cover mask and a head-mounted display (HMD).

Study 2 consisted of two sessions. The participants began by warming up to familiarize participants with the haptic devices and to assist them understand what forms of haptic input they will receive. The participants were free to touch and feel the balls for as long as they wanted. After the warm-up, the participants were placed in a virtual examination room where they would learn about the Leopold's Maneuvers and perform the maneuvers on a virtual patient. The participants went through the purpose of the Leopold's Maneuvers, step-by-step preparation steps, and learned and performed the maneuvers on the virtual patient. At the end of the activity, with their HMD put on, the study facilitator handed over different haptic devices and the participants were asked to palpate the patient's abdomen. After that, they completed a post-activity questionnaire and a brief interview.

Figure 30. Study 2 Participant

4.3. Results

4.3.1. Participants

Thirteen (n = 13) students from Texas A&M University College of Nursing volunteered to participate in the study. A counterbalanced design was used with (n = 6) students utilizing first the SG, then SGVG, and VC, and (n = 7) students utilizing first SGVG, then SG, and VC in order.

Participants were aged 18-24 (61.54%, n = 8), 25-30 (30.77%, n = 4), and 31-35 (7.69%, n = 1). More than half of the participants (61.54%, n = 8) had not taken the NURS 323 Care of Women, Families and Newborns course and had not learned Leopold's Maneuvers (69.23%, n = 9). One of the participants was enrolled in the NURS 323 course but had not learned the Maneuvers yet. 76.92% (n = 10), the majority of the participants responded that they were not familiar with Leopold's Maneuvers, 15.38% (n = 2) of the participants were familiar, and 7.69% (n = 1) of the participants were very familiar. Among 4 participants who learned Leopold's Maneuvers before were asked how they learned the maneuvers and they selected all of the options that applied. Two responses were learnt via a didactic lecture, two responses from a book, three responses from video, and one response was learned from virtual reality. When asked if they have used VR before 76.92% (n = 10) of the participants said "Yes" and 23.08% (n = 3) said "No". They had experience with VR in education, game, socializing, and training/simulation. When asked if they have experienced haptic devices before, 38.46 % (n = 5) said "Yes" and 53.85% (n = 8)" said "No". 53.85% (n = 7) of the participants were not familiar with haptic technology, 38.46% (n = 5) were familiar, and 7.69% (n = 1) were very familiar. They mostly experienced vibration on their mobile phone, the wearable devices, and the game controllers.

Variable	**n**	**%**
Age		
18-24	8	61.54
25-30	4	30.77
31-35	1	7.69
Taken NURS 323		
Yes	5	38.46
No	8	61.54
Leopold's Maneuvers Learning Experience		
Learned Leopold's Maneuvers (LM)		
Yes	4	30.77
No	9	69.23
Familiarity with LM (M = 1.6, SD = 1.07)		
Not familiar	10	76.92

Familiar	2	15.38
Very Familiar	1	7.69
LM Learning Tool		
Didactic Lecture	2	
Book	2	
Video	3	
Virtual Reality	1	
Mobile Application	0	
VR Experience		
Used VR		
Yes	10	76.92
No	3	23.08
Kind of VR		
Education	5	33.33
Game	6	40
Socializing	1	6.67
Conference/Meeting	0	0
Training/Simulation	4	26.67
Haptics Experience		
Used Haptics		
Yes	5	38.46
No	7	53.85
Familiarity with Haptics (M = 2.23, SD = 1.01)		
Not familiar	7	53.85
Familiar	5	38.46
Very Familiar	1	7.69
Kind of Haptics		
Mobile Phone (Vibration)	5	31.25
Game Controller (Vibration)	4	25
Wearables	5	31.25

(ex. smart watch)		
AR/VR Device (ex. VR controller)	2	12.5

Table 3. Study 2 Participants Demographics

4.3.2. Presence Questionnaire

Participants were asked to rate the questions mentioned below in Table 4 on a 5-point Likert scale and the results are shown in Figure 31. The presence questionnaire contained 8 questions, 1 CF question, 3 SF question, 1 DF question, and 3 RF question. Each SF and RF factor items were analyzed together as a total.

SP01. The sense of presence is higher when using SG than using VC. The results show that SG has a higher sense of presence than VC for all four factors.

SP02. The sense of presence is higher when using SGVG than using SG. The results show that SG has a slightly higher sense of presence in total.

Question	Factors
How well could you move or manipulate objects in the virtual environment?	CF
How completely engaged were all of your senses?	SF
How natural did your interactions with the environment seem?	SF
How engaging was the experience?	SF
How much sense of "being there" did you get in the virtual examination room?	RF
To what extent were there times during the experience when the computer-generated world became the "reality" for you, and you almost forgot about the "real world" outside	RF
The haptic feedback was realistic.	RF

Table 4. Presence Questionnaire

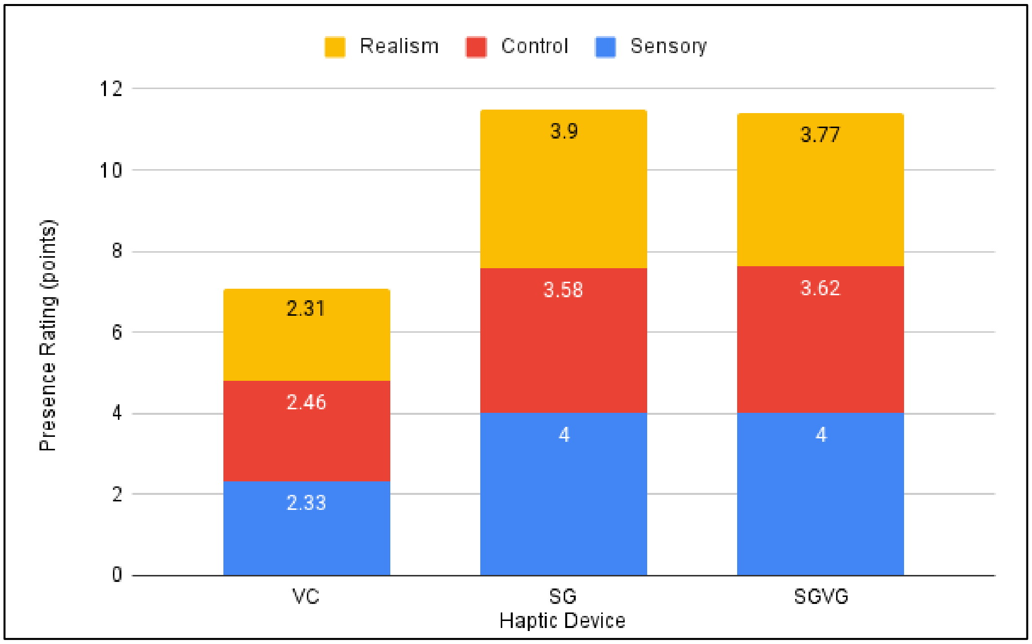

Figure 31. Presence Questionnaire Results

4.3.3. Simulator Sickness Questionnaire

Participants responded to the SSQ on a 5-point Likert scale (1- Not at all, 5- Very much). Overall, the majority of the participants did not have any problem during the experience. However, two of the participants who rated high on general discomfort, difficulty concentrating, and difficulty focusing, claimed they were uncomfortable wearing the HMD and the haptic gloves. One of them also mentioned that maybe it was either their first time using the VR or they were too immersed in the virtual environment, watching the demonstration video was hard to listen to and hard to process.

Question	Factors
General Discomfort	Nausea
Nausea	Nausea
Difficulty Concentrating	Nausea
Difficulty Focusing	Nausea
Fatigue	Oculomotor
Difficulty Focusing	Oculomotor

Vertigo (Feeling of uneasiness)	Disorientation

Table 5. Simulator Sickness Questionnaire

Factors	**n**
Nausea	1.52
Oculomotor	1.54
Disorientation	1.31

Table 6. Simulator Sickness Questionnaire Results

4.3.4. Knowledge Test

To assess if *Leopold's Maneuvers VR* assisted the participants in learning the Maneuvers process, participants completed the same four-question questionnaire before and after the activity. The individual test results show that the majority of participants' knowledge improved, and their overall knowledge improved by 26.96% after learning and performing via *Leopold's Maneuvers VR*.

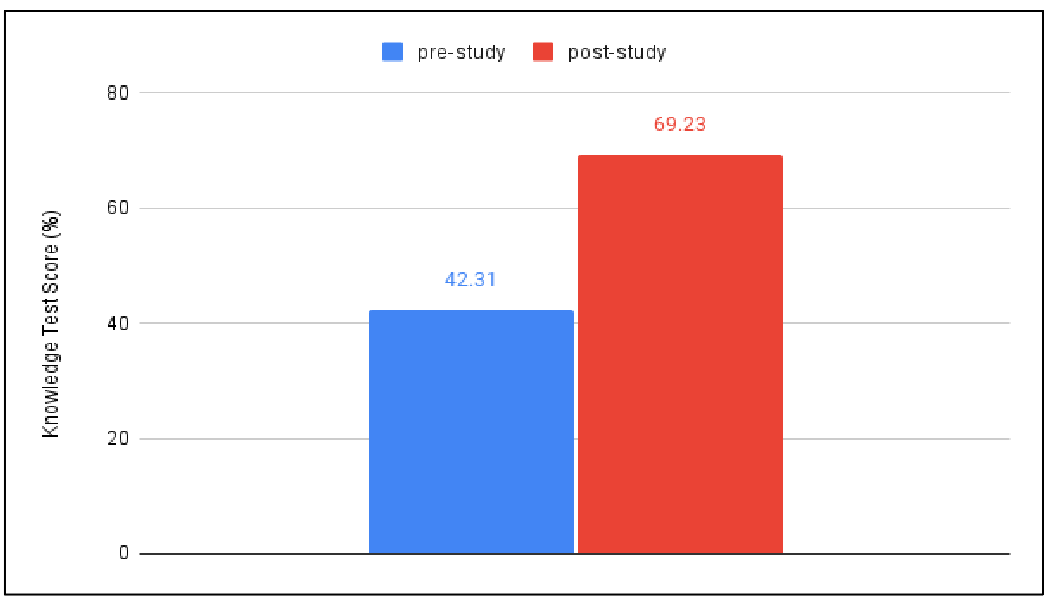

Figure 32. Knowledge Test Results

4.3.5. General Experience

Haptic Feedback

When asked to rate "Do you feel as if the haptic feedback from the virtual environment in response to your actions was clear?" and "Do you feel as if the haptic feedback from the virtual environment in response to your actions was useful in helping you perform the task?" On a 5-point Likert scale, overall rating for each glove was 3.58 for SG, followed by 3.5 for 3.58, and 2.31 for VC.

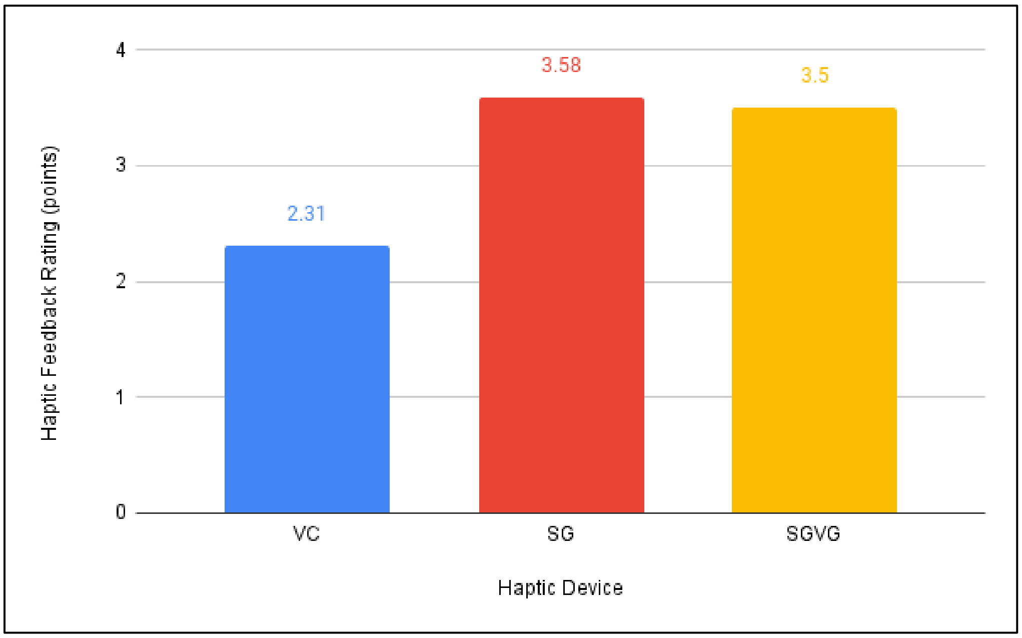

Figure 33. Haptic Feedback Rating

Preference

When asked to pick their favorite haptic devices 61.5 % (n = 8) picked SGVG and 38.5% (n = 5) picked SG. When asked to pick their least favorite haptic devices, 100% (n = 13) picked VC.

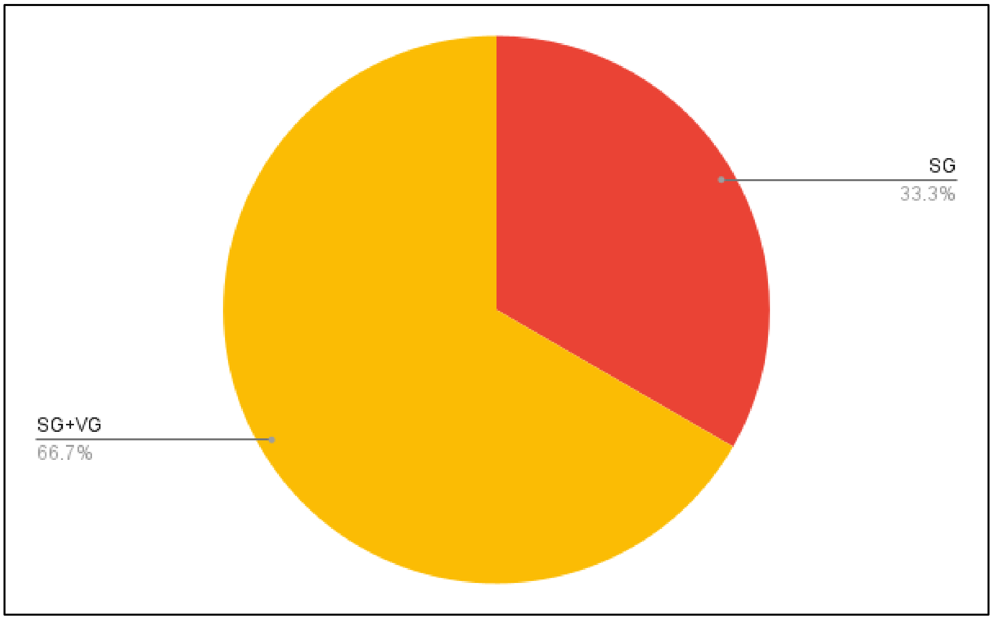

Figure 34. Haptic Device Preference

The reason why the participants liked SGVG the most was because enabling vibration on their palm made it feel the abdomen and the fetus better. Below are some of the verbal comments the participants provided during the interview:

"(SGVG) Gives more sense of feeling in your palm, not just your fingers. (User ID: P3)"

"It did feel more like my whole hands were being used instead of going against pressure with my fingers.(User ID: P4)"

"More feedback the better. Only the SG didn't do anything for me.(User ID: P6)"

"I felt like I could feel more with the vibrations enabled.(User ID: P7)"

"Both (SGVG) helped me to learn the maneuver better. (User ID: P9)"

"It just felt more real. It felt like you could feel the blood basically coursing through the mother and the baby. (User ID: P11)"

"It was like you were actually touching something and then the vibration helped me palpate more I guess. (User ID: P12)"

"Because you're supposed to palpate with your palm. (User ID: 13)"

The reason why the participants picked SG as their most favorite device was because the feeling of the vibration felt unnatural and made it difficult to feel the force feedback. Below are some of the verbal comments of the participants provided during the interview:

"It's way more natural to move my hands and stuff. Because it just went with how you actually moved your hand. So I prefer that.(User ID: P2)"

"Being able to move your fingers is important. VG made it more difficult for me to distinguish between different areas of her abdomen.(User ID: P5)"

"When VG was turned on, I couldn't tell which finger was getting feedback. It messed with my sense of being able to tell where the baby was because my whole hand was vibrating. I feel like it was just an interference instead of helping. (User ID: P10)"

The reason why all the participants picked VC as their least favorite was because VC was unnatural, made it hard to manipulate their hands, and not interactive. Below are some of the verbal comments participants provided during the interview:

"They don't feel like as natural because I was just holding them. (User ID: P1)"

"Harder to manipulate my hands to do exactly what I wanted them to.(User ID: P2)"

"Confusing and it didn't feel as real.(User ID: P3)"

"All I could do was pet the patient. If it was just playing a game it would be good. (User ID: P4)"

"Not being able to move your fingers doesn't feel natural. (User ID: P5)"

"Didn't feel like you were touching the body. You just feel the vibrations so it feels like a game. Not realistic. (User ID: P7)"

"Didn't feel realistic as to how it would be palpating the patient in the video. Awkward. I didn't get the actual hands on experience of my own hands. (User ID: P8)"

"It definitely didn't feel as real as using the gloves.(User ID: P9)"

"Didn't really understand what was going on. Tried to figure out how to hold the controller to put my hands on the patient. (User ID: P10)"

"It didn't feel as natural. It just felt like I was playing with game controllers rather than having the use of my hands. (User ID: P11)"

"It felt like I was just holding sticks. It didn't feel like I was touching anything. It was like me just pointing the controller towards the belly. (User ID: P12)"

X-Ray Mode vs Normal Belly Mode.

When asked to pick their preference between normal belly mode and x-ray mode, 81.25% (n = 13) picked x-ray mode and 18.8% (n = 3) picked normal belly mode. Among these results, three participants picked both.

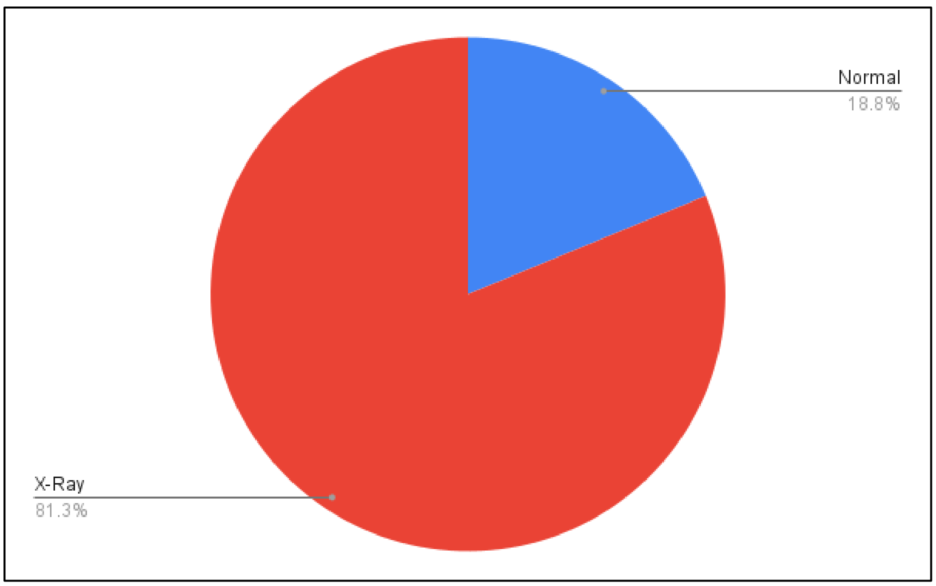

Figure 35. Visual Mode Preferences

The reason why they preferred x-ray mode over normal mode were:

"That helped me understand why it was different in certain places. (User ID: P1)"

“It was helpful getting to see the X ray of the baby and seeing how the belly moves when you're doing your exam.(User ID: P5)”

“It helped me see where the baby was. That way I could see where I was palpating if I was doing it in the right way.(User ID: P7)”

“It was really helpful and a lot better because I didn't really understand how the baby was inside until I saw that. I was just pushing around but I didn't really see it in my head.(User ID: P8)”

“It was really helpful when turned on.(User ID: P9)”

“It helps to see what I was really trying to feel there. Even if I didn't understand what I was feeling, then I could be like "Okay, here's what I'm supposed to be feeling”(User ID: P10)”

“I think it's good to practice the maneuvers first without seeing it. And then just to verify if you are correct in your assumption of where the fetus was to use the X ray mode after that.(User ID: P11)”

“I haven't taken LMDB before anything yet. So I just looked at the belly and I really didn't know the position of where the baby was. But when you put the X-ray modes on, it was really nice to see, like the layout of how it was and where the fetus was. Touching and palpating the belly, it felt a little bit better.(User ID: P12)”

"I could see what was like in the abdomen where the baby was supposed to be and it helped me visualize where you want your hands.(User ID: P13)"

The reason why three of the participants picked both of the visual modes were:

"I liked that you were able to have both options. Because it was nice feeling the stomach before and just trying to see if I could feel the feelings that the narrator was describing. But then it was nice to be able to see "Oh, this is how the baby is it maybe? Oh, their shoulders over here." So this is what this would feel like, kind of thing. So I liked both options. (User ID: P2)"

"It was kind of cool to try and guess first and then turn the X ray on because then you saw what you were trying to feel. And it gave you a good visual. So I liked that. That was like, my favorite parts turned on. Okay, that was the back. So it was good. (User ID: P3)"

"Normal belly mode was helpful in that because it's so realistic. With Leopold's in particular and you're just completely blind. With X-Ray mode, it helps educationally. I could see the baby and understand what was happening under the belly. (User ID: P4)"

4.3.6. User experience with *Leopold's Maneuver VR*

In the post-activity questionnaire, a series of 5-point Likert scale questions were asked in regards to the usability and acceptability of *Leopold's Maneuver VR*. The responses were overall positive and can be seen in Figure 36 and Table 7 below.

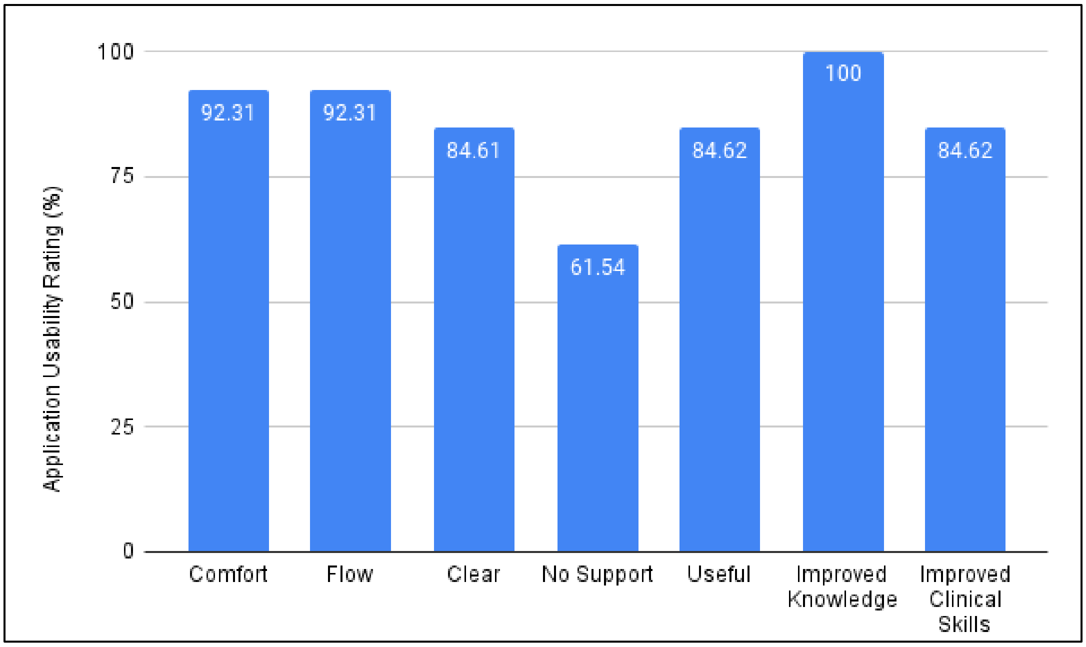

Figure 36. Application Usability and Acceptability Rating

Question/Likert Scale		Percentage of Participants who said "Strongly Agree"	Percentage of Participants who said "Agree"	Percentage of Participants who said "Neutral"	Percentage of Participants who said "Disagree or Strongly Disagree"
I felt comfortable interacting with the virtual patient.	M = 4.46 SD = 0.63	53.85% (n = 7)	38.46% (n = 5)	7.69% (n = 1)	0%
The flow and user interface of the application is intuitive and easy to follow.	M = 4.46 SD = 0.84	61.54% (n = 8)	30.77 (n = 4)	0%	7.69% (n = 1)
The instruction given by Leopold's Maneuver VR was clear and provided in an easy format.	M = 4.46 SD = 0.93	69.23% (n = 9)	15.38% (n = 2)	7.69% (n = 1)	7.69% (n = 1)
I felt very confident using the app.	M = 3.77 SD = 0.89	23.08% (n = 3)	38.46% (n = 5)	30.77% (n = 4)	7.76% (n = 1)
I would need support to be able to use this app.	M = 3.00 SD = 1.30	15.38% (n = 2)	23.08 % (n = 3)	23.08 (n = 3)	38.46% (n = 5)

Leopold's Maneuver VR is useful for learning about how to assess pregnant women.	M = 4.38 SD = 0.74	53.85% (n = 7)	30.77% (n = 4)	15.38% (n = 2)	0%
Leopold's Maneuver VR is a useful tool for learning Leopold's Maneuver skills.	M = 4.46 SD = 0.63	53.85% (n =7)	38.46% (n = 5)	7.69 (n = 1)	0%
Using Leopold's Maneuver VR improved my knowledge.	M = 4.54 SD = 0.50	53.85% (n = 7)	46.15% (n = 6)	0%	0%
Using Leopold's Maneuver VR in the future will help improve my clinical skills.	M = 4.62 SD = 0.62	69.23% (n = 9)	23.08% (n = 3)	7.69% (n = 1)	0%
Leopold's Maneuver VR improved my clinical skills.	M = 4.38 SD = 0.74	53.85% (n = 7)	30.77 (n = 4)	15.38% (n = 2)	0%
I perceive that the system actually helped me in performing the tasks.	M = 4.15 SD = 0.77	38.46% (n = 5)	38.46% (n = 5)	23.08 % (n = 3)	0%

Table 7. User Experience Test Results

Below are some of the verbal comments regarding their experiences provided from the participants during the interview:

"I really liked it. It was really helpful because we're learning the LM in class and actually be able to do it with our hands. The interaction was smooth and clear. (User ID: P1)"

"My experience was really good. The VR world was super realistic so when I took off the headset I was like "Oh, I forgot I was in this room". I had a good time and I definitely learned a lot. Step by step instructions of how to do the assessment and then the video was helpful. (User ID: P2)"

"It was pretty cool. Definitely the environment looked really realistic. (User ID: P5)"

“It was good. It was a little confusing at first because I've never done any of that stuff before and I've never seen it. I was confused on what I was supposed to be doing and what I was supposed to be. A lot better than just the simulations we worked on computers because it feels like you're actually there.(User ID: P7)”

“I thought it was really cool. I thought it was intuitive. I felt like I was actually doing the thing. It was really useful. I felt like I was in the room because all my senses were engaged. (User ID: P13)”

5. CONCLUSIONS AND FUTURE PLANS

5.1. Conclusions

The purpose of this project was to develop *Leopold's Maneuvers VR*, a haptic-enabled virtual reality simulation that provides immersive and engaging learning experiences. The use of haptic gloves enabled nursing students to manipulate the virtual patient's abdomen with their hands, allowing them to touch and feel the virtual patient's abdomen. We conducted two user studies; study 1 was to investigate the haptics' effectiveness and usability, and study 2 was to investigate the effectiveness of *Leopold's Maneuvers VR* application.

Study 1 was conducted with 22 subjects, who had to guess the objects' sizes, shapes, and hardness. Our findings from Study 1 are: (1) Conditions with SG had a high level of sense of presence than those without SG: SGVG showed the highest sense of presence in post-survey rankings, followed by SG, VG, and VC. (2) SG showed the highest task performance in task 1 , guessing the sizes, followed by SGVG, VC, and VG. (3) In contrast to our expectations, VC outperformed in task 2 and 3, respectively, guessing the shapes and hardness. (4) VG showed the lowest task performance in all three tasks.

Based on the findings of Study 1, three haptic devices, VC, SG, and SGVG, were utilized in Study 2. Study 2 was conducted with 13 subjects, who experienced *Leopold's Maneuvers VR* application. Our findings from Study 2 are: (1) SG provided the highest level of presence in post-survey rankings, followed by SGVG and VC. However, the result demonstrates that SG and SGVG provided almost the same level of presence. (2) Knowledge assessments conducted before and after the activity revealed that the 70% participants showed an improvement in their knowledge about Leopold's Maneuvers. 9 of the participants' knowledge improved, 2 of them remained the same, and 2 of them decreased. Overall, though, knowledge increased by 29.69%. (3) Qualitative feedback from the participants demonstrated the *Leopold's Maneuvers VR* application could be a useful learning tool.

In conclusion, the findings clearly suggest that using force feedback instead of only vibrotactile feedback could improve the sense of presence. SG gives more immersive and realistic sensations than VC, which provides unnatural experiences similar to grasping a stick and feeling vibrations.

Furthermore, haptic-enabled VR simulation not only provides immersive and embodied learning experiences to students but also improves their knowledge.

The main limitations of this study would be first, the small sample size. The number of participants who took part in Study 1 was 22, while the number of participants who participated in Study 2 was 13. Some of the analyses did not yield significant results, thus limiting the insights from this study. Second, heavy and bulky equipment. Head-mounted display (HMD) and *SenseGlove* are both somewhat heavy, which may make the participants feel uneasy and tired. These could have had an impact on the user experience. During the user interviews, some participants stated that their wrists became tired over time and that the HMD generated general discomfort, making it difficult for them to concentrate. Last but not least, technical issues. We ran into a number of technical problems while conducting the study. The custom-made vibration glove had trouble interacting with Unity, which created the significant problems. Some participants' participation in the study was delayed due to technical challenges, which may have influenced the user experience.

5.2. Future Plans

We intend to use the data and feedback gathered from this research to improve the *Leopold's Maneuvers VR* application. One of the improvements could be implementation of the audio feedback. The app includes audio elements such as narration to guide the user throughout the experience; however, audio feedback is not implemented, which is one of the feedback options that could improve the immersion and engagement. Possible implementation of the audio feedback could be the reaction of the virtual patient. For example, during the preparation stage, when the user asks the virtual patient for their name and date of birth, the current app just shows the speech bubble with the information. Furthermore, a larger sample size and enhanced application could be used in a future user study to generate statistically meaningful results.

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