USER COGNITION OF HAPTIC/TACTILE STIMULATION IN TELEMEDICINE SETTINGS

An Undergraduate Research Scholars Thesis

by

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Submitted to the LAUNCH: Undergraduate Research office at
Texas A&M University
in partial fulfillment of requirements for the designation as an

UNDERGRADUATE RESEARCH SCHOLAR

Approved by
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May 2022

Major: Computer Engineering (Electrical Track)

RESEARCH COMPLIANCE CERTIFICATION

Research activities involving the use of human subjects, vertebrate animals, and/or biohazards must be reviewed and approved by the appropriate Texas A&M University regulatory research committee (i.e., IRB, IACUC, IBC) before the activity can commence. This requirement applies to activities conducted at Texas A&M and to activities conducted at non-Texas A&M facilities or institutions. In both cases, students are responsible for working with the relevant Texas A&M research compliance program to ensure and document that all Texas A&M compliance obligations are met before the study begins.

I, Mihir Hingwe, certify that all research compliance requirements related to this Undergraduate Research Scholars thesis have been addressed with my Research Faculty Advisors prior to the collection of any data used in this final thesis submission.

This project did require approval from the Texas A&M University Research Compliance & Biosafety office.

TAMU IRB #: 2019-0230D Approval Date: 03/31/2022 Expiration Date: 01/27/2023

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ABSTRACT

User Cognition of Haptic/Tactile Stimulation in Telemedicine Settings

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With the ongoing pandemic, telemedicine is being used more than ever before. However, physicians are unable to conduct soft tissue physical examinations when they are meet with their patients remotely. To assess this limitation, we propose a soft tissue physical examination procedure using wearable haptic gloves which will allow a physician to perform physical examinations remotely with the help of a nurse.

Our sense of touch is active and the haptic gloves in our proposed procedure utilizes passive tactile feedback. This may result in the physician not being able to fully comprehend the tactile stimulation they receive from the wearable device. A potential workaround is to use have the physician appropriate the nurses' remote hands using the Rubber Hand Illusion. In this study, the proposed procedure is simulated using an XY table developed to administer passive haptic/tactile feedback to a user. Users' abilities to perceive objects within their own

environments using both an active and passive mode of sensing is tested as well as the current ability of the experimental components to induce the Rubber Hand Illusion.

After completing the initial set of experiments, we concluded that there is a significant performance difference between active and passive exploration highlighting the importance of researching the potential link between embodiment and improved passive touch perception. Additionally, the results gave us some insight on what improvements are needed to better simulate the proposed physical examination procedure. Based on these results, we can improve our equipment and determine if embodiment using the Rubber Hand Illusion can improve a users' cognition of passive tactile/haptic stimulation in a future study.

ACKNOWLEDGEMENTS

Contributors

I would like to thank my faculty advisor Dr. Shinjiro Sueda, Dr. Fracis Quek, Dr. Cynthia Hipwell and Dr. Rebecca Friesen, for their guidance and support throughout the course of this research.

Thanks also go to my friends and colleagues and the department faculty and staff for making my time at Texas A&M University a great experience.

Finally, thanks to my teammates at the INVENT lab Nick Baetas, Nick Smotherman and Danny Volipi for their help conducting the study.

The data analyzed/used for the Exploration of Remote Environments Using the Rubber Hand Illusion were provided by Mihir Hingwe, Nick Baetas and Danny Volipi. The analyses depicted in were conducted in part by the TAMU Embodied Interaction Laboratory and INVENT Laboratory and these data are unpublished.

All other work conducted for the thesis was completed by the student independently.

Funding Sources

No additional funding was provided.

NOMENCLATURE

BTI	Body Transfer Illusion
RHI	Rubber Hand Illusion
POV	Point of View

1. INTRODUCTION

Recent advancements in telepresence technology and the ongoing pandemic have made drastic impacts on the way we communicate and work. Schools, companies, and other institutions have used virtual conference programs such as Zoom or Microsoft Teams to communicate with employees and students and improve productivity despite the increased restrictions.

During the pandemic, there has also been an increase in the use of telemedicine to reduce the contact between physicians and patients and bring medical care to remote areas. The interest of telemedicine technology can be seen through government actions such as the executive order that was signed on Aug. 3rd, 2020 which brought telehealth care to remote rural communities across the United States [20]. However, with current state of telemedicine technology, there is no way for physicians to accurately conduct physical examinations of patients [13][14]. Without these examinations, physicians are unable to properly identify and diagnose certain illnesses.

In recent years, there has been a lot of research using robotics in medical settings [12][18][19]. From surgical robots, to robots specialized in taking care of the elderly, it may seem that robotics is the best option to improve the practicality of telemedicine. However, the acceptance of medical robots has been shown to vary based on a patient's previous exposure to the technology and their cultures acceptance of robotics technology. For example, a patient who was raised in Japan, where robots are commonly seen in pop culture, will be more accepting of robotics technology in medical settings versus someone raised in cultures where technology is less accepted [12]. While reviewing prior literature, there didn't seem to be any studies on users' acceptance of physical examinations using medical robotics in particular. However, it is safe to assume that patients will have more trust in medical professionals examining more vulnerable areas of their bodies such as their necks.

The goal of our project is to develop a procedure using haptic devices which would allow a physician, with the help of a nurse or other medical practitioner, to remotely conduct accurate soft tissue physical examinations. This should reduce the overhead of purchasing expensive technology and add a human element to the examination.

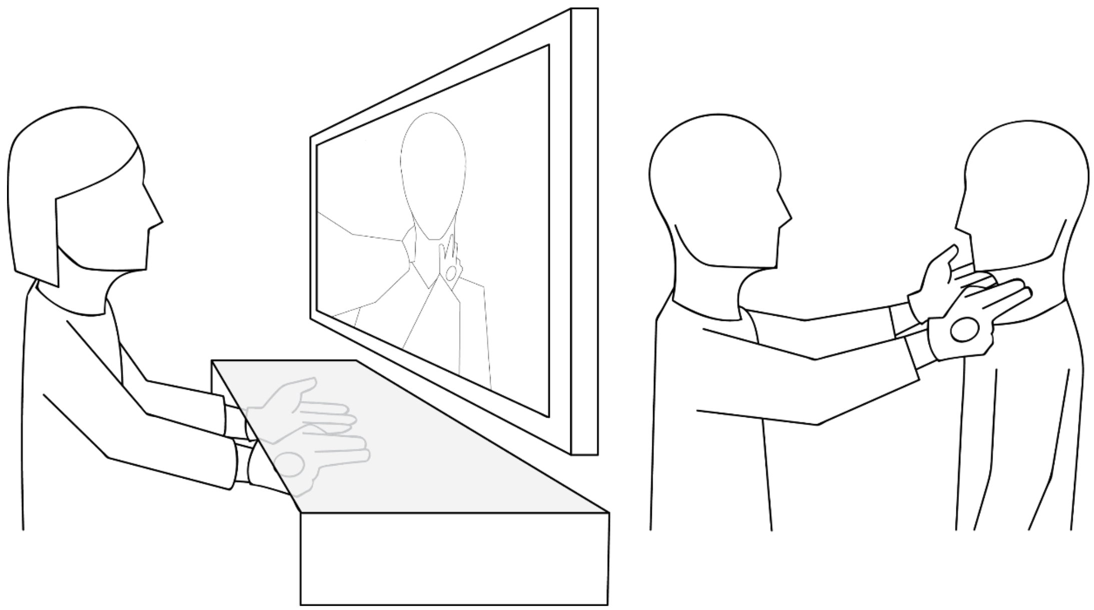

Figure 1.1: The proposed procedure which would allow physicians to perform soft tissue examinations remotely in telemedicine applications. Image provided by Peter Quek.

Our proposed setup is shown in Figure 1.1. The physician, on the left, and nurse, on the right, are both wearing haptic glove devices which would allow the physician to receive haptic feedback based upon the movements of the nurse's hands.

With the current proposed procedure, the tactile sensation felt by the physician via the haptic glove devices is passive. This is problematic as haptic/tactile perception is usually active which means that the individual receiving tactile/haptic stimulation is in control of the sensing process thus improving their interpretation of the felt sensation [15][16][17]. A possible solution to this challenge is the use of the Rubber Hand Illusion (RHI) in order to give the physician a sense of ownership over the nurse's remote hand. The RHI is first explored by Botvinick and Cohen where a user appropriates a fake rubber hand by hiding their hand directly underneath the fake hand. The user's hand and the fake hard are then synchronously stimulated using a paintbrush resulting in the user obtaining a sense of ownership over the fake hand [21].

In Figure 1.1, the physicians' hands are hidden underneath the display while they see the nurse's hands thus mimicking the setup of the experiment. The setup should then induce the RHI and have the physician appropriate the nurse's hand. We hypothesize that the physician would then be able to interoperate the tactile stimulation received from the haptic glove devices as their own.

There are a plethora of scientific questions surrounding this hypothesis. Is there an improvement in a user's ability to perceive passive tactile feedback when they have a sense of ownership over remote hands? Do users' cognition over tactile stimulation decrease significantly when it is administered passively? Under what conditions is the RHI induced given the current setup and when does the illusion break? How do users explore objects actively and how can we implement this within our approach?

For the scope of this initial study, we seek to first demonstrate the need of using the RHI in our proposed soft tissue examination procedure and determine what improvements need to be made to the current experimental components described in the next section in order to induce the RHI for future experimentation.

2. METHODS

2.1 Experimental Components

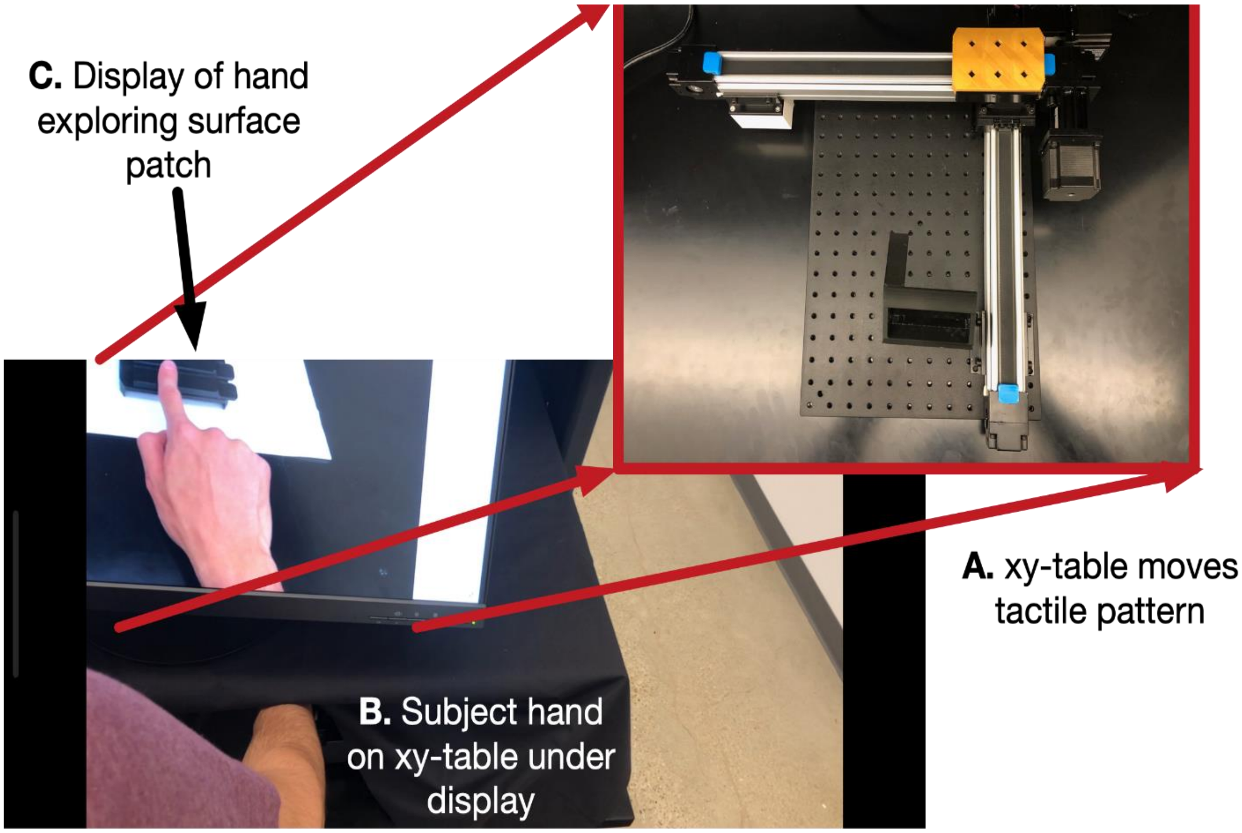

Figure 2.1: Experimental setup used to simulate the proposed soft tissue examination system.

To conduct the initial experimental studies, it would be impractical to design and develop the wearable haptic glove devices described in our proposed soft tissue examination procedure. Creating these devices would be expensive and very time consuming. For our initial studies, it would more practical to create a device which administers passive tactile feedback without using complicated sensors and electrical systems.

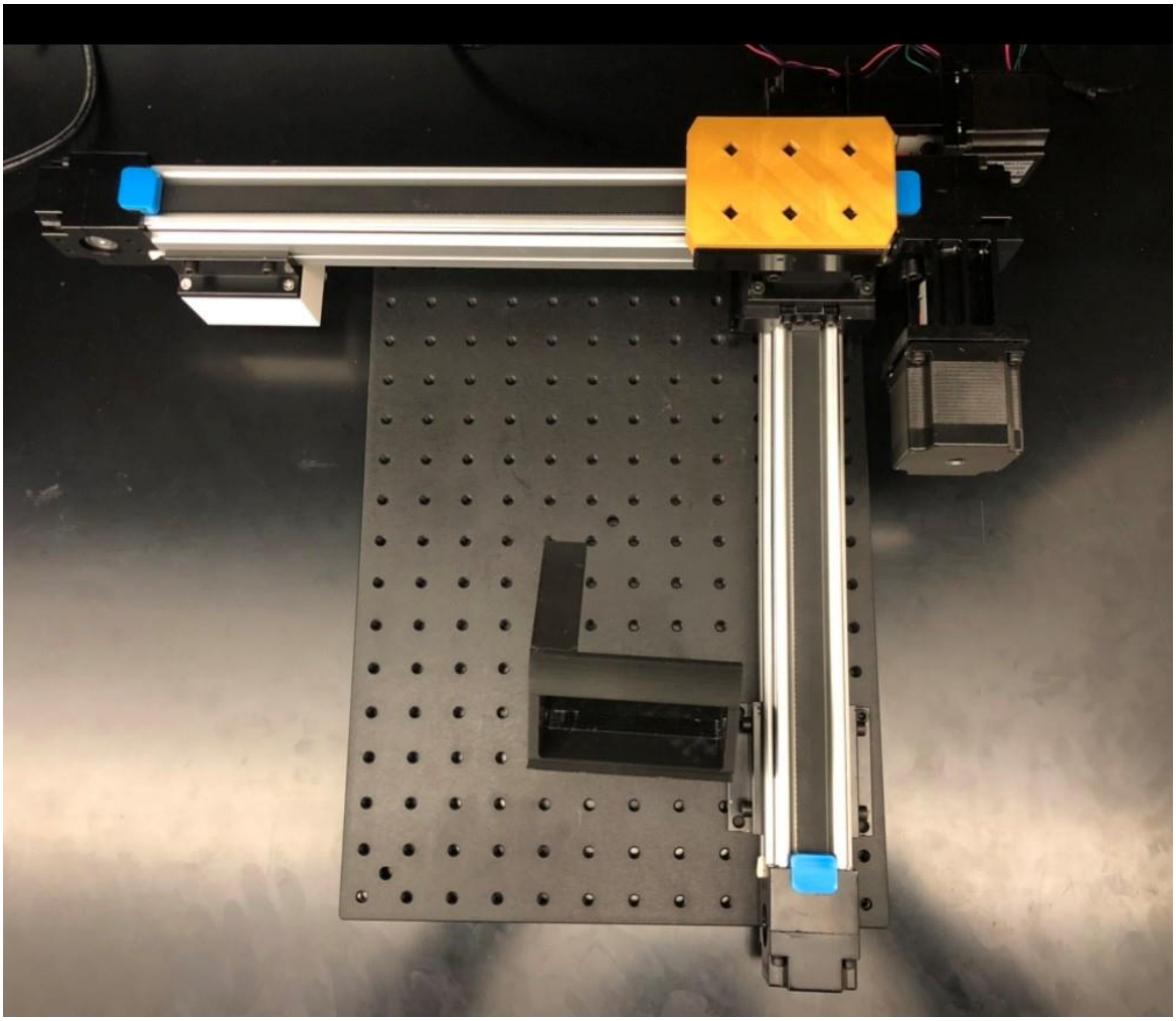

Figure 2.2: Top-down view of the XY table developed to simulate the feedback felt by the physician in our proposed soft tissue examination procedure.

The device used to simulate the passive tactile stimulation is a programmable XY table seen in Figure 2.1 and Figure 2.2. This device consists of two linear guide rail actuators controlled using a Raspberry Pi 4B. The Raspberry Pi 4B was chosen to control this device as it would allow us to remotely connect and program the desired movements onto the XY table at an affordable price.

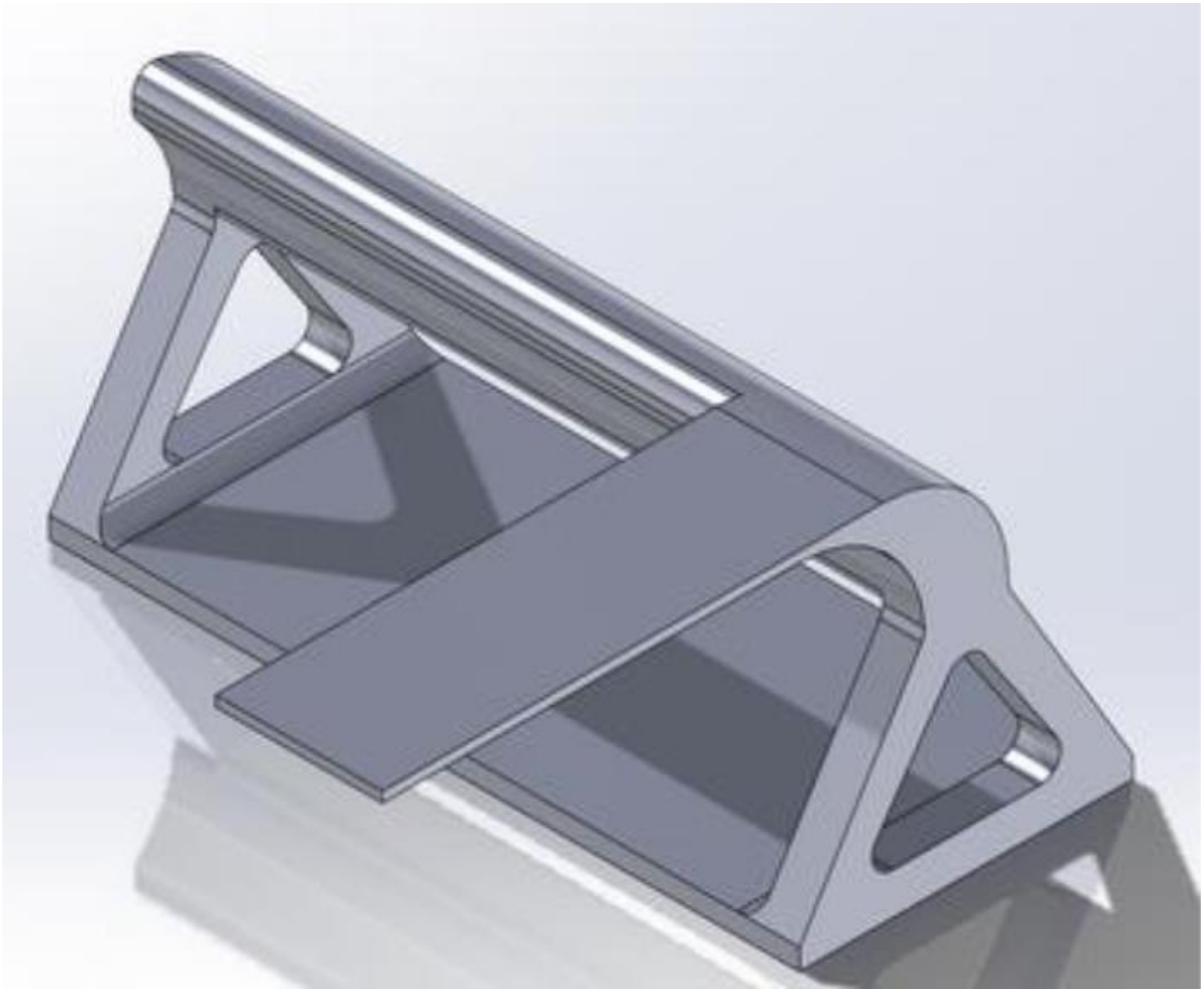

Figure 2.3: CAD model of the hand holder.

The XY table is connected to a heavy metal platform in order to reduce the vibration from the movement of the linear guide rail actuators. A hand holder (Figure 2.3) is also attached to the heavy base allowing users to comfortably rest their hands while isolating their index finger. The movement of the XY table would then allow a 3-D printed surface to move under the users' hand thus applying passive tactile stimulation to the isolated index finger. The device is placed underneath a wooden platform which allows the user to hide their hands. On top of the platform is a monitor which displays a video or image that the user can see.

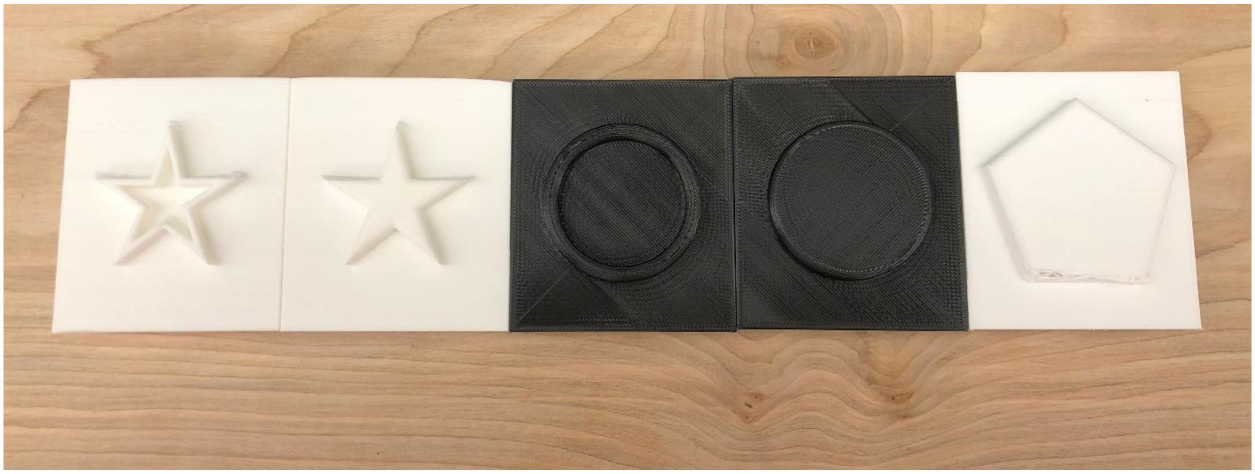

Figure 2.4: 3D Printed shapes used during the third experiment.

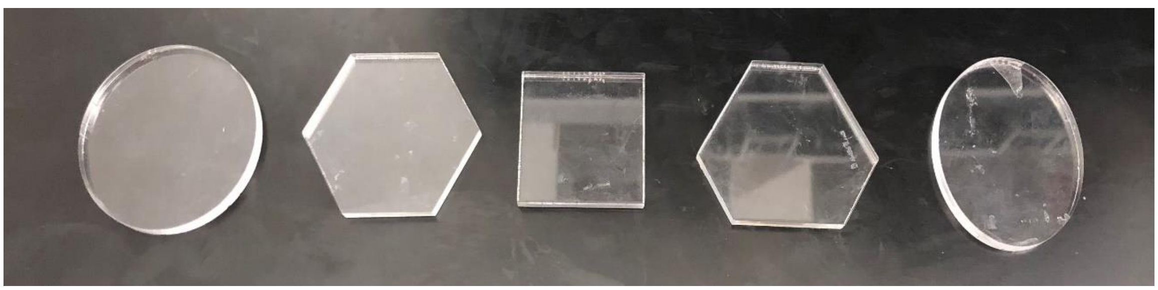

Figure 2.5: Laser cut shapes used for the active and passive touch experiments.

The tactile stimulation used during the initial experiments consisted of five 3D shapes as seen in Figure 2.4 and five laser cut 3-D shapes in Figure 2.5. The 3D printed shapes were rougher than the five laser cut shapes which allowed users to better feel the surface of these shapes when they were moved underneath the users' index finger with the XY table. The laser cut shapes are used during our first and second experiments in which we examine the difference between active and passive touch. The shapes chosen were printed to be similar to each other to determine users' abilities to distinguish small characteristics of objects when actively or passively sensing an object in their environment.

2.2 The RHI Paradigm

Previous research into the RHI has established a paradigm used by experimenters to have the greatest chances of inducing and quantifying the illusion during their experiments. The most important factors determining the strength of the RHI and its ability to occur in the first place are the positioning and shape of the fake hand, the congruency and synchroneity of the visuo-tactile stimulation, and certain personality traits of the user [1][2][3][4][5][6][7][8][9][10]. Furthermore, research has shown that depending on combination (visuo-tactile, visuo-motor, etc) of senses used to induce the illusion, can determine the strength of ownership and the sense of agency over the fake hand [1][2][3][4][5][6][10]. However, for the scope of this project, we were focused on determining if the experimental setup shown in Figure 2.1 satisfied the shape, positioning, congruency and synchroneity requirements of the paradigm.

2.3 Experiment 1: Active Touch

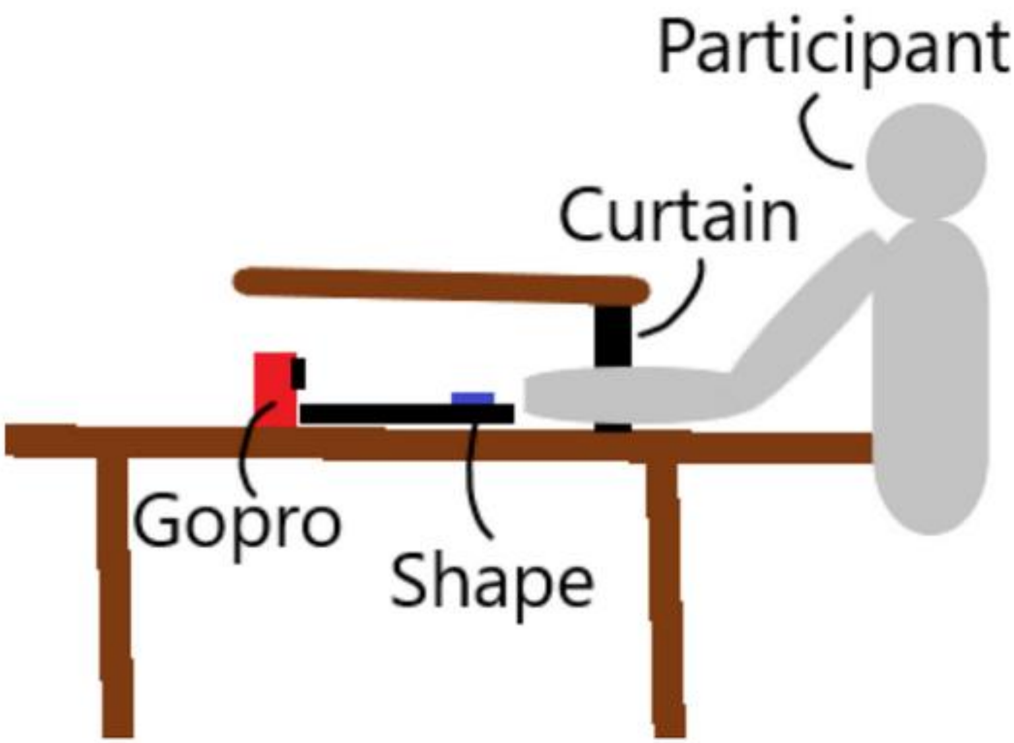

Figure 2.6: Experimental Setup of the Active Touch Experiment.

To determine users’ abilities to comprehend objects in their surrounding environment actively, we designed an experiment which would task participants with discerning the shapes shown in Figure 2.5 using active touch. The experimental setup is shown above in Figure 2.6.

2.3.1 Participants

The participants of this study were 5 individuals who were part of the INVENT Laboratory directed by Dr. Cynthia Hipwell. All participants signed a form of consent which gave us permission to use the data and film obtained during their trials.

2.3.2 Procedure

Figure 2.7: Experimental setup of the Active and Passive Experiments from the participants point of view.

Figure 2.8: Shape options presented to users during the active and passive touch experiments.

Participants were presented with the setup shown in Figure 2.7. They were then asked to move their right hand underneath the platform about an inch or two above the surface of the table. The shape option image, shown in Figure 2.8, was displayed on the monitor in front of the participant. A shape chosen at random was then moved underneath the participant's hand.

After a countdown, the 10 second timer was started and the participant could begin examining the object using all of their fingers. Once the time was up, the user was asked to stop examining the object and guess which shape they had felt. This process was repeated a total of 10 times using each of the five shapes twice. Additionally, the hand movements of the user were recorded using a go-pro camera place beneath the platform. This entire process was then repeated one more time, however, the user was restricted to only using their index finger to examine the shape.

2.4 Experiment 2: Passive Touch

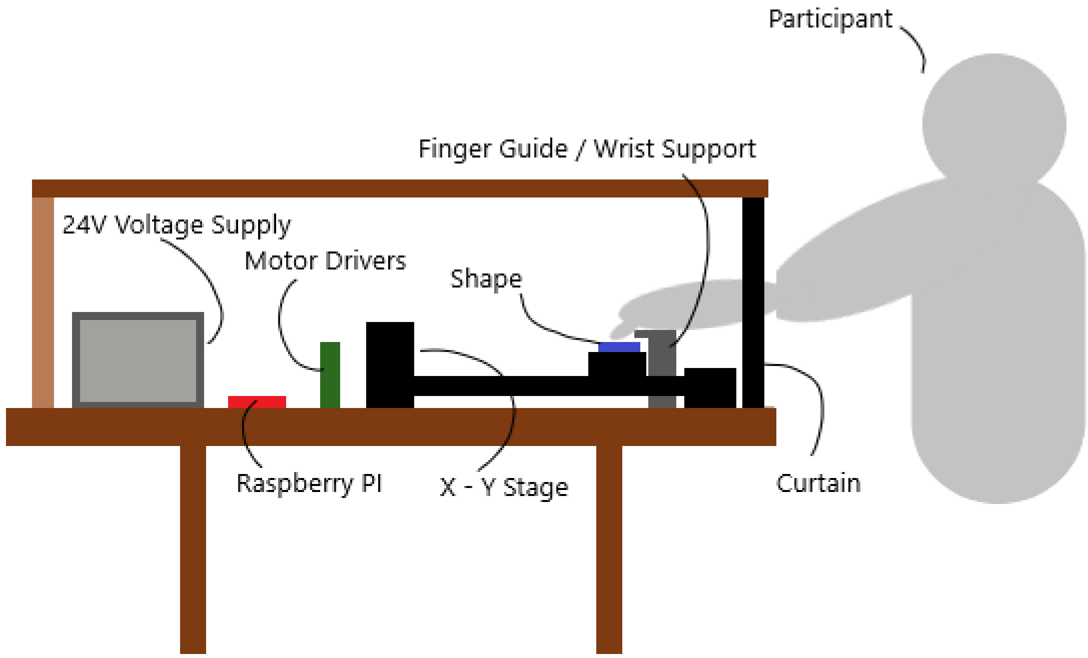

Figure 2.9: Experimental Setup of the Passive Touch Experiment.

An experiment similar to the one described in the previous section was conducted to determine users' abilities to comprehend objects in their surrounding environment using passive touch. As seen in Figure 2.9, the XY table was used to administer passive haptic stimulation to the users' index fingers.

2.4.1 Participants

The participants of this study were 5 individuals who were part of the INVENT Laboratory directed by Dr. Cynthia Hipwell. All participants signed a form of consent which gave us permission to use the data obtained during their trials.

2.4.2 Procedure

Participants were once again presented with the setup shown in Figure 2.7 while the monitor displayed an image of Figure 2.8. The participants were asked to place their hand on the platform and extend their index finger. One of the shapes from Figure 2.5 was secured onto the XY table used to administer tactile stimulation to the user's right index finger. The XY table moved the shape in a circular pattern underneath the participants right index finger making sure all edges of the shape came into content with the participants' finger. After the movement was complete, participants were asked to guess which shape they felt. This process was repeated a total of 10 times using each shape twice.

2.5 Experiment 3: Can the Current Experimental Components Induce the RHI?

A final experiment was conducted with a subset of the previous participants to obtain qualitative data on the experimental setup shown in Figure 2.1. The setup, used to simulate the tactile stimulation felt by the physician in the proposed soft tissue examination procedure (Figure 1.1) must be able to induce the RHI using the established paradigm. The XY table was placed underneath the platform and participants were asked to place their right hands on the hand holder.

The 3D printed shapes shown in Figure 2.4 were attached to the XY table and used to administer tactile stimulation to the participant in no particular order. A prerecorded video was displayed on the monitor in front of the user which showed a virtual hand exploring the same shape in a zig zag pattern. As the virtual hand explored the object in the video, the XY table moved the same shape underneath the participants index finger. With this synchronous motion, the participant should then feel what the virtual hand felt. After repeating this a few times, a dialogue was opened between the experimenter and participant to gauge what they felt during this experiment and determine what improvements need to be made to the XY table in order to induce the RHI.

3. RESULTS

3.1 Results of the Passive and Active Touch Experiments

3.1.1 Results of the Active Touch Experiment

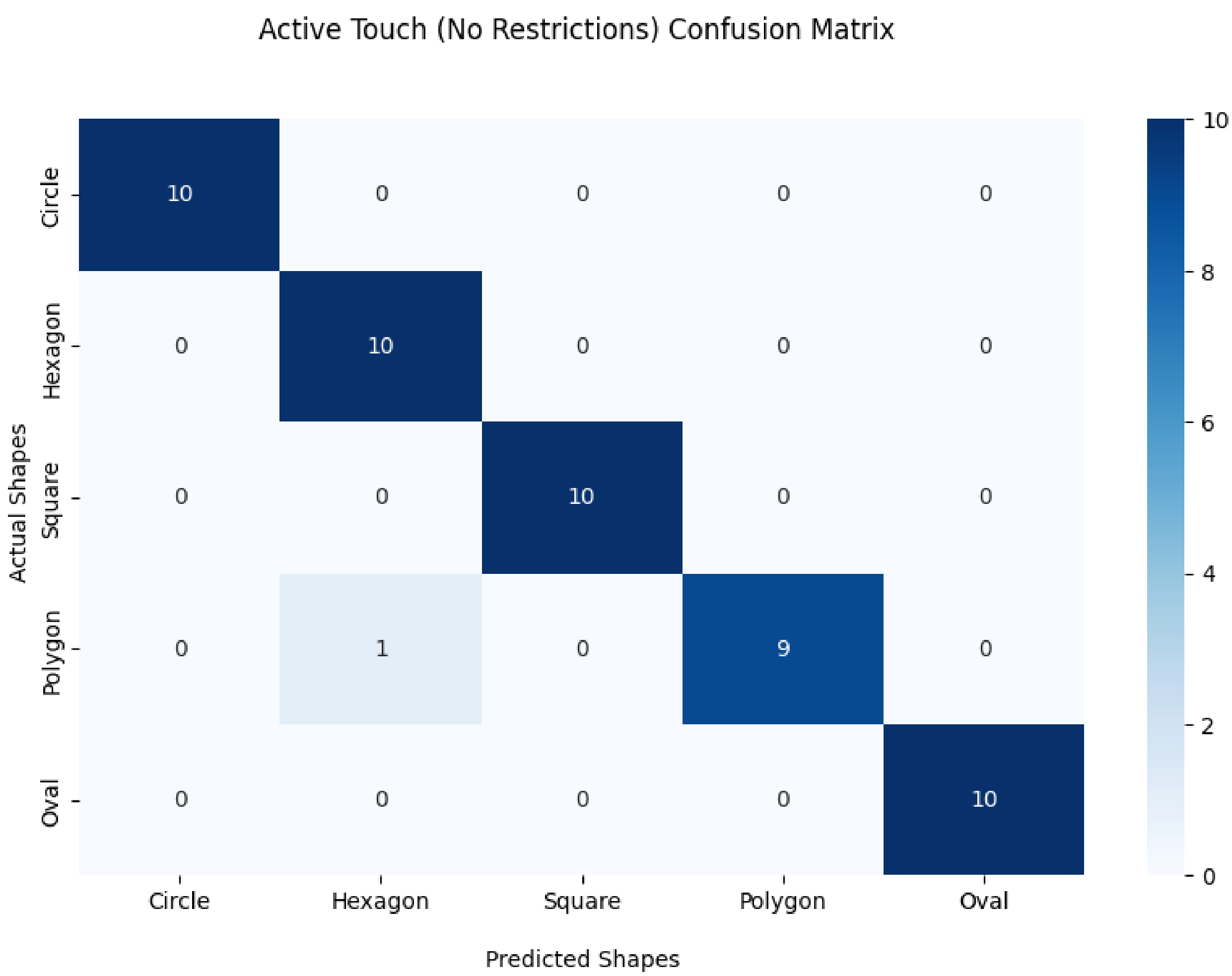

Figure 3.1: Confusion Matrix of data recorded during the Active Touch Experiment under no restrictions.

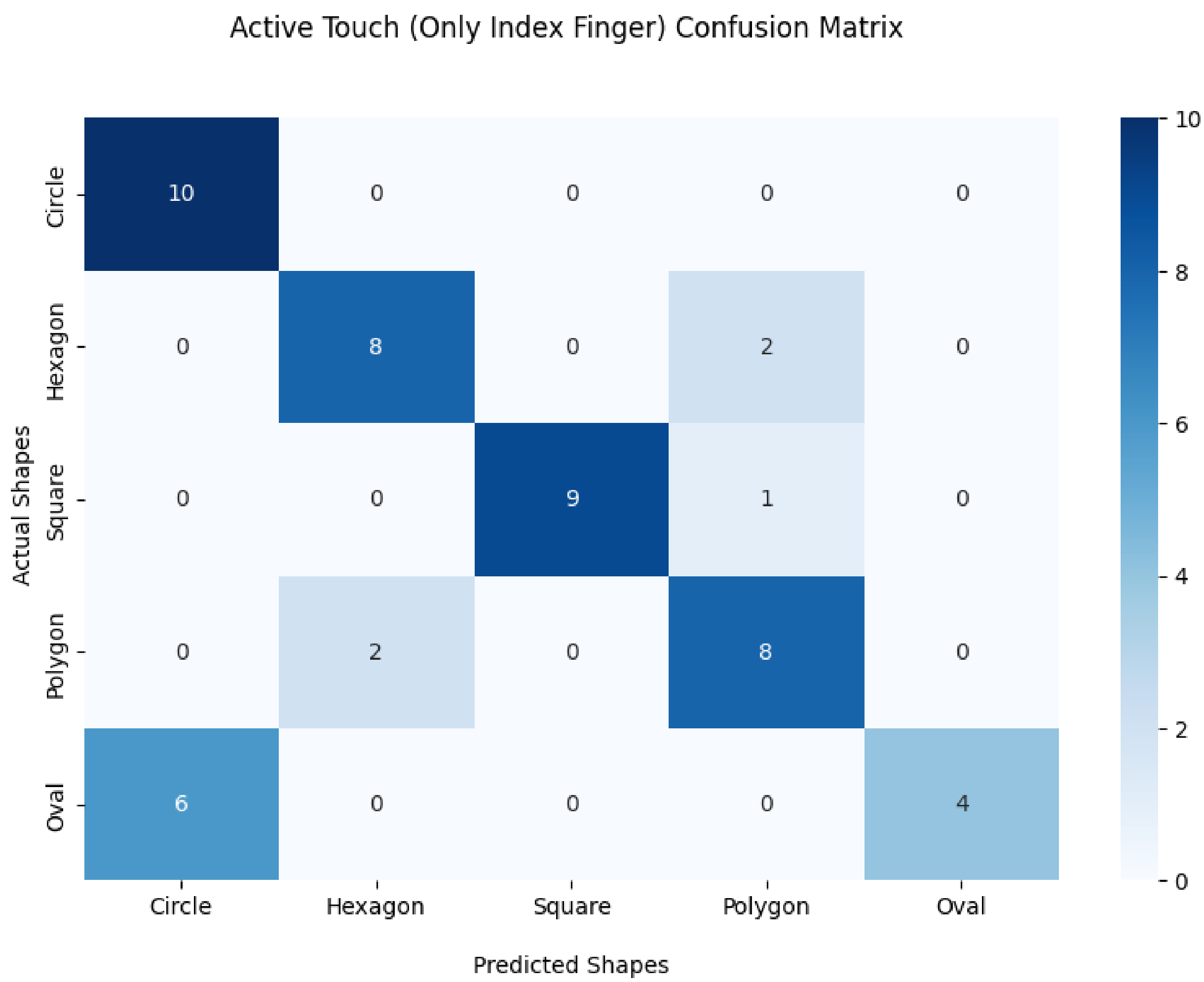

Figure 3.2: Confusion Matrix of data recorded during the Active Touch Experiment with participants only using their index fingers.

In total, 98% of the shapes presented were guessed correctly when exploration using all fingers was permitted (Figure 3.1). 4 of the 5 participants guessed all the shapes presented to them correctly. When participants were restricted to using only their index finger to explore the presented shapes, the accuracy dropped to 78%. Furthermore, as seen in Figure 3.2, participants had trouble differentiating shapes which were similar to each other when using only their index finger. The hexagon shape was commonly identified as the polygon shape and vice versa. The oval was most misidentified shape.

After observing the film of the participants exploring the shapes, all users used a similar movement pattern to identify the shape. This method involved using all their fingers to simultaneously touch the edges of the shape and determine its outline. When participants were restricted to only using their index fingers, a similar strategy was used which involved participants using their index finger to trace the edges of the shape. In the cases where participants incorrectly guessed the shape using their index fingers, it was usually because they were unable to fully trace the perimeter of the shape within the given time frame.

3.3.2 Results of the Passive Touch Experiment

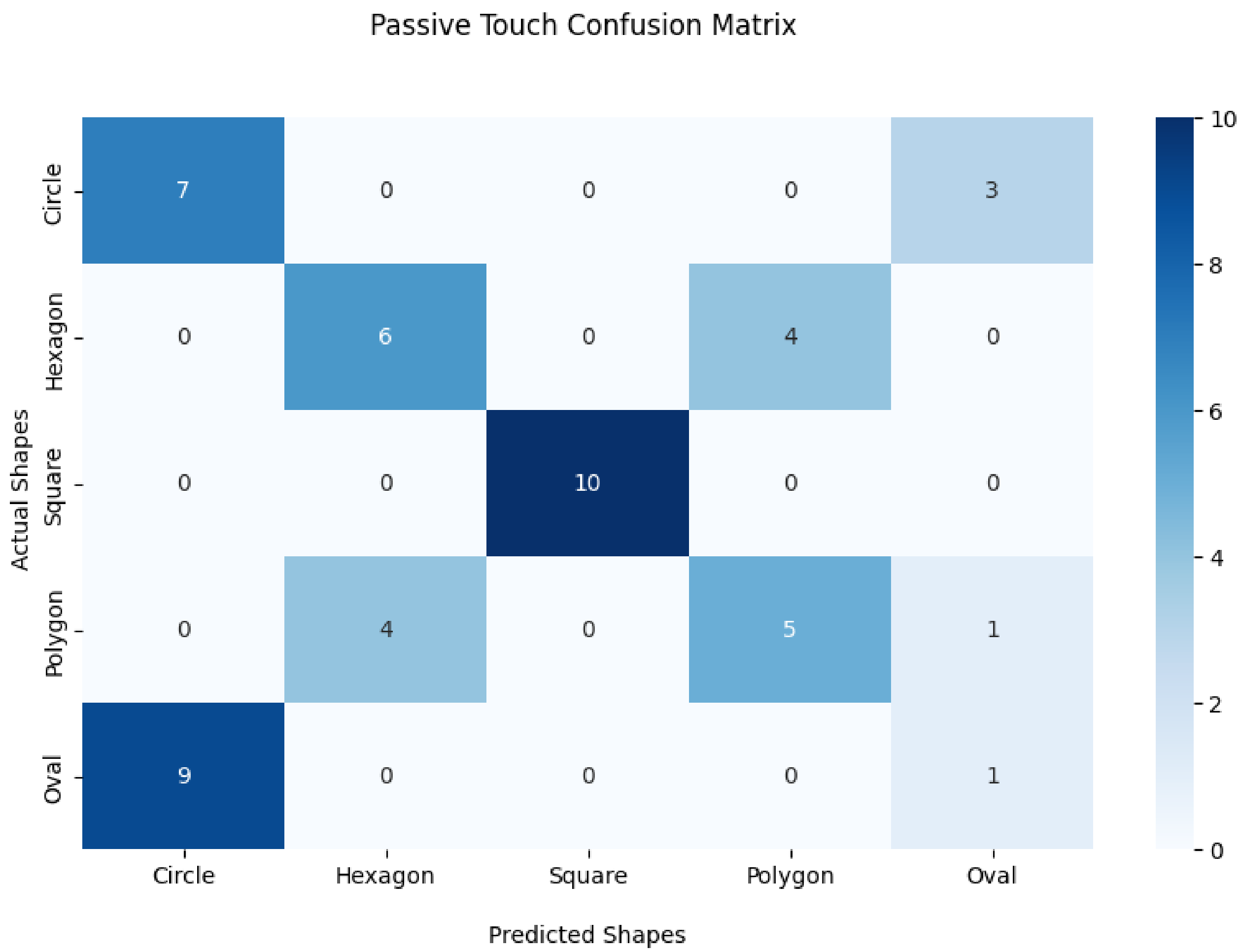

Figure 3.3: Confusion Matrix of data recorded during the Passive Touch Experiment.

The results from the passive experiment show that only 58% of the shapes were identified accurately. As seen in the confusion matrix in Figure 3.3, similar shapes were the most misidentified shapes. Additionally, during the experiments, participants commented on the difficulty of identifying the shapes. The most misidentified shape was the oval which was only correctly identified once.

3.2 Qualitative Analysis of the Experimental Components

The discussion with the participants revealed some improvements that need to be made to the experimental setup. Participants all claimed that they were not able to feel any sense of ownership over the virtual hand seen in the video displayed in front of them. Additionally, participants mentioned slight incongruencies between what they felt tactually and what they saw visually. There were also complaints on the comfort of the hand holder. Some participants commented on the discomfort preventing them from concentrating on the video displayed in front of them.

3.3 Discussion

The first experiment shows that there is a significant advantage in using all fingers to actively explore an object versus using only one finger. However, this can be due to other factors such as the amount of time given to users to explore the object. By using all fingers, participants can explore the edges of the shape faster leading to more accurate results. Participants also obtain the ability to examine all edges of the shape using a grasping motion which is a common strategy used by participants. Increasing the amount of time given to the participants to explore the shape with only one finger could improve the accuracy by allowing the user to examine all edges of the shape.

Though active exploration using all fingers yielded better results compared to active exploration using one finger, exploration of a shape using passive touch yielded the poorest results. Participants performed 20% worse than the active touch experiment with the index finger restriction and 40% worse than the experiment without the restriction. This shows that there is a clear advantage in exploring an object using active touch. These results further demonstrate the need of improving the perception of passive touch in our proposed soft tissue examination procedure.

The comments made by users during the third experiment demonstrate that there are changes that need to be made with the experimental setup, namely the XY table. Currently, the videos are filmed first and the XY table is programed separately to mimic the movement in the video. This is a source of incongruency which can be fixed by possibly placing cameras above the hand being recorded to track its movements. Using this data, the XY table can possibly move more accurately. Another possibility is to display a live virtual hand and use cameras to track its movements. This method would not be too expensive as we would only require a few additional cameras to view the hands in a top-down POV and side POV. This image data can be transmitted to the Raspberry Pi 4 controlling the XY table and move the table more synchronously.

The hand holder was also an issue. To induce the RHI, the hand must remain still so that the user can lose track of that hand. If the hand holder is uncomfortable, users may focus too much on the lack of comfort preventing the illusion from taking place. Before the next set of experiments, the experimental setup and hand holder should be adjusted to improve the comfort of the user. An adjustable standing table and elbow rest would allow the user adjust the setup based upon their height.

Overall, the three experiments have given us insight into what improvements need to be made to our experimental components and setup. Though passive sensing feedback may not outperform active sensing, a significant improvement in performance over purely passive experiments in future studies will demonstrate the ability of embodiment to improve a users' ability understand passive haptic/tactile stimulation.

4. CONCLUSION

After conducting our experiments on active and passive touch perception and analyzing the data, we can conclude that the mode of tactile exploration plays a substantial role in users' cognition of an object in their environment. Furthermore, we have also obtained insight into what improvements need to be made to our experimental setup to induce the RHI for future experimentation.

4.1 Future Work

4.1.1 The Effect of the RHI on Passive Touch

After improvements are made to the current experimental setup, we will once again repeat the active and passive touch experiments described in the methodology section with a larger and more diverse group of participants. With the XY table being able to properly induce the RHI we will then also conduct an experiment to determine users' abilities to identify shapes using passive tactile/haptic while under the RHI. The results of these experiments will be compared to determine if embodiment through the RHI can in fact improve a users' cognition of passive haptic/tactile stimulation. Depending on the results, the proposed remote soft tissue examination procedure could possibly be altered.

4.1.2 Further Use of the RHI Paradigm

Prior RHI studies have also shown the importance of personality traits for the induction of the rubber hand illusion [8] [9]. For the majority of the population, the key trait is sensory suggestibility which is a measure of how easily a user can be tricked by stimulating the senses. As the rubber hand illusion is thought to be caused by incongruencies in what the user sees and feels, it makes sense that the higher the users' suggestively, the stronger the illusion.

Additionally, studies have shown that experience working with one's hands reduces the ability of the illusion to take place [10]. For example, if the participant is an athlete who plays a sport which requires extensive use of their hands, or a pianist, it is more difficult to cause the illusion. It is hypothesized that this is because of the users being more aware of their own bodies and having a stronger sense of proprioception and therefore a lower sensory suggestibility.

Measuring the sensory suggestibility during future studies could give us more insight on the viability of using the RHI and embodiment to improve passive tactile/haptic feedback cognition.

Additionally, proprioceptive drift is the only standard quantitative measurement to determine the strength of the RHI. With the user seeing a set of moving hands on the screen in front of them as opposed to a resting fake hand, measuring the proprioceptive drift can be difficult and inaccurate. Thus, the only way of determining the strength of the illusion is the use of questionnaires. However, discovering a way to measure proprioceptive drift accurately in our experimental setup or improving the standard RHI questionnaire would result in more impactful data from future studies.

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