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Evaluating the Microsoft Kinect compared to the mouse as an effective interaction device for medical imaging manipulations

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Evaluating the Microsoft Kinect™ compared to the mouse as an effective interaction device for medical imaging manipulations

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ABSTRACT

Volume-rendered medical images afford medical professionals increased information to provide their patients with more advanced diagnoses than previously allowed with 2D slices. Three-dimensional (3D) images enable a non-invasive depiction of a patient's body, which a surgeon would expect to see during an invasive surgery. These generated 3D representations can more effectively and efficiently convey information about the patient to the surgeon, bypassing the mental reconstruction required by radiologists to interpret the same patient's data displaced on a two-dimensional (2D) array of images. Time demands on doctors prohibit mastering complicated software packages with steep learning curves. Designs of medical imaging software must be easy to learn with effective functionality for the software to be used and accessible to medical professionals. Interacting with the software is a key component of usability and accessibility. Commercially-off-the-shelf (COTS) interaction devices provide new opportunities to manipulate 3D medical imaging software to further reduce a traditionally steep learning curve in medical imaging software. Implementing these devices into medical environments can create new concerns with sterilization and effective utilization. Specific COTS devices offer sterile, touch-less interaction that would be ideal for medical operating rooms (OR), anatomy labs or clinics. These devices allow medical professionals direct control of the patient's data being examined. This thesis explores the usability and functionality of the Microsoft Kinect™ as an interaction device for medical imaging technology by being able to complete a task called windowing or

changing the tissue densities displayed in an anatomical region. A user study was conducted to evaluate participant's performance and experience, while completing a task called windowing. Windowing is changing the tissue densities displayed in an anatomical image. Participants completed four rounds of five tasks to view particular anatomical features throughout two datasets. Participants using both devices had a 75% accuracy to correctly identify the anatomy, while those using the Kinect (μ = 9.739 minutes) spent on average 2-minutes less time to complete the series of 20 tasks, compared to those using the mouse (μ = 11.709 minutes). Participants using the Kinect also had larger window width values than mouse users, however this did not appear to affect their accuracy in identifying the tasks.

CHAPTER 1. INTRODUCTION

Over the past 20 years, medical facilities have been implementing computers into countless locations including hospitals, clinics, and medical vehicles. The technology has been implemented in stationary locations and as mobile units depending on the need, in an effort to improve patient care [4]. Records are no longer tabulated in a folder and escorted with a patient around a hospital or clinic. Instead, they are available to medical professionals digitally and in any location. Along with these records, doctors can request computed tomography (CT) or magnetic resonance imaging (MRI) scans of a patient to view their internal structure without invasive surgery [3]. Improved computer capabilities and speed has prompted inclusion of this technology into operating rooms and other sterile environments. However, this technology brings concerns of patient safety due to inappropriate sterilization procedures of computer screens and keyboards [5]. Studies have shown an increase in the number of health-care associated infections (HAIs) due to poor sterilization methods of computer technology [5, 6]. Currently, a patient's CT or MRI images are manipulated by an assistant who is considered non-sterile but with guidance from the operating doctor [10]. This guidance can be misinterpreted and increase the frustration felt by doctors during already stressful surgeries [2, 9-13]. Touch-free interaction device options have begun to emerge on the commercially available market to potentially reduce the number of HAIs transferred via computer equipment, while enabling the operating surgeon direct access to the patient's data [9, 11]. This thesis research explores the usability and functionality of the commercial-of-the-shelf (COTS) Microsoft Kinect as an interaction device for medical imaging technology. The objective of this work is to validate the Kinect as having comparable usability to a mouse by not limiting the users ability to complete specific tasks. Participants in this work completed a task called windowing or changing the tissue densities displayed in a three-dimensional (3D) anatomical region. This chapter discusses the background research and motivation and for this work further.

1.1 Computers in Medical Imaging

Implementation of COTS interaction devices for manipulating 3D medical imaging technology in medical facilities is showing promise to be one of the next innovative technologies to improve healthcare around the world. A hospital in Toronto, Canada implemented a Kinect™ into one of their operating rooms and used the technology during six surgeries [1]. In 2012, trial runs began in London at Guy's and St Thomas's hospital where surgeons were able to access patient's CT scans during the surgery. The doctors used the technology to view and navigate through a 3D model of the patient's abdominal aorta by arm gestures. The surgeon reported utilizing the system four or five times during the 90-minute operation [2]. These devices offer unique functionality compared to the traditional mouse and keyboard configuration, but when applied to medical scenarios, can create distinct challenges that require special consideration to select the appropriate COTS device for the circumstance.

Computers have become commonplace in hospitals and clinics. This technology offers advancements in how patient records are managed to the types of data that can be gathered about a patient for quicker diagnosis. Virtual reality (VR) for medical applications was originally developed during the mid-eighties. This rudimentary technology required several hours of computing time to produce images taken with a CT or MRI scanner to produce 3D anatomical representations of a patient's body [3]. Over the past 15 years, using volume rendered images as a tool for diagnosis has become more acceptable for use in diagnosis by medical professionals [3]. Hospitals are now equipped with stationary and mobile computers in many locations such as patient's rooms, nurses stations, operating rooms, and doctor's offices [4, 5]. This computerized system allows doctors and nurses to view patients' medical records, check laboratory test results [4], and examine 3D images from a patient's CT scans.

As the number of computers and the overall access to patient's information has increased, the implementation of this technology has been shown to include insufficient sterilization procedures. The lack of appropriate sterilization measures has lead to an increase in the number of HAIs across the United States. These HAIs are expensive, deadly and preventable. Bures et al. estimated in 2000 that 2 million patients developed nosocomial infections in the United States at a cost of $4.5 billion each year [5]. The CDC reported that approximately 1.7 million HAIs caused over 99,000 deaths in 2007 [6]. The Keystone Project, implemented in Michigan hospitals, promotes research that improves patient safety with 1,800 lives and $231 million saved, resulting in

140,700 less hospital days incurred by patients. The project implemented the Comprehensive Unit-based Safety Program, developed at John Hopkins University, throughout Michigan hospitals to collect data about infections and share prevention procedures with other locations. Reducing the time patients' spent in hospitals and the overall cost of the visit is in the best interest of patients as well as a more cost-efficient way to provide care. [7].

Appropriate disinfection strategies were not in place to prevent the spread of germs [8] when computers were first implemented in a hospital setting. Even with procedures in place to prevent and control the spread of infectious diseases, the adoption and monitoring of the health saving policies does not always occur [7]. Many hospitals have monitored the spread of contamination and found that computers continue to be a problem with irregular disinfection procedures. [4, 5, 8, 9] One study observed how contamination could spread within a hospital unit [8]. They hypothesized that after gloved medical professionals interacted with the patient and transferred information to the computer, ungloved support staff would retrieve information from the computer and transfer the contamination to other locations in the hospital [8]. With routine cleaning regimes [4], researchers have observed a decrease in the number of days patients suffered from infections during catheter use [7].

Communication is another barrier that must be overcome when working with medical imaging technology. Technicians will typically operate the computers in an operating room (OR) to display a patient's data for a surgeon. This configuration is an effort to give doctors the information they need, while maintaining a sterile working environment [10]. However, this structure creates communication barriers between doctors and technicians increasing operating time and chances for mistakes [2, 9-13]. One research team observed the instruction between a surgeon and assistant to be seven minutes in length before the assistant was able to reach a specific location in the user interface for the surgeon to have the information needed to continue with the surgery [12]. Communication barriers can create frustration [2, 9-13] and increase the cognitive mental workload faced by surgeons [10, 12]. These factors result in poor healthcare for patients and increased medical errors among professionals [13]. Specifically, emergency rooms are known for frequent disruptions due to being a complex arrangement of social interactions amongst medical personnel [14]. Another factor in communication challenges is the hierarchical relations that develop between surgeons, other doctors, technical assistants, nurses, etc., which echoes a militaristic model [13].

Doctors avoiding hospital protocols to prevent the spread of contamination can also be a major issue when trying to reduce HAIs. To gain personnel access to a patient’s data, those performing surgery will dirty the bounds of sterility by defining sterile and non-sterile sides to their clothing. One researcher observed a surgeon pulling their surgical gown over their gloved hand that was considered to be sterile, and operate a computer [12]. This allowed them the fine grain control to interact directly and visualize a specific region of anatomy. The surgeon moves away from the patient and operating table, during this time, to view these images, which can decrease organizational efficiency, increase risks of complication and increase financial costs. However, they concluded that this was the best solution to effectively control the viewed images, without removing themselves from the room to scrub out to view the images and scrub back into the operating room [12].

Neither situation of miscommunication or blurry sterile boundaries is best for the patient. Researchers must explore new opportunities within technology to minimize the communication and compromised sterile environments to improve the safety and well-being of patients who seek treatments in those environments. Technology has advanced to handle the storage and has developed the ability to visualize medical data, but many problems involving interaction with the technology have yet to be solved [15]. Designing seamless healthcare through people and technology working at a single unit, will open doors for improved healthcare and reduced medical expenses [12, 14].

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CHAPTER 2. BACKGROUND

This thesis explores the use of a touch-free interaction device to meet the challenges faced by medical professionals to reduce the occurrences of HAIs caused by touch interaction with computer technology. Available technologies to improve interaction with medical technology will be reviewed in this chapter to serve as the foundation for this research.

2.1 Possible Interaction Devices

Traditional two-dimensional interaction through a mouse and keyboard are unintuitive interaction devices when working with a 3D medical image. COTS interaction devices, developed for the gaming community, offer new opportunities to the medical industry to lessen the daily struggles that are faced by medical professionals by lowering the barrier of access to a patient's information. A variety of interaction devices have been applied to medical imaging to improve the usability to 3D medical imaging technology for medical professionals. Some of these devices are in development and initiation phase, while others are commercially available.

In recent years, researchers have experimented with several novel devices that improve the experience for radiologists interacting with 2D and 3D images. The first is a P5 Glove Controller (Figure 1a), which provides 3D manipulations for radiologists while exploring medical images. The controller offered a systematic two-handed control, while one hand is strapped in the glove;

the other hand is able to push the buttons along the top of the controller. The glove enables six-degrees of freedom (6 DOF) and improved accuracy and task completion time. Due to inaccuracies in the calibration process, the devices required ample amount of time for participants to interact with the VR environment [1].

(a) (b)

Figure 1. (a) P5 Glove Controller is a interaction device enables intuitive interaction from hand gestures and other familiar motion. (http://www.mindflux.com.au/images/glove_photo_lrg.gif) (b) ShuttleXpress jog wheel is an alternative to traditional mouse. (http://www.prokit.co.uk/product_images/b/772/1267190337__85802_zoom.jpg)

The second device, a ShuttleXpress jog wheel (Figure 1b) replaces a traditional mouse to improve scrolling through medical images by using the center control knob to continuously scroll through image data. The study evaluated four different devices: a trackball, a tablet with two interfaces and a jog-wheel [2]. The rotation of the wheel was translated to the rate of scrolling achieved by the participants. Overall performance of study participants showed no difference between the ShuttleXpress or a traditional mouse. They found that direct speed and control of images enhanced a medical professionals interpretation of the images. The study concluded that a number of interaction devices should be available to medical professionals for those who prefer non-standard interaction techniques based on the task they need to complete [2].

Figure 2. a) The gamepad offers numerous button combinations due to ergonomic design for ease of use and improved learning. (http://gaming.logitech.com/en-us/product/f710-wireless-gamepad) b) Wii Remote™ offers one-handed interaction with a series of buttons and positional tracking. (http://www.nintendo.co.jp/wii/index.html) c) The Kinect™ offers touch-free interaction through an infrared array of points and two cameras to capture the movements of users to control the interaction. (http://www.xbox.com/en-US/kinect)

A typical video game controller, Wii Remote™ and Kinect™ are three interaction devices that were developed in the gaming industry and have shown promise in the medical industry. The gamepad (Figure 2a) uses ergonomically positioned dual analog joysticks and buttons to enable fingers and thumbs on both hands to interact with multiple buttons at any given time. The countless combinations of inputs from the user and ergonomic design have shown to enable quick learning and understanding of how to effectively use this interaction device [3].

A Wii Remote™ (Figure 2b) is also an option within the array of commercially available interaction. It is a single-handed, tracked remote offering interaction with a 3D virtual environment. The positional data from the user's movements is detected by infrared receivers and used by software to replicate a user's movements within a virtual environment. [4]. The Wii Remote™ has gained momentum as an interaction device and has been used for recognizing gestures, controlling the motion of animated characters and simulating musical instruments [5].

Gallo et al. presented an application that incorporated a Wii Remote™ as a viable interaction tool for a semi-immersive medical environment. The techniques were specifically designed for medical imaging and focused to provide a more natural interaction for pointing and manipulating patient anatomy [20]. Designing interactions for 3D spaces is more complex than designing interactions for 2D spaces. One of the struggles researchers are finding with tracked interaction devices, such as a Wii Remote™, is the ability to complete actions like button presses. The fine movements ultimately change the location of the device and change the VR location associated with the button press. [5]

A study to compare the ability of a mouse and keyboard, gamepad and Wii Remote™ to rotate virtual objects and changing the movement path of the object found that a mouse and keyboard had the quickest results with a 20.40

seconds completion time, following by a gamepad with a 21.55 seconds completion time, and a Wii Remote™ providing the slowest performance at 29.09 seconds [3]. Both the rotation and translation of objects are necessary for manipulations of medical imaging anatomy by medical professionals.

The Microsoft Kinect™ (Figure 2c) is the most recent COTS interaction device option in the medical industry. Through the use of an array of infrared points projected on a participant and one infrared camera , the device uses structured light scanning to track the individual's skeletal movement [6, 7]. The device has a horizontal field of view of 57° and a vertical field of view of 43°, with a resolution of 3 mm in each of those directions. The active depth distance is between 0.8 and 3.5 meters from the device, with a resolution of 10 mm [8]. The device offers the capability of touch-free interaction for necessary sterile medical environments [9]. For the implementation of the Kinect™ into a Toronto OR, the use of the technology was able to decrease surgery time by approximately two hours [10].

One study evaluated a Wii Remote™ and Kinect™ for 3D geographical mapping [11]. Hand gestures were used to navigate a virtual environment by measuring yaw, pitch and roll. On a seven point scale, where a score of seven meant strongly agree and one meant strongly disagree, the Kinect™ showed less variability in task performance by participants (Kinect™: $\mu = 5.4$, $\sigma = 0.82$, Wii Remote™: $\mu = 5.17$, $\sigma = 0.94$) and was less distracting (Kinect™: $\mu = 5.39$, Wii Remote™: $\mu = 4.41$). Results found that natural interface techniques faired better and engaged the user in the environment more effectively [11].

A similar gesture based application for a Kinect™ included a system to manipulate MRI scans during a neurobiopsy developed by Jacob and Wachs. The implemented algorithm follows the hand's motion to determine intentional and unintentional gestures for the system to follow [12]. Santhanam et al. utilized a Kinect™ to monitor respiratory change via contours of the human body by capturing regular images to prevent exposure to radiation of CT scans [13]. Visual control has been demonstrated for face tracking to manipulate laparoscopic camera location based on face 'grammar' [14]. Implementing touch-free interaction devices has shown to benefit the medical community and offers more opportunities for sterile environments to improve access to patient's anatomical data in an OR [14, 15].

2.2 Touch-less Gestures

Designing the appropriate gesture vocabulary is as important as selecting the hardware for the application. Effective gesture design is critical to ensure that users will be able to memorize and utilize the gestures to be able to work with the technology. An action that does not intuitively tie to its gesture will require additional time to learn and create frustration with the software.

Selecting effective gestures to complete medical imaging manipulations requires an evaluation of both the functionality of the technology and an understanding of human capability. These selections come with an understanding that people often use gestures to communicate with their surroundings [16]. Gestures must be unique [17], intuitive [17, 18, 19], memorable [18], and socially acceptable [20, 21]. These gestures can range from simple to complex motions as long as a user is both confident and comfortable using the selected gestures to interact with the technology. Selective studies have been conducted to identify and develop gestures for basic computing functions [17].

Nothing is more important than a gesture's usefulness. Research has been conducted to reduce the gulf of execution present between a user's desired action and how the action will be carried out [19]. These studies identify user-defined gestures for specific commands and can be very insightful when selecting the appropriate gesture for a particular application. Selecting gestures that resonate with users is a must for intuitive interaction. Stern et al. defined intuitiveness as "the cognitive association between a command or intent, and its physical gestural expression" [17].

One study had participants interact with objects on a touch screen [19]. They found that although participants were instructed to interact with the table surface, some preferred to work above the table when completing their gestures [19]. This observation highlights the potential for effective implementation of a Kinect™ as a touch-free interaction device.

Another study had students define hand gestures to navigate a virtual driving game through eight commands; start, finish, forward, backward, left, right, fast mode, and slow mode. A total of 59 gestures were developed by users and reduced based on popularity of each gesture. They found a 70:30 relationship between participants and gestures, where 70% of participants used 30% of the gestures defined during the study. The final gesture set is displayed in Figure 3. The authors discussed the option of users selecting a personalized gesture set from a vocabulary of pre-defined gestures. They concluded that there is no one-size-fits all gesture set for touch-less interaction [17]. A user defined gesture vocabulary would allow personalization of gestures and in theory encourage better retention of gestures.

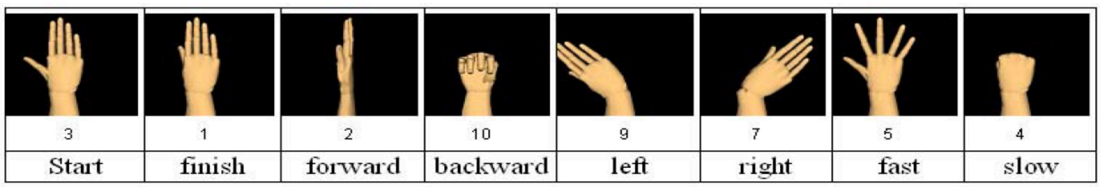

Figure 3. Select gestures based on user-determined popularity [17].

Urakami explored touch-free gestures further by determining acceptable ones to meet the needs of both novice and expert users. Participants were asked to define their own vocabulary of gestures for 17 actions divided between novices and experts. 316 gestures were analyzed for novices and 176 for experts. The study concluded that certain features of gestures were preferred by a majority of users (See Table 1) [18].

Table 1. Feature preferences of users designing their own gestures for a series of commands [18].

Feature	Percentage of novice users	Percentage of expert users
Dominant hand	99 %	
Only one hand	61.39 %	73.86 %
One finger	43.67 %	49.77 %
Five finger	48.10 %	35.80 %
Pointing	47.33 %	48.52 %

Flat hand	40.21 %	30.77 %
Path and static pose	90%	
Single complexity	84.18 %	87.50 %

Gestures in a medical environment are carried out in a public setting, therefore understanding socially acceptable movements is a necessity. To effectively design gestures for use by doctors, individuals must be comfortable using the motions and in all cases introverts and extroverts need to be comfortable performing these actions to communicate with the technology [22]. Gestures must be selected as to not undermine a doctor’s status as the authority of the social hierarchy in the OR by having them perform “childish” gestures.

Without considering the acceptability of a gesture-based design, a reliable product might be rejected by its user base, creating a useless product [20]. Socially acceptable gesture design is necessary to encourage individuals to move past their natural hesitation against touch-free interaction devices, which require motions that are normally not used on a daily basis [21]. In one study, participants were given 18 gestures and indicated where they felt most comfortable performing the gesture; at home, driving, as a passenger on bus or train, restaurant or pub, and workplace. Approximately 65% of the gestures were acceptable to use in the workplace [20, 21].

2.3 Motivation

Medical professionals need solutions to improve the access to technology in sterile environments. For example, doctors need to navigate [8] and rotate medical images [12, 23]. Many applications have been proposed to incorporate additional sensors to improve tracking and performance in operating rooms [7], but many of these systems remain detached from the needs and demands of an individual in a medical setting [1, 8]. Devices that have been designed for 3D interaction are rarely used [1]. Minimal research has been conducted to identify the end-user requirements for medical applications [1, 14], creating technology that is not appropriately suited for the environment [24]. The products that are available on the market are expensive and are typically confined by industry professionals and university laboratories. Those that are implemented in hospitals are often selected for their low cost over comfort and usability [25]. The research that has been conducted is focused on the validation of software functionality separate from understanding everyday users and designing products to better suit their needs [14].

Many research publications discuss the features of a touch-free interaction design for medical settings;

- usability (user friendly, natural and effective) [26],
- ergonomic interactions [26],
- type of devices [23],
- support of macro and micro tracking to control interaction [27],
- distinctive gestures for clear intention between the software's gesture vocabulary and users communication gestures [12, 27],
- feeling of immersion [23],
- minimal training [23],

- ease of tracking an individual from multiple locations in an OR [27],
- override any automated system for patient safety concerns [14],
- minimize complex calibration [8, 23].

The adoption of new technology needs to benefit medical professionals by lowering time required to complete a desired series of tasks and reduce frustration levels. Operating rooms could benefit from touch-less technology to promote additional involvement of medical personnel to solve problems [27]. Implementing a Kinect™ into a sterile environment provides opportunity to continue to reduce HAIs and improve the usability and effectiveness of computational technology into medical decision-making. Before this technology can be effectively implemented, however, researchers need to identify which features are necessary and what gestures are most efficient for the tasks at hand to improve use.

The purpose of this research is to evaluate a COTS interaction device, the Kinect™. Data was collected through user studies conducted at medical schools to answer the following research question:

How effective is the Kinect™ as an interaction device compared to a traditional mouse when working with medical imaging software?

Based on preliminary observation, implementation of this COTS device can improve medical professional's access to 3D anatomical images. However, an initial study showed dissatisfaction amongst users due to the novelty factor of the technology and a lack of precision that was caused by the Kinect™. This is in chapter 3.

Touch-less interaction devices offer manipulation capabilities otherwise not possible, reduced time, and intuitive gestures for manipulation. Technology advancements in the medical community require extensive understanding of all capacities of a product. Governing organizations want to ensure that this product will save lives by giving doctors more information, information that is consistently accurate and well defined. This study seeks to determine the value of the Kinect™ to complete a task called windowing. See Chapter 4 for the results of this second study.

The Kinect became the fastest selling consumer electronic of 2011, with over 8 million units purchased in the first 60 days on market [28]. Applications have been designed ranging from engaging technology savvy youth [29] to increasing the fitness of senior citizens [30]. With this rapid acceptance and ability to accommodate individuals from many demographics, it is hypothesized that the Kinect will be accepted by medical professionals for medical imaging manipulations by overall reduction in the amount of time to complete the tasks and reduced frustration experienced by participants using the interaction device.

2.4 Thesis Organization

The remainder of this thesis is structured as follows. Chapter 3 is a published article from the Proceedings of SPIE Medical Imaging Conference 2013. This work was an initial study that opened new questions and discussion that would lead to the work covered in this thesis. Chapter 4 is a modified journal being prepared for submission to Computers in Biology and Medicine. This chapter includes the methodology and results of the currently discussed work. Chapter 5 concludes with an overall summary of the two studies.

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CHAPTER 3. COMPARING THE MICROSOFT KINECT™ TO A TRADITIONAL MOUSE FOR ADJUSTING THE VIEWED TISSUE DENSITIES OF THREE-DIMENSIONAL ANATOMICAL STRUCTURES.

Published in the Proceedings of SPIE Medical Imaging 2013: Image Perception, Observer Performance, and Technology Assessment

Bethany J. Juhnke, Monica Berron, Adriana Philip, Jordan Williams, Joseph Holub, Eliot Winer

Abstract

Advancements in medical image visualization in recent years have enabled three-dimensional (3D) medical images to be volume-rendered from magnetic resonance imaging (MRI) and computed tomography (CT) scans. Medical data is crucial for patient diagnosis and medical education, and analyzing these three-dimensional models rather than two-dimensional (2D) slices enables more efficient analysis by surgeons and physicians, especially non-radiologists. An interaction device that is intuitive, robust, and easily learned is necessary to integrate 3D modeling software into the medical community. The keyboard and mouse configuration does not readily manipulate 3D models because these traditional interface devices function within two degrees of

freedom instead of the six degrees of freedom presented in three dimensions. Using a familiar, commercial-off-the-shelf (COTS) device for interaction would minimize training time and enable maximum usability with 3D medical images. Multiple techniques are available to manipulate 3D medical images and provide doctors more innovative ways of visualizing patient data. One such example is windowing. Windowing is used to adjust the viewed tissue density of digital medical data. A software platform available at the Virtual Reality Applications Center (VRAC), Isis, was used to visualize and interact with the 3D representations of medical data. In this paper, we present the methodology and results of a user study that examined the usability of windowing 3D medical imaging using a Kinect™ device compared to a traditional mouse.

3.1. Introduction

Usability is an important factor for integrating three-dimensional (3D) imaging into medical environments. A major barrier for implementing 3D medical imaging into clinical practice is time-consuming training required to learn how to interact with the software [1]. COTS hardware such as the Nintendo® Wii Remote™, Microsoft® Kinect™, and Xbox 360 gamepad are interaction devices with which many individuals have some familiarity as they are available in the public market. If these could be used for medical training, diagnosis, and treatment tasks, it is hypothesized that accessibility and usability could increase in less time for less cost. These devices have the possibility to enable more efficient 3D spatial interaction than the traditional mouse because they manipulate position and orientation with six degrees of freedom (DOF) [2] as opposed to two. These devices are designed for a fast learning and ease of use for a broad range of users. Harnessing this for medical tasks involving digital medical data offers tremendous potential.

3.2. Background

3.2.1 Commercial-off-the-shelf devices

The gamepad is a controller that uses the fingers and thumbs to provide user input, and it has been used as a COTS device for interacting with 3D virtual environments because it is both ergonometric and low cost (Figure 1c). It has been found that the gamepad enables easy learning as an interaction device, and its various buttons provide numerous possibilities for manipulation input. The gamepad also offers a high degree of precision and control because of the inclusion of dual analog joysticks [3].

After the release of the Nintendo® Wii™, developers discovered the potential of the Wii Remote™ as a COTS device for interaction with a 3D virtual environment (Figure 1a). In 2007, a system for head tracking using head-mounted infrared lights was developed which gave positional data to track the user's head when detected by the Wii Remote™ cameras [4]. Research groups began to look at the Wii Remote's™ capabilities for pointing and aiming in a head-mounted virtual reality space. One study analyzed two Wii Remote™ based tracking methods specifically for human computer interaction research because the Wii Remote™ offered previously unheard of tracking capabilities for a device that was so inexpensive in comparison to older devices [5]. However, the study concluded that the Wii Remote™ was imprecise, relying on nothing but two infrared points for location and an accelerometer for each axis of rotation [6].

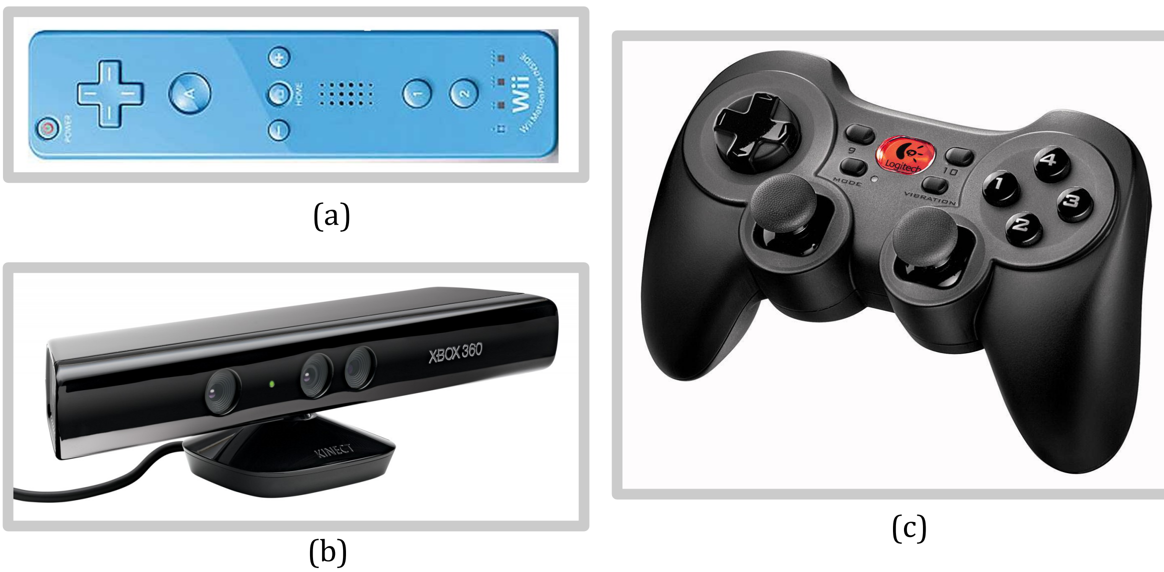


Figure 1. (a) The Nintendo® Wii Remote™ is a COTS device that operates via one-handed navigation. (www.ic4uae.com/Product.aspx?productid=63005) (b) The Microsoft® Kinect™ is a COTS device that operates via touch-free navigation. (annporter.wordpress.com/2012/04/10/interior-design-via-kinect/) (c) The gamepad is a COTS device that operates via two-handed navigation. (compactiongames.about.com/od/hardware/tp/gamepads.htm)

The Kinect™ uses two cameras, one being an array of infrared points projected onto a user. The Kinect™ takes point locations from both cameras and uses the disparities to triangulate each point’s position in 3D space. There is a third RGB camera for overlaying an actual image onto the 3D mesh to create a lifelike partial 3D model of the subject. In order to sense human movement and hand gestures, the Kinect™ has built-in skeletal tracking, which approximates the position of the user's limbs [7]. The Microsoft® Kinect™ is regarded as an effective COTS solution for hands-free manipulation of 3D visual representations such as volume renderings of medical data (Figure 1b) [8].

Research to understand user's personal preference for interaction devices with respect to 3D medical imaging has been limited. However, studies addressing other 3D environments have evaluated user preference of COTS interaction devices. One study compared the Wii Remote™ and Kinect™ as interaction devices for 3D geographical mapping and used yaw, pitch, and roll gestures to navigate. In the study, the Computer System Usability Questionnaire provided results on a scale of 1 (strongly disagree) to 7 (strongly agree). Tasks were rated easier with the Kinect™ and had less variability (μ=5.4, σ=0.82) than the Wii Remote™ (μ=5.17, σ=0.94). The study also found that the Kinect™ was observed to be more efficient (μ=5.39) than the Wii Remote™ (μ=4.41) because users found the Kinect™ less distracting. The study's findings conclude "the more the interface is natural (in the sense that it disappears behind the gesture) the more the users are involved in the virtual environment and hosted activities" [9]. Another study compared the Wii Remote™, gamepad, and mouse and keyboard as interaction devices for rotating a virtual object in one task and changing the object's path in a second task. Findings of the study concluded that the average time to perform both tasks was slowest for the Wii Remote™ (29.09 s), second slowest for the gamepad (21.55 s), and fastest for the mouse and keyboard (20.40 s). Participants were unable to complete the rotation task using the Wii Remote™ in 80% of total attempts, and the Wii Remote™ was selected as the least favorite interface by 90% of the participants [3].

Maintaining a sterile environment, in addition to usability, is an important consideration for integrating 3D imaging into medical environments. Sterility is extremely critical in medical settings, especially operating rooms, intensive care units, and autopsy suites. While the gamepad and Wii Remote™ provide the 3D motion mapping that the traditional mouse does not, such interaction devices require physical contact with the medical user and could increase contamination by transferring pathogens [10]. The Microsoft® Kinect™ provides touch-free interaction, allowing remote manipulation of 3D medical images through hand gestures [9].

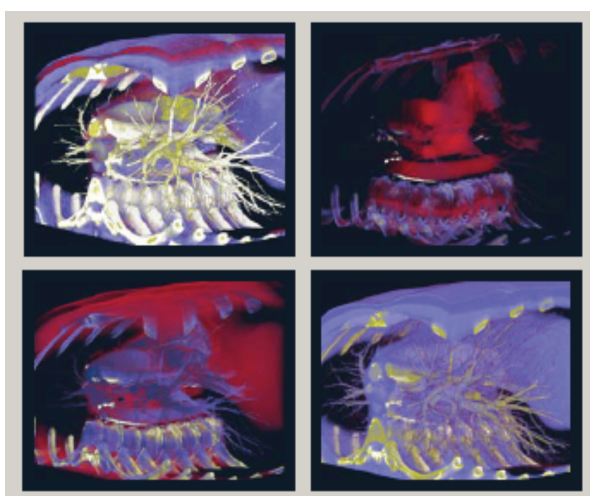


Figure 2. The windowing technique enables medical professionals to adjust the viewed tissue density of 3D medical images. In this figure, the same 3D cardiac image is displayed in four different viewed tissue density ranges.

3.2.2 Windowing

The method of changing the tissue densities displayed in 3D medical images (Figure 2) is called windowing. Through windowing, one can isolate tissue density ranges for investigation of a specific anatomical feature. For example, orthopedic specialists could track changes in bone density by adjusting the windowed values to view a patients bone structure [11]. Most 3D medical imaging studies focus on rotation, clipping, zooming and translation, with only limited research focused on the usability of COTS devices with respect to windowing [12, 13].

In one study, ten medical professionals tested a Kinect™ and a voice recognition software configuration compared to a traditional mouse and keyboard configuration. Participants recreated medical image screenshots using windowing, rotation, and zooming techniques. The Kinect™ and a voice recognition software configuration took 75.1 seconds on average, while a traditional mouse and keyboard configuration took 52.1 seconds on average to complete the task. Preferred interactions with windowing techniques for medical professionals were not discussed [13]. Although this study was valuable: 1) recreating medical viewpoints is not a typical task performed by medical professionals and 2) performing tasks to find and identify anatomical features requires specific anatomical knowledge.

Implementation of COTS interaction devices for manipulation of 3D medical images in medical facilities is the wave of the future as these devices offer extended capabilities beyond tradition mouse and keyboard configurations.

However, medical environments create unique challenges that need to be addressed before the appropriate COTS devices can be selected and used effectively. Medical professionals need tools that are efficient and easy to learn and use. From our observation, technicians are often asked to operate computers with patient data instead of the doctor to maintain a sterile working environment. This situation is not ideal. Natural communication barriers between the doctor and technician increase operating time and chances for mistakes. This research explores options of returning computer control to the doctor through touch-less navigation of 3D medical images through the use of a Microsoft® Kinect™.

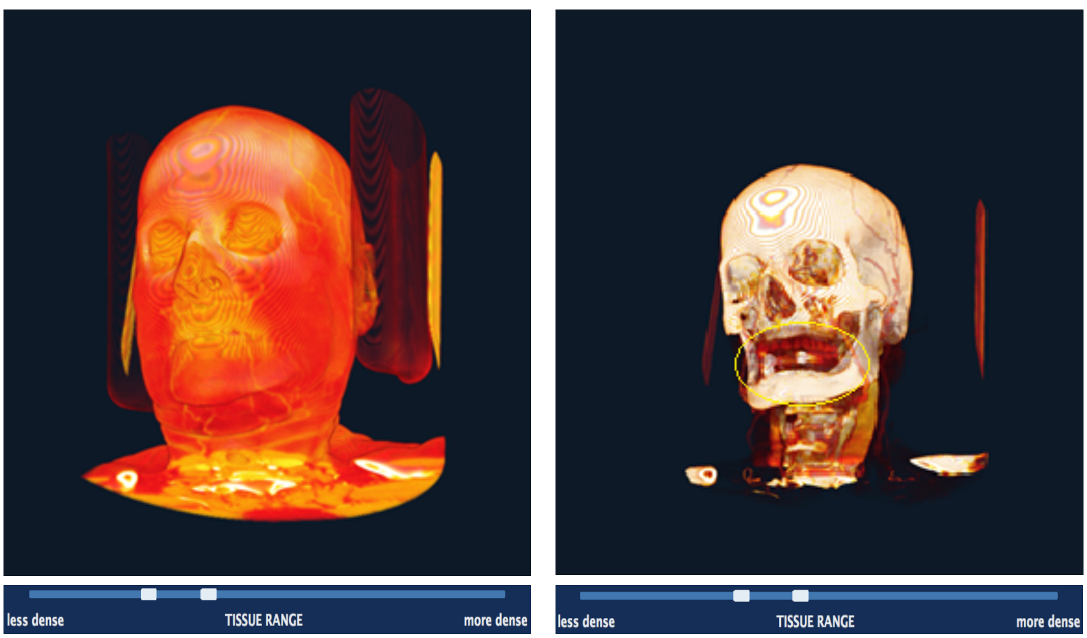
3.3. Methodology

This study compared user performance for a windowing task when using both the Kinect™ and a traditional mouse. A software platform, Isis, was developed at the Virtual Reality Applications Center (VRAC) for the express purpose of studying various technologies for use in visualizing and manipulating digital medical data. Isis includes zooming, rotating, coloring, clipping and windowing functionality; however, all features except windowing were disabled for the experiment. The study consisted of three sections: pre-evaluation, task performance and post-evaluation.

3.3.1 Pre-evaluation

This section began with a pre-survey. Participants were asked to complete basic background questions about themselves, education, experience with medical imaging and commercially available virtual realty technology (e.g., Kinect™, and 3D movies). The pre-evaluation wrapped up with the completion of the Mental Rotation Test [14]. These evaluations served to identify a participant's ability, which could impact the study.

3.3.2 Task performance



(a) (b)

Figure 3. (a) An anatomical region is shown, and the participant will be instructed that he/she has two minutes to locate a specific structure by only windowing. For this specific anatomical region, the participant will be instructed to locate the teeth. (b) When the participant indicates that he/she has windowed to display the target anatomical structure displayed most clearly, the moderator captured the slider bar values and task completion time.

Participants performed the same eight tasks with both the Kinect™ and the mouse. The task order was alternated to reduce a learning curve associated with repetition and the order of interaction devices was randomized between participants. Before each interaction, participants familiarized themselves with the interaction device and its corresponding response with the software. Participants were given two minutes to complete each task.

For each task a different orientation of an anatomical region was shown on a computer screen (Figure 3a). Based on a verbal command, participants adjusted the double handled slider bar to reveal the appropriate anatomy. Once a participant indicated they adjusted the position of the tissue density range such that the targeted anatomical structure was displayed most clearly (Figure 3b) the study moderator captured the location of both slider bars and task completion time. If the participant was unable to successfully locate the anatomical structure within a two-minute time frame, the next anatomical region was displayed and the previous task was counted as incorrect. The procedure was repeated for eight anatomical structures.

Once the tasks were complete using the first interaction device, participants were trained with the interaction device not previously used. The participant was asked to identify the same eight anatomical structures in a different order, using the same methodology used for the first interaction device. Slider bar values and task completion time were again captured if the participant indicated that the targets anatomical structure was clearly displayed within the two-minute time period. The captured data was evaluated to determine if the selected region corresponds with calibrated values for CT Hounsfield units of specific tissue types [15].

Mouse |-----|-----|-----|-----|-----|-----|-----|-----|-----|-----| Kinect™

Figure 4. Scale used to preference between the mouse and Kinect™ during comparison evaluation.

3.3.3 Post-evaluation

Participants were asked to complete two final evaluations based on their experience with the Kinect™ and mouse. The first was a comparison survey with a 10-point scale between the mouse and Kinect™. They were given six statements and asked to mark their preference between the two devices (Figure 4). Participant's marks were numerically converted for analysis purposes. The mouse was assigned the rating zero and the Kinect™ was assigned a rating of 10. Finally, participants answered five questions to provide qualitative feedback about their experience with the interaction device. Their statements are included in appropriate sections of the results section.

3.3.4 Equipment

The computer used for the study was a Dell Precision T5500 with a Xeon W5580 at 3.20GHz CPU, 4 GB of RAM, and nVidia Quadro FX 5800 graphics card. The monitor was a 24in Dell 2408WFPb, running at a resolution of 1920x1200. The Kinect™ was the Xbox 360 version.

3.4. Results

3.4.1 Demographics

Participants included first through fourth year veterinary medical students who had taken a gross anatomy course. A total of 17 participants were part of the study; 4-first year students, 5-second year students, 7-third year students and 1-fourth year student. Participants range in age from 22 to 45 with a median age of 24. Two participants were male, while the rest were females. All participants

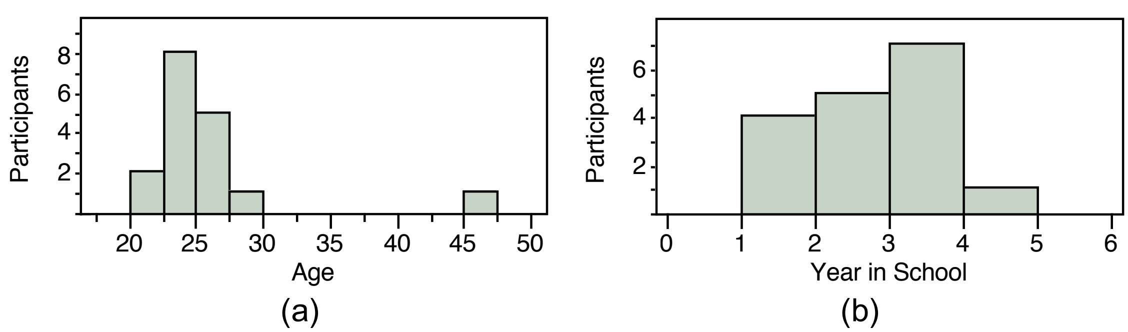


Figure 5. (a) Distribution of participants by age. (b) Distribution of participants by year in school.

reported minimal experience with 2D medical images with these being in an observation setting (classroom and clinical observation) or a radiology course offered at the university. Three students had prior experience with 3D medical imaging and all cases were mono-vision.

3.4.2 Procedure

Each participant was presented an informed consent document to begin the study. They were familiarized with the study, including information about the tasks they would be asked to complete, pre- and post-evaluation surveys. Participants were also made aware that the study was completely voluntary and they had the right end the study at any time. Participants were compensation for their time. This procedure is in accordance with Institutional Review Board (IRB) policy.

Each participant was given eight tasks with both the Kinect™ and mouse, equaling 16 tasks per participants. One participant's results were removed from the study due to an error in the timing function, thus data from 256 tasks was available to evaluate. The first metric analyzed was task completion. Participants had two minutes to adjust the anatomy via windowing based on the task command. 22 (nine for Kinect™ and 13 for mouse) tasks were not completed within the allotted time period. The next metric examined was accuracy. Specific Hounsfield units were assigned to the various anatomical structures in the participant tasks [15] as shown in Table 1. However, determining if a response was "correct" was not as simple as seeing if the range determined by the participant included either the single value or range predetermined in Table 1. For example, when two ranges were being compared they might overlap. It was difficult to determine what percentage of overlap constituted an answer as correct. It was decided to simply extend the range the participant determined. It was tested using percentages (5%, 20%) as well as adding 500 to each side of the range. The only thing affected was the number of tasks considered correct. With only a 5% range increase over 100 tasks would be deemed incorrect. With a 20% range increase, approximately 30 cases would be incorrect. This is truly a judgment as participants are deciding based solely on visual feedback. A representation could visually be close, but mathematically be incorrect. After having performed this study, it is recommended that an expert determine if final values are correct or not. For the remainder of this paper, the ±500 is used. Using this, 12 cases (nine for Kinect™ and three for mouse) were deemed incorrect. Overall, 18 tasks were removed from the Kinect™ and 16 tasks from the mouse for reasons of exceeding the time limit or incorrectly identifying the anatomical feature.

Table 1. Selected calibrated Hounsfield Units specific to tasks [15].

Tissue Type	Hounsfield Units		Tissue Type	Hounsfield Units
Muscle	1027		Ribcage	1575
Blood	1055		Hard Bone	1783
Skin	1075		Cranium	1903

3.4.3 Task Analysis

The remaining 222 completed and correct tasks were further analyzed between use of a mouse or the Kinect™ device. The completion time, window width lower bound and window width upper bound were captured for each task. The data presented below shows 80% confidence and higher, including associated median values for the Kinect™ and Mouse. Tasks are not presented in the order of participant completion.

Task One (Table 1 - Blood): Window so the blood vessels from the chin to eye sockets are clearly displayed.

Participants took less time to complete this task when using the Kinect™ compared to the mouse. Time was statistically significant at a confidence level of 85% and p=0.15 with a one-sided t-test. The median time to complete this task for the Kinect™ was 25.02 seconds, while the mouse took 38.96 seconds. Window center and window width were not statistically significant above an 80% confidence level with p=0.2.

Task Two (Table 1 - Blood): Window so the blood vessels and skin are visible.

Differences were not of statistical significance above an 80% confidence level with p=0.2.

Task Three (Table 1 - Cranium): Window so the skull is clearly displayed with no muscle visible.

For this task, participants choose a more centralized window center when using the Kinect™ compared to using the mouse. Window center was statistically significant at a confidence level of 80% and p=0.2 with a one-sided t-test. The median window centers for this task were 1612 for the Kinect™ and 1754.5 for the mouse. Time and window width were not statistically significant about an 80% confidence level of p=0.2.

Task Four (Table 1 – Ribcage to Cranium): Window so the skull and ribcage are isolated.

Differences were not of statistical significance above an 80% confidence level with p=0.2.

Task Five (Table 1 - Skin): Window do the skin is visible and opaque.

Differences were not of statistical significance above an 80% confidence level with p=0.2.

Task Six (Table 1 - Skin): Window so only the skin is showing with no internal anatomies visible.

Differences were not of statistical significance above an 80% confidence level with p=0.2.

Task Seven (Table 1 – Skin to Muscle): Window so the skin and soft tissue begin to disappear.

Participants took less time to complete this task when using the Kinect™ compared to the mouse. Time was statistically significant at a confidence level of 85% and p=0.15 with a one-sided t-test. The median time to complete this task for the Kinect™ was 17.76 seconds, while the mouse took 22.70 seconds. Window center and window width were not statistically significant above an 80% confidence level with p=0.2.

Task Eight (Table 1 – Hard Bone): Window to make the teeth as visible as possible.

For this task, participants choose a more centralized window center when using the Kinect™ compared to using the mouse. Window center was statistically significant at a confidence level of 90% and p=0.1 with a one-sided t-test. The median window centers for this task were 1903.5 for the Kinect™ and 2220 for the mouse. Time and window width were not statistically significant about an 80% confidence level of p=0.2.

As seen, four of the 24 task measures were statistically significant for the eight tasks. However, this is due to the relatively small number (> 16) of data points compared for each task and interaction device. Analysis of all task data was also complete.

Time: Overall, the time for participants to complete tasks took longer on the

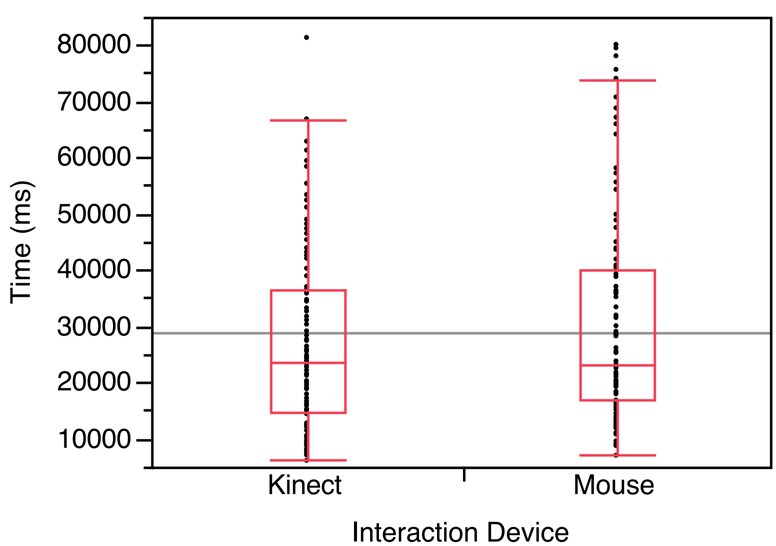


Figure 6. Distribution of participant times for all completed tasks. Participants spent more time completing tasks with the compared with the mouse.

median with the Kinect™ compared to the mouse. Time was statistically significant at a confidence level of 85% at p=0.15. However, the median values for the Kinect™ were not vastly different, the median time for all tasks were 23.82 seconds for the Kinect™ and 23.2 seconds for the mouse. Times for the Kinect™ ranged from 6.1 seconds to 81.32 seconds, while the time ranges for the mouse were 7.02 seconds to 80.09 seconds.

Center: Differences were not of statistical significance above an 80% confidence level with p=0.2.

Width: Differences were not of statistical significance above an 80% confidence level with p=0.2.

3.4.4 Survey Analysis

After completion of the tasks, participants were asked a series of questions. The first set was a comparison survey to evaluate the participant's preference between the two interaction devices. The first two statements asked about shifting the tissue density range from higher tissue densities to lower tissue densities and the reverse of shifting from lower tissue densities to higher tissue densities. There was no statistically significant difference present above an 80% confidence level with p=0.2.

The second set of statements in the comparison survey evaluated participants' preference for making large adjustments compared to small adjustments with the interaction devices. Participants preferred making large adjustments with the Kinect™ and small adjustments with the mouse. Adjusting the tissue densities by larger or small margins was statistically significant at a 99% confidence level of p=0.01.

The final statement was independently evaluated. Participants preferred to use the mouse to obtain their desired range of tissue densities. A score closer to zero indicates a preference for the mouse, while a score closer to ten indicates a preference for the Kinect™. The median score for obtaining their desired range of tissue densities was 2, with a maximum score of 8 and a minimum score of 0.

Participant scores on the MRT were analyzed along side the preference scale completed after using both interaction devices to determine if there was a correlation between high-visual-spatial skills and participants preference toward one device or the other. Individuals who scored higher on the MRT preferred using the Kinect™ to shift from higher to lower tissue density ranges. This correlation was statistically significant at a 90% confidence level of p=0.1. The five remaining preference ratings did not show statistical significance above an 80% confidence level and p=0.2.

3.5. Discussion

The results of this study suggest improvements to Kinect's™ interaction design need to be addressed before the device can effectively be implemented as a primary interaction device for 3D medical imaging. Most participants choose the mouse as their preferred device for reasons of precision. Participants were able to accurately choose the desired location for the slider bars, which allowed for smaller window widths. The Kinect™ struggled to identify participant hands when moved close enough together to achieve smaller window widths. It would no longer recognize two objects, but only one and would seek to find the “missing” hand.

A trend in the data also showed that participants using the Kinect™ very rarely moved both slider bars to one extreme end or the other on the Hounsfield units range when select the appropriate view of an anatomical feature. The median values for both devices were within a few units, the range window centers for the Kinect™ was from 598.5 to 2256.5 compared to the mouse with a range of 206 to 2508. The extreme ranges of data were much more accessible with the mouse compared to the Kinect™.

For this study we used direct mapping for interaction, where the number of pixels across the screen directly mapped to the viewable width available with the Kinect™. Research needs to be conducted to improve the mapping between the participant hand locations and the interaction with the software, specifically in the extreme regions of the lower and upper ranges of Hounsfield Units and when a user’s hands get close enough to achieve small window widths.

A novelty factor was also present during participant use with the Kinect™, participants were unfamiliar with how to effectively correct when an undesired response occurred. It appeared that many of the participants used a trial and error approach when operating the Kinect™ compared to known method of operating the mouse for many years. These two approaches showed a learning curve that must be identified and overcome before the Kinect™ can be an effective device to replace the mouse in 3D medical imaging environments. Understanding how professionals intend to use an interaction device will improve the overall design and functionality.

The effect of the Kinect™ being a novelty to the participants also affected the amount of time each participant took for each task. The Kinect™ appeared to have more fumbling that resulted in increased time per task. Evaluating quartile time data showed consistently lower time to complete tasks for the Kinect™ compared to the mouse, except at the median. Individuals using the mouse spent their extra time contemplating the correctness of their answer, since readjusting a hand position did not result the slider bars shifting location. For example one participant exceeded the time limit for all of the tasks involving the mouse and only two out of eight upon switching to the Kinect™.

Overall, the preferred interaction device to complete a window task was the mouse. Students were familiar with the device and how it would interact with the software. Additional research must be conducted to identify standards for effective implementation of the Kinect™ into 3D medical imaging environments.

3.6. Conclusion

Using the Kinect™ as an interaction device to perform 3D medical imaging windowing tasks shows opportunity. With the appropriate design that improves Kinect™ interaction in the extreme regions of Hounsfield units and when a participant's hands are close enough for small window widths. Kinect™ does have the opportunity to offer a sterile working environment for medical professionals. If the precision is improved, the interaction device will be a plausible option for operating rooms and other sterile environments. The Kinect™ has the potential to reduce the time on task for participants, however, there would be a reduction in the time professionals would spend analyzing an anatomical region.

3.7. Future Work

Additional work needs to be completed to reevaluate this work and also identify improved methods of mapping participant's hand movements to the windowing functionality. There is opportunity for the Kinect™ to be an effective interaction design, but not until an appropriate design is developed to improve the efficiency of the work, instead of decrease the efficiency of the work.

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CHAPTER 4. EVALUATING THE MICROSOFT KINECT™ AS AN INTERACTION DEVICE FOR WINDOWING MEDICAL IMAGES.

Prepared for submission to Computers in Biology and Medicine. Entirety of results will be summarized prior to submission due to page restrictions.

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Abstract

Improvements in visualization technologies has allowed three-dimensional (3D) medical images to be volume-rendered from magnetic resonance imaging (MRI) and computed tomography (CT) scans. This technology has been implemented into operating rooms, clinics and other medical facilities, but has been shown to be another source of contamination causing many health-care associated infections (HAIs). Spaces that are classified as sterile environments could benefit the most from touch-free interaction devices to access medical software. Commercial-off-the-shelf (COTS) devices provide opportunities for touch-free interaction to maintain the sterile environment required in operating rooms. Researchers have begun to explore the use of the Kinect™ as a touch-free device for medical applications. However, limited research has been conducted to determine the overall usability of the Kinect™ for medical applications. This paper evaluates the Kinect™ for its usability and functionality

when working with medical 3D anatomical images. The objective of this work was to explore participant's use of the Kinect™ to complete interaction manipulations. Isis, a software platform developed at the Virtual Reality Applications Center at Iowa State University, was used by participants to completing a task called windowing to view anatomy within a 3D image generated from a patient's series of CT scan. This paper, presents the methodology and results of a user study to examine the usability and functionality of the Kinect™ to complete windowing of 3D medical anatomical images.

4.1 Introduction

The advancement of technology has enabled doctors to access computed tomography (CT) or magnetic resonance imaging (MRI) scans of patients to view internal organs without invasive surgery. This technology has been included in operating rooms (ORs) and other sterile environments for additional information during surgery. To promote the sterile environments required in ORs, medical assistants control computer equipment with guidance from the operating doctor. These relationships can have communication errors and increased frustration through already stressful surgeries. Touch-free interaction devices have emerged on the commercially available market to enable the operating surgeon direct access to a patient's data. This paper explores the usability and functionality of the commercial-of-the-shelf (COTS) Microsoft Kinect™ as an interaction device for medical imaging technology. The objective of this work is to validate the

Kinect™ as having comparable usability to a mouse by not limiting the users ability to complete specific tasks. Participants in this study completed a task of changing the tissue densities displayed in a three-dimensional (3D) anatomical region or more commonly called, windowing.

4.2 Background

Computers are a relatively new addition to hospitals and clinics. Virtual reality (VR) for medical applications was originally developed during the mid-eighties. This rudimentary technology required several hours of computing time to produce images taken with a CT or MRI scanner to produce 3D anatomical representations of a patient's body. Using volume rendered images as tools for diagnosis has become a somewhat common practice for medical professionals [1], enabling the examination of 3D images from a patient's CT scans.

The addition of computers into medical facilities has come with insufficient sterilization procedures. The lack of appropriate sterilization has lead to an increase in the number of health-care related infections (HAIs) across the United States. Bures et al. estimated in 2000 that 2 million patients developed nosocomial infections in the United States at a cost of $4.5 billion each year [2]. The CDC reported that approximately 1.7 million HAIs caused over 99,000 deaths in 2007 [3]. Reducing the time patients' spend in hospitals and the overall cost of the visit is becoming a wise business decision, along with being in the interest of patients [4].

Appropriate disinfection strategies were not in place to prevent the spread of germs [5] when computers were first implemented in the hospital setting. Many hospitals have monitored the spread of contamination and found computers continue to be a problem with irregular disinfection procedures [2, 5-7]. With routine cleaning regimes [6], researchers have observed a decrease in the number of days patients suffered from infections during catheter use [4].

Communication is another barrier that must be overcome when working with medical imaging technology. Medical assistants would be responsible for manipulating medical images for the operating surgeon to maintain sterility in the OR [8]. However, this structure creates communication barriers between doctors and technicians increasing operating time and chances for mistakes. These barriers can create frustration [8-13] and increase cognitive mental workload faced by surgeons [10, 12].

Doctors avoiding hospital protocols to prevent the spread of contamination can also be a major issue when trying to reduce HAIs. To gain personnel access to a patient's data, those performing surgery will dirty the bounds of sterility. One researcher observed a surgeon pulling their surgical gown over their gloved hand, considered to be sterile, and operate the computer. This allows them the fine grain control to interact directly and visualize a specific region of anatomy [12].

Neither situation of miscommunication or blurry sterile boundaries is best for the patient. Researchers must explore new opportunities within technology to minimize the communication errors and compromised sterile environments to improve the safety and well being of patients. Currently, medical technology is able to visualize and analyze a patient's data within seconds, however many problems involving interaction with technology have yet to be solved [14]. Designing seamless healthcare through people and technology working as a single unit, will open doors for improved healthcare and reduced medical expenses [12].

4.2.1 Radiological Advancements

As the capabilities of technology continue to advance, new opportunities enable advanced methods for medical diagnosis. Researchers have developed the technology to perform a virtual colonoscopy in hopes of replacing a conventional optical colonoscopy. The virtual colonoscopy begins with a computed tomography (CT) scan of the patient. Doctors are able to use visualization software to reconstruct the region and navigate around in search of polyps. They found the application to have a 94% sensitivity to real polyps and a 96% sensitivity to false-positives, which are acceptable numbers to doctors. The software is able to locate polyps in corners and folds of the colon as well as the outside of the colon wall; both cases are hard or impossible for optical colonoscopy methods to detect [15].

Opportunities have also developed to improve how radiologists interact with the images captured of patients. For decades, radiologists have used a traditional mouse to navigate the expansive amount of data collected about each patient. However, these traditional techniques are not always optimal for accessing large amounts of data in an efficient amount of time. Researchers have explored using the P5 Glove Controller (Figure 1a) as an opportunity to provide 3D input for radiologists exploring medical anatomy. Radiologists are able to interact with the anatomy with 6-degrees of freedom. They found that individuals benefitted from 3D input compared to 2D input with improve accuracy and time on task [16].

(a) (b)

Figure 1. (a) P5 Glove Controller is an interaction device that enables intuitive interaction from hand gestures and other familiar motion. (http://www.mindflux.com.au/images/glove_photo_lrg.gif) (b) ShuttleXpress jog wheel is an alternative to traditional mouse. (http://www.prokit.co.uk/product_images/b/772/1267190337__85802_zoom.jpg)

Atkins et al., compared the ShuttleXpress jog wheel (Figure 1b) with two traditional interactions techniques available with the mouse: 1) scroll wheel and 2) click and drag. Their evaluation focused on speed, accuracy, navigation path and user preference for finding anomalies in patient data by radiologists. Researchers found no difference between performance time to complete the tasks for participants using different devices, although the rate at which they scroll through the data for the first time varied depending on the interaction technique. They concluded that the techniques were comparable in performance and encouraged multiple interaction devices be available at workstations for individuals to select the method that works best for their needs [14].

3.2.2 Commercial-Off-The-Shelf Technology

A variety of commercial-off-the-shelf (COTS) products that were originally designed for the gaming industry have also been evaluated for incorporation into the medical industry as interaction devices. The gamepad (Figure 1a) uses ergonomically positioned dual analog joysticks and buttons to enable fingers and thumbs on both hands to interact with multiple buttons at any given time. The large number of combinations of inputs from the user and the ergonomic design have shown to enable quick learning and understanding of how to effectively use the interaction device [17].

The Wii Remote™ (Figure 2b) is another option within the array of commercially available interaction devices. The Wii Remote™ is a single hand-held remote that is tracked and offers 3D virtual environment interaction. The positional data from the user's movements is detected by receivers and used by the software to replicate the user's motion within a virtual environment [18]. The Kinect™ (Figure 2c) is the most recent option for COTS interaction devices as

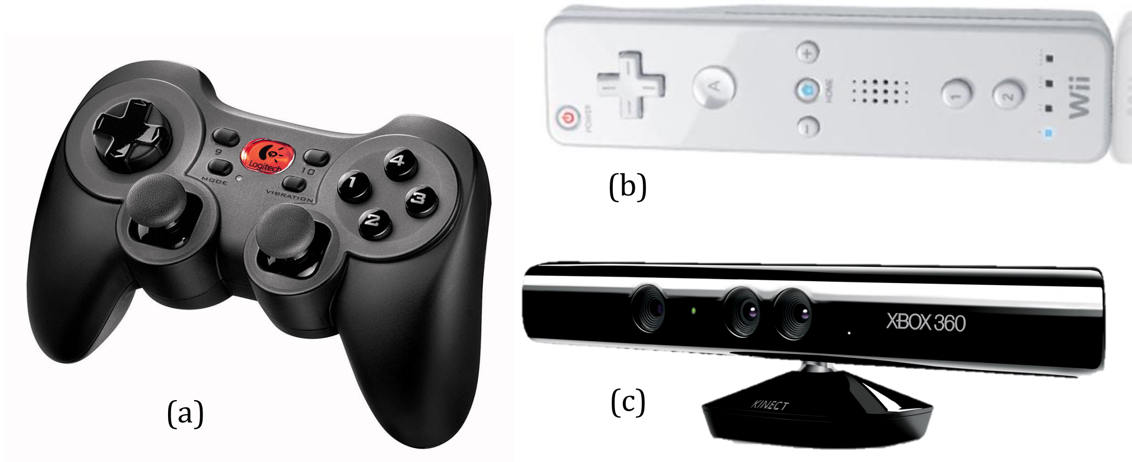


Figure 2. a) The gamepad offers numerous button combinations due to ergonomic design for ease of use and improved learning. (http://compactiongames.about.com/od/hardware/tp/gamepads.htm) b) Wii Remote™ offers one-handed interaction with a series of buttons and positional tracking. (http://toys.dailysteals.com/deal/4039/Nintendo-Wii-Gaming-Console-with-Wii-Remote-and-Nunchuk) c) The Kinect offers touch-free interaction through an infrared array of points and two cameras to capture the movements of users to control the interaction. (http://www.giantbomb.com/kinect-support/3015-3249/)

applications for interaction in the medical industry. The device uses an array of infrared points projected on a participant and two cameras to calculate the three-dimensional nature of a participant's movement through skeletal tracking. The device offers touch-free interaction for potentially sterile environments that occur in medical environments [3].

4.2.4 Kinect™ Applications

Selecting the appropriate interaction device is vital to improving the interaction for various users based on their environment. Every task requires specific manipulations, which can improve or worsen the user experience based on the interaction device and how the software is designed to handle the user specified interactions. Since the introduction of the Microsoft Kinect™ as a COTS interaction device, researchers have been applying the technology to the medical industry.

Rothberg and Bailey proposed a solution to reduce the number of health-care related infections by reducing the amount of equipment that needs to be sterilized between patients, enabling quicker turnover of personnel from patient to patient, specifically in emergency medical situations. Their solution was to use a Microsoft Kinect™ to provide touch-less navigation and interaction with medical software and technology in the operating rooms, emergency rooms, and other locations around hospitals and clinics [3]. Effective usability design through the use of the Kinect™ as the interaction device has the opportunity to offer hands-free interaction for sterile environments, such as the operating room, emergency rooms and clinics.

4.2.4.1 Monitoring Applications

One-way the Kinect™ has been proposed to be used is in the medical industry is for monitoring purposes. One application uses the Kinect™ to monitor real-time respiratory motion of patients. Using a Kinect™ and a translational surface laying on the patient's chest, they showed that the Kinect™ is capable of measuring respiratory motion. This application was reported as a proof of concept and is still in development at the University of Iowa [19]. Another application monitors the movement of senior citizens and can be used to prevent life threatening falls. The software evaluates the individual's stride-to-stride variability to monitor a decline in functionality to predict when a fall may occur. This application is being developed at the University of Missouri [20].

4.2.4.2 Individuals with disabilities

Smart Planet explored the Microsoft Kinect™ as an option for the medical industry. The article reported that Intel intends to use the recently released, now open-sourced, complete core source code to create an application that can be used by Stephen Hawking to speak more efficiently. The current application Hawking uses to speak monitors his movements and can only produce one word per minute. The article concluded that providing the Kinect™ code completely open-source would enable improved technology for those with disabilities [21]. A similar application developed by the Research Center for Advanced Science and Technology at the University of Tokyo helped children with severe disabilities communicate through movement [22]. The Kinect™ offers new opportunity to improve how those with disabilities connect with their surrounding communities.

4.2.4.3 Rural Connections

The Kinect™ has also been proposed to provide cutting edge medical knowledge to rural communities across the Unites States and around the world. During the 1980s and 1990s, medical schools across the country restricted entry for fear of a surplus of doctors. Unfortunately, this has caused hospitals and clinics to face a shortage of trained professionals to serve the aging community

[23]. A telementoring system created by Bailey and Jensen, enabled doctors to consult medical specialists about aging patients and those with severe injuries. The low-cost system combines a laptop, Kinect™, Azure connection and Office 365 account. The Kinect™ allows touch-free control of the software communication system, while performing medical procedures on patients and receiving guidance from a specialist. The system could cost tens of thousands of dollars less than existing telemedicine systems [24].

Craig Mundie, Chief Research and Strategy Officer for the Microsoft Corporation gave a speech at the Pacific Health Summit on June, 23, 2011, his presentation was titled: “How computing can help transform healthcare.” He discussed the rapid increase that will occur over the next few years to incorporate a big data model into current platforms of medical infrastructures. Big data is utilizing large amounts of data collected from patients and using machine learning and analytics to improve patient outcomes, while lowering the overall cost of health care. The improvements of big data will offer learning avatars in rural communities, who are not able to access state of the art medical facilities, to have the information to appropriately diagnosis patients. This solution uses the Kinect™ to expanded access to third world communities, by providing basic treatments of well-known diseases and ailments from autonomous big data driven avatars [25].

4.2.4.4 Developments in Imaging Interaction

Gallo et al. have developed a system using the Kinect™ to perform gesture based touch-free interaction with a medical software package. The paper profiled the Kinect™ as an input device with interaction techniques that were designed for individuals to interact with the medical images. Users did not test the system to evaluate the effectiveness of the gestures selected for the tasks [26].

News sources have discussed the application of the Kinect™ in the medical industry [9, 27]. As other nations deploy applications in operating rooms, clinics and other healthcare locations, the United States media outlets and technology communities have prompted the discussion about the application of the Kinect™ as an interaction device for medical technology. The Japanese are expanding the use of Kinect™ into their operating rooms and other medical arenas [22]. Exploration of the Kinect™ in the operating room has begun in Canada and has been used six times during surgery, with future plans to implement the technology in other parts of the hospital [27].

Trials have begun to evaluate the Kinect™ as an effective interaction device in operating rooms in London. A surgeon at Guy's and St. Thomas's hospital has been using the device to interact with patients CT scans during surgery. Over the course of the first surgery, he interacted with the application five times throughout the 90-minute surgery. He reported to a news agency that the interaction was very intuitive, allowing him complete access and control of the application and avoid working through a technician to view the patient's anatomy [9].

4.2.5 Windowing

One of the features in medical imaging software is called Windowing, which is the feature used for this study. Windowing is performed to change the tissue densities displayed in a three-dimensional anatomical image (Figure 3). This manipulation isolates specific tissue types for further investigation into anatomical regions. For example, through this technology, orthopedic specialists are able to track changes of their patients bone density by eliminating the tissue that is not bone [28]. Limited research has been conducted to understand the effectiveness of using windowing as a technique to explore anatomical regions,

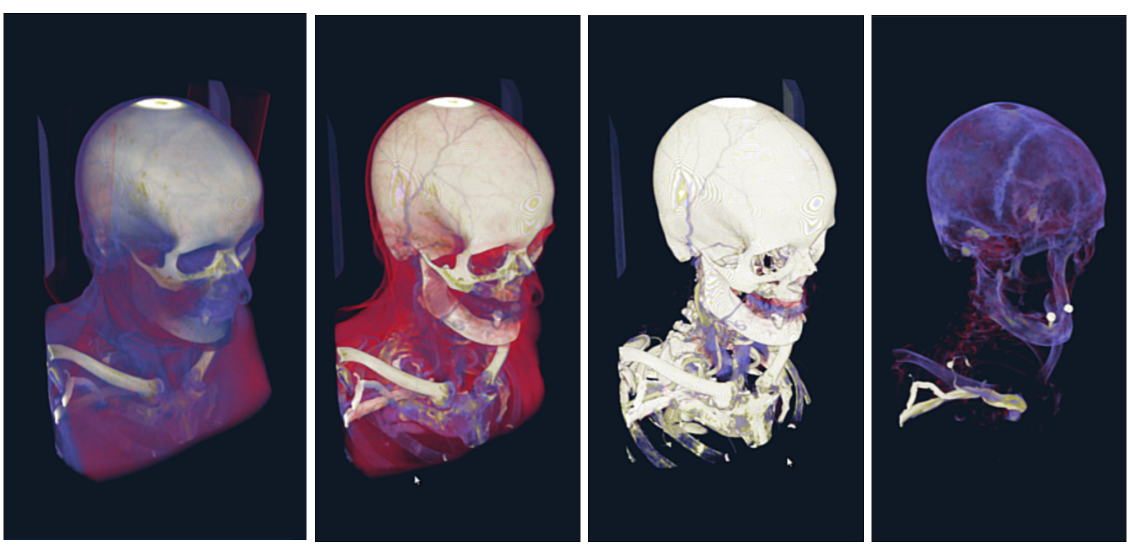


Figure 3. The windowing technique enables medical professionals to adjust the viewed tissue density of 3D medical images. In this figure, the same 3D anatomical image is displayed in four different viewed tissue density ranges.

most COTS specific medical imaging usability studies focus on rotation, clipping, zooming and translation [26, 29].

4.2.6 Motivation

The Kinect™ is gaining momentum as an interaction device to improve the accessibility of medical professionals to patient data. This paper looks to answer a series of questions about the usability of the Kinect™ compared to the mouse.

- Does the Kinect™ improve the efficiency of altering tissue densities for trained medical personnel?
- Has the tested interaction method been designed effectively to reduce the learning curve and improve the overall experience?
- Are trained medical personnel able to access tissue density information with the precision and accuracy offered by a mouse and keyboard?

4.3 Methodology

For the study in this article, user performance and experience was evaluated when completing the task of windowing with either the Kinect™ or a traditional mouse. Isis, a software package developed at the Iowa State University's Virtual Reality Applications Center (VRAC), was used for the development and execution of the study. Isis is capable of clipping, rotating, zooming, coloring and windowing anatomy loaded from medical imaging data. All features other than windowing were disabled for the purpose of the study. The study was carried out in three major sections: pre-evaluation, task completion, and post-evaluation.

4.3.1 Pre-evaluation

Each participant completed a pre-survey prior to completing the interaction tasks. They were asked to fill-out basic information about themselves, classes completed in school, and previous experience with medical technology. This information was gathered to be able to evaluate user performance compared to previous experiences.

4.3.2 Task Completion

Participants used either a Kinect™ or a traditional mouse as the interaction device to manipulate medical anatomy data and perform windowing. The participants were randomly assigned to complete tasks with one device and were not given the opportunity to try the other interaction device during the study. For the study, participants interacted with a double handled slider bar with the Isis graphical user interface (GUI) either simultaneously or independently, dependent on whether they were using the Kinect™ or mouse, respectively. The double handled slider bar represented the windowing values. The lower slider was the minimum value, while the upper slider was the maximum value. From these values window width (the distance between the slider bars) and window center (center point between two sliders) could be calculated. This interaction changed the tissues densities displayed within the anatomy.

The tasks were selected with assistance from anatomy professors, to ensure participants would be knowledgeable of selected anatomy. Each participant completed five tasks per round and completed four rounds total. The rounds were divided into two sets; A (first two rounds) and B (second two rounds). Participants used the same group of tasks for each set during the round and the order was randomized between rounds (Table 1).

4.3.2.1 Set A

1. Display an opaque skull, while eliminating all skin and musculature.
2. Display the zygomatic bones visible through the skin
3. Display the facial artery visible through the skin
4. Display the pulmonary arterial trees visible within the lungs
5. Display the spinous process surrounded by muscle

4.3.2.2 Set B

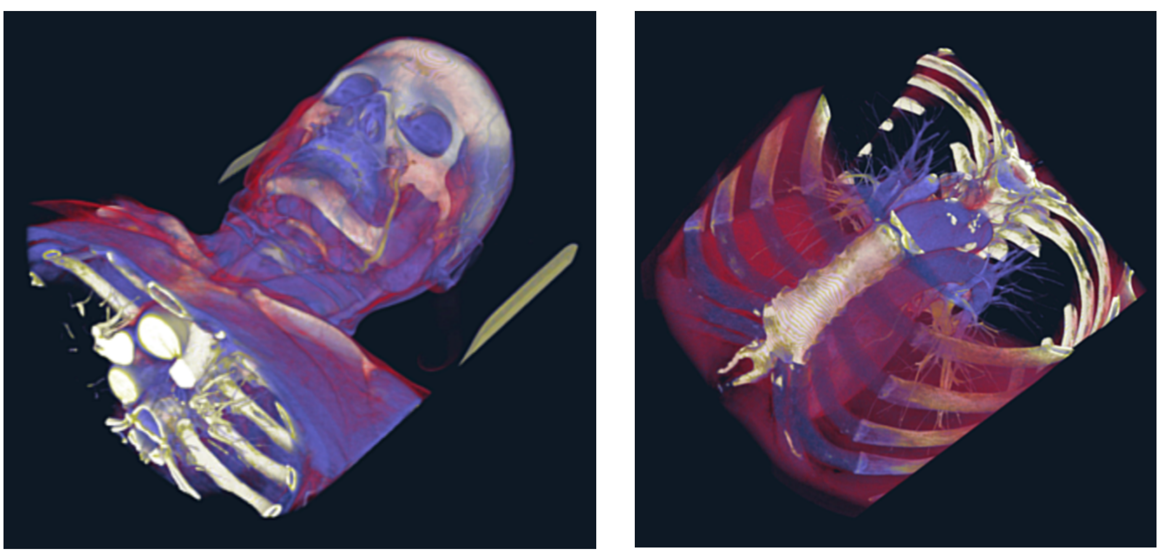
1. Display the best view of the costal cartilages
2. Display the best discrimination of the sternal angle joint
3. Display the pulmonary artery.
4. Display the skin of the thoracic wall as opaque, while hiding the superficial musculature
5. Display the ribcage so the heart is clearly visible through the ribs

Tasks were presented to participants in the following order to prevent bias in order of difficulty. The orders of tasks were randomly selected from a listing of all possible combinations of task orders.

Table 1: Randomized task orders to prevent possible difficulty bias based on generated order of tasks.

	Task				
Set A – Round 1	3	4	2	1	5
Set A – Round 2	1	3	2	4	5
Set B – Round 3	3	2	5	4	1
Set B – Round 4	2	1	4	5	3

Two datasets were selected for set A and set B tasks for the four rounds. The first two rounds were completed using a dataset of a head region (Figure 4a). The second two rounds were completed using a dataset of the chest cavity (Figure 4b).



(a) (b)

Figure 4. a) Head dataset used for set A rounds. b) Chest cavity dataset used for set B rounds.

Participants were given two minutes to complete each task with a short break between rounds. They gave verbal cues when they felt they had appropriately completed each task and the task was advanced. The computer screens of participants were recorded during the study to capture the anatomy selected by participants for accurate grading.

4.3.3 Post-Evaluation

Once all tasks were completed, participants were asked to complete two follow-up surveys. The first was an attitude measurement to determine how participants felt as they were using the interaction device to complete the series of tasks. The participants rated the following emotions on a five-point scale from Always to Never;

- Bored
- Interested
- Frustrated
- Anxious
- Calm
- Excited

The second was a questionnaire to further evaluate the interaction device. The participants rated the following statements on a five-point scale from Strongly Agree to Strongly Disagree;

- I would prefer to use this device for medical imaging interaction

- The interaction felt awkward
- The interaction device distracted from the task
- I found the task to be rather difficult
- The interaction device was too complicated to use.

Followed by two free answer questions:

- What features on the device did you enjoy using?
- What did you find the most difficult about using the interaction device?

4.3.4 Equipment

The Kinect™ device used was the Xbox360 version. The three computers used were Dell Precision T5500 with Xeon W5580 at 3.20GHz CPU, 4 GB of RAM, and nVidia Quadro FX 5800 graphics card. The monitors were 24in Dell 2408WFPb, running at a resolution of 1920x1200.

4.4 Results

4.4.1 Demographics

Overall, 32 individuals participated in the study. All participants are currently studying at Touro University in Vallejo, California. Participants ranged in age from 24 years old to 63 years old with a median age of 28 (Figure 5a). Twenty participants were male, while twelve participants were female. A majority of students were in their first year of medical school (19), while 7 were 2nd year students, 3 were 3rd year students and 2 were professors or staff of the anatomy laboratory (Figure 5b).

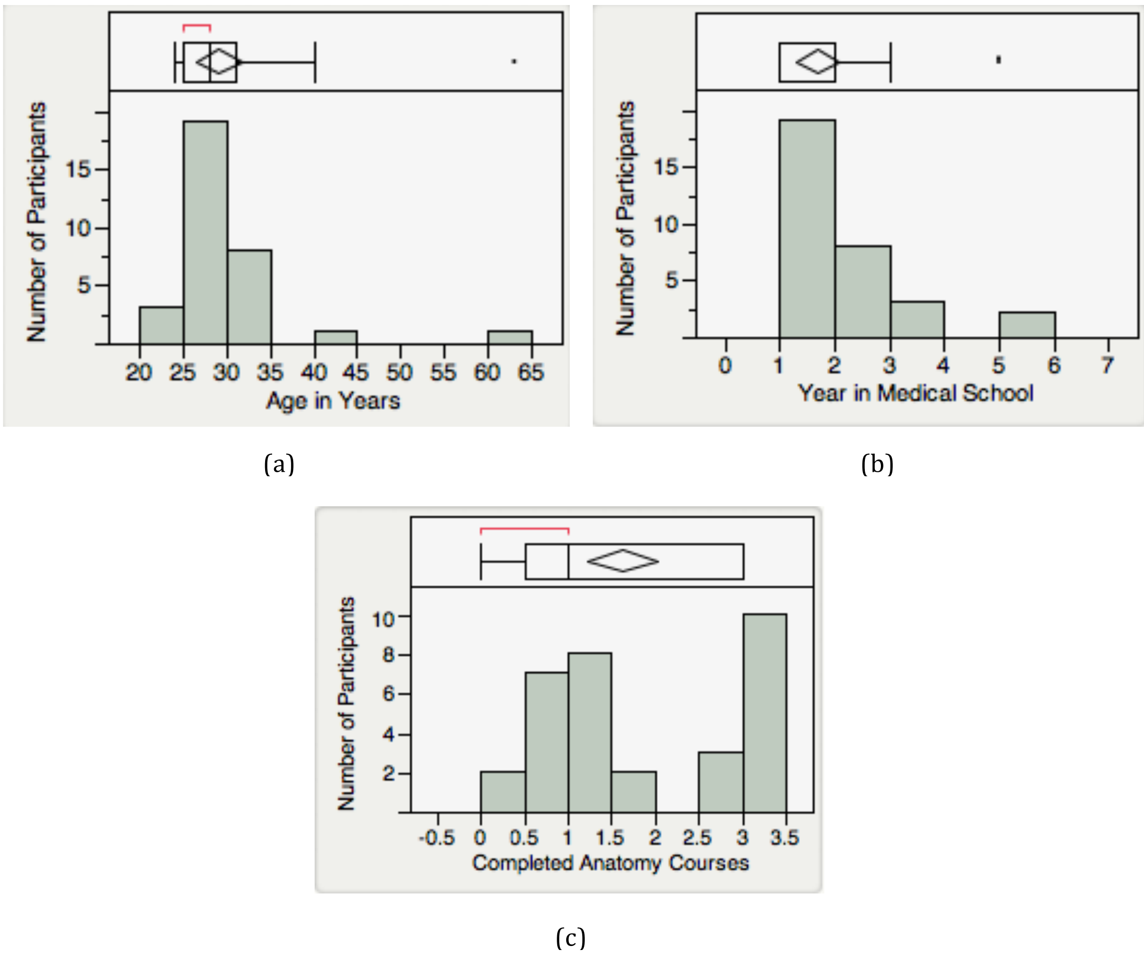


Figure 5. a) Distribution of participants by age. b) Distribution of participants by years attended in medical school. c) Distribution of participant's completed anatomy courses.

During the course of the student's preparation in medical school, they will complete three anatomy courses. Participants ranged in their levels of completion of the series of anatomy courses from those who have not begun, to those who have completed all three required courses. For analysis purposes, participants were given one point for completing the course and half of a point if they indicated that they were in the process of completing the course. A majority of participants had completed all three of the courses (10 participants), with the next highest portion being those who have completed one anatomy course (8 participants) (Figure 5c).

Table 2. Number of participants, who reported previous experience viewing two-dimensional, three-dimensional monoscopic and three-dimensional stereoscopic images.

	Frequently	Occasionally	Rarely	Very Rarely	Never
Seen Two-Dimensional	9	16	6	2	0
Worked with Two-Dimensional	5	7	8	3	9
Seen Three-Dimensional Monoscopic	1	7	10	5	9
Worked with Three-Dimensional Monoscopic	0	3	4	2	23
Seen Three-Dimensional Stereoscopic	0	3	9	3	17
Worked with Three-Dimensional Stereoscopic	0	1	3	3	25

Of the participants, 24 had no prior experience using the Kinect™, while eight participants reported previous experience using the Kinect™. Only two of the participants with previous experience using the Kinect™ used the Kinect™ as their interaction device to complete the tasks for this study. The remaining participants with previous experience using the Kinect™ used the mouse to complete the tasks for the study. All but five participants reported previous experience viewing a three-dimensional movie. Participants were assigned an interaction device to use based off of a counterbalance method to achieve equal number of participants using each interaction device. Their assigned interaction device was not based on their previous experience or background with the technology.

Participants also reported on their previous experience with various types of imaging types; two-dimensional, three-dimensional monoscopic and three-dimensional stereoscopic. Results are reported in Table 2.

4.4.2 Overall Task Completion Analysis

Overall, participants completed a total of 640 tasks. Of those, 14 tasks were removed from the analysis because participants reached the time limit of 2 minutes for each task. 18 tasks were removed because participants rotated the image as they searched for the anatomy against prior instruction. Rotation of images was only available within the mouse configuration for the study, therefore those participants were asked to not rotate the image because the same functionality was not available to participants using the Kinect™.

These results include all tasks for all rounds and both interactions devices. The data was evaluated in whole or in larger subsections to follow trends between the four rounds completed by participants. Overall, 608 individual task results were evaluated throughout the course of this evaluation.

The first point of analysis was the accuracy achieved by participants completing tasks. Participants improved their accuracy over the course of the four rounds. During the first round they completed 109 tasks correct (29 incorrect, 8 rotated, and 4 reached allowed time), to the fourth round of

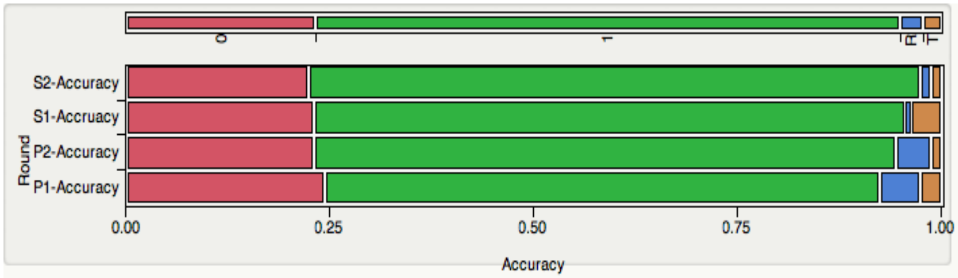


Figure 6. Percentages of responses based on accuracy of participants responses between rounds. Pink corresponds to incorrect response, green are correct responses, blue are rotated responses and orange are tasks that reached their allotted time of two-minutes.

completing 120 tasks correct (36 incorrect, 2 rotated, and 2 reached the allowed time) (See Figure 6).

The second metric evaluated was the amount of time participants took the complete the tasks. Participants improved their overall completion time of tasks throughout the rounds from round one to round four. Time was statistically significant; values are presented in Table 3 (See Figure 7). Looking specifically at

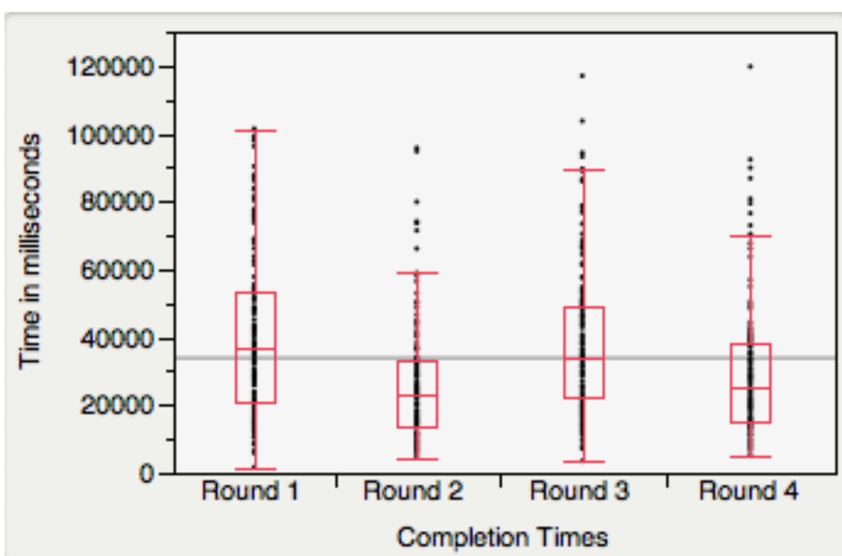


Figure 7. Time for participants to complete tasks during the four rounds.

the data that resides outside of the quantiles, there was no trend between participants who possibly completed the tasks consistently in more time compared to other participants. Of the 20 tasks completed over the four rounds, only two participants completed more than one task in an amount of time that was above the quantile for that round.

Table 3. Average completion times, number of tasks evaluated, standard deviation and statistically significance between rounds based on completion times.

Rounds		*Statistical Significance*		
Round 1 Set A	μ = 40.766 seconds (n = 148, σ = 24.115 seconds)			
Round 2 Set A	μ = 26.302 seconds (n = 151, σ = 17.957 seconds)	*99% at $p < 0.05$*		
Round 3 Set B	μ = 39.170 seconds (n = 153, σ = 22.536 seconds)	*Difference was not statistically significant*	*99% at $p > 0.05$*	
Round 4 Set B	μ = 29.433 seconds (n = 156, σ = 19.921 seconds)	*99% at $p < 0.05$*	*Difference was not statistically significant*	*99% at $p < 0.05$*
		Round 1 Set A	Round 2 Set A	Round 3 Set B

Participants using the Kinect™ took less time to complete the tasks compared to those using the mouse. Time was statistically significant; values are presented in Table 4 (See Figure 8).

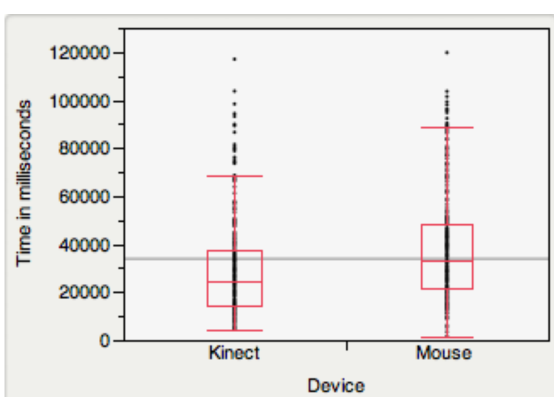


Figure 8. Time for participants to complete the tasks using a specific interaction device.

Table 4. Average completion times, number of tasks evaluated, standard deviation and statistical significance for all tasks comparing interaction devices.

Overall Completion Times	Mouse	Kinect™	*Statistical Significance*
All rounds	μ = 38.760 seconds (n = 290, σ = 22.738 seconds)	μ = 29.399 seconds (n = 318, σ = 20.476 seconds)	*99% at p > 0.05*

Participants who correctly completed the task took less time than those who incorrectly completed the task. Time was statistically significant; values are presented in Table 5 (See Figure 9). Completion times distributed above the quantile were not consistently completed by the same participants, as only a couple of these data points were completed by the same participant.

Table 5. Average completion times, number of tasks evaluated, standard deviation and statistical significance for all tasks comparing interaction devices.

Overall Completion Times	Incorrect Tasks	Correct Tasks	*Statistical Significance*
All rounds	μ = 38.000 seconds (n = 149, σ = 24.638 seconds)	μ = 32.522 seconds (n = 459, σ = 21.022 seconds)	*99% at p > 0.05*

Participants using the Kinect™ were able to correctly identify the anatomy in less time than those who incorrectly identified the anatomy with the Kinect™.

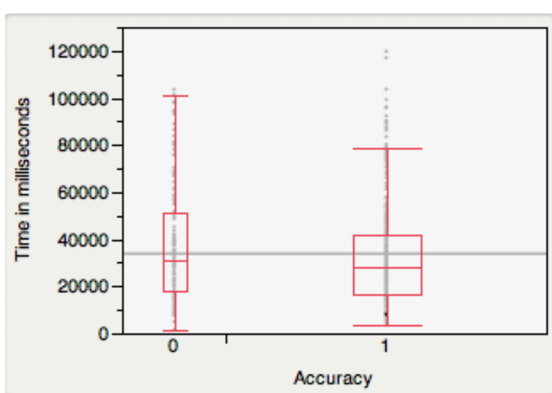


Figure 9. Time for participants to complete the tasks depending on accuracy of task response.

Participants in both correctly and incorrectly identifying the anatomy did so in less time with the Kinect™ compared to those using the mouse. Time was statistically significant; values are presented in Table 6.

Table 6. Average completion times, number of tasks evaluated, standard deviation and statistical significance for all tasks comparing accuracy and interaction device.

Overall Completion Times	Incorrect Tasks	Correct Tasks	
Mouse	μ = 42.676 seconds (n = 73, σ = 25.172 seconds)	μ = 37.443 seconds (n = 217, σ = 21.763 seconds)	*Difference was not statistically significant*
Kinect™	μ = 33.508 seconds (n = 76, σ = 23.406 seconds)	μ = 28.109 seconds (n =242, σ = 19.339 seconds)	*95% at $p < 0.05$*
	95% at $p > 0.05$	*99% at $p > 0.05$*	*Statistical Significance*

Summing the time for each participant to complete all 20 tasks, it was found that participants using the Kinect™ (μ = 9.739 minutes) took approximately 2 minutes less time to complete the series of tasks compared to those individuals using the mouse (μ = 11.709 minutes). Time was statistically significant; values are presented in Table 7 (See Figure 10).

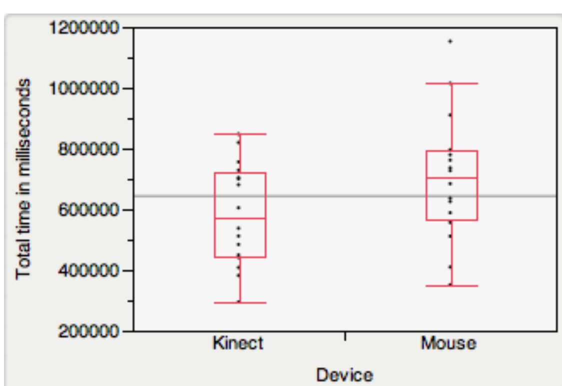


Figure 10. Total time for participants to complete all 20 tasks over the course of the four rounds.

Table 7. Average completion times, number of tasks evaluated, standard deviation and statistical significance for the sum of all task times comparing interaction devices.

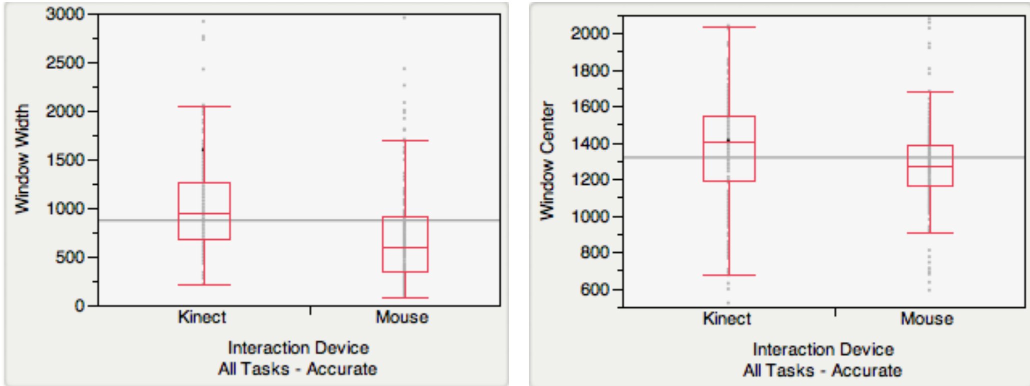
Overall Completion Times	Mouse	Kinect™	*Statistical Significance*
Sum of all tasks	μ = 702.535 seconds 11.709 minutes (n = 16, σ = 208.776 seconds) 74.8 % correct 217/290 correct	μ = 584.323 seconds 9.739 minutes (n = 16, σ = 168.255 seconds) 76.1% correct 242/318 correct	*99% at p > 0.05*

The third metric was a comparison of window width and window center achieved by participants. These results were separated by those individual tasks that correctly identified the anatomical feature and those individual tasks that were incorrectly identified.

First, was the evaluation of the accurate tasks. Participants using the Kinect™ had larger window width values and higher window center values compared to those who used the mouse, for the tasks where the anatomy was accurately identified. This was statistically significant and values are presented in Table 8 (See Figure 11).

Table 8. Number of tasks, mean, standard deviation and statistical significance of window width and window center values split between Kinect™ and mouse users for those who accurately identified the anatomical feature.

Overall Accurate score	Kinect™ (n=242)	Mouse (n=217)	*Statistical Significance*
Window Width	μ = 1028 HU (σ = 484 HU)	μ = 696 HU (σ = 467 HU)	*99% at p < 0.05*
Window Center	μ = 1356 HU (σ = 291 HU)	μ = 1276 HU (σ = 223 HU)	*99% at p < 0.05*



(a) (b)

Figure 11. a) Window width values from all tasks for accurate tasks split by interaction device. b) Window center values from all tasks for accurate tasks split by interaction device.

Second, was the evaluation of the inaccurate tasks. Participants using the Kinect™ had larger window width and higher window center values compared to those using the mouse, for the tasks where the anatomy was inaccurately identified. Window width and window center was statistically significant; values are presented in Table 9 (See Figure 12).

Table 9. Number of tasks, mean, standard deviation and statistical significance of window width and window center values split between Kinect™ and mouse users for those who inaccurately identified the anatomical feature.

Overall Inaccurate scores	Kinect™ (n=76)	Mouse (n=73)	*Statistical Significance*
Window Width	μ = 1066 HU (σ = 524 HU)	μ = 640 HU (σ = 371 HU)	*99% at $p < 0.05$*
Window Center	μ = 1627 HU (σ = 311 HU)	μ = 1410 HU (σ = 228 HU)	*99% at $p < 0.05$*

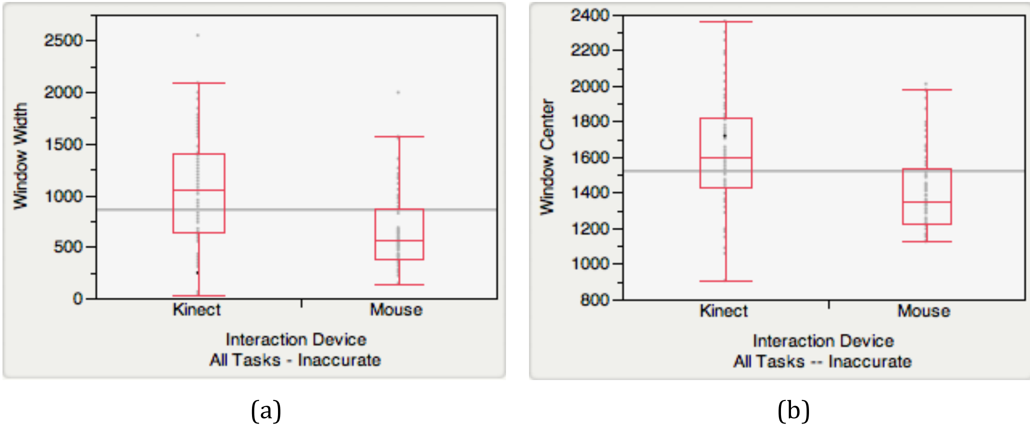


Figure 12. a) Window width values from all tasks for inaccurate tasks split by interaction device. b) Window center values from all tasks for inaccurate tasks split by interaction device.

4.4.3 Individual Tasks Analysis

Each of the ten tasks were evaluated individual to follow any trends that did not appear in the overall analysis. Set B task four is presented here as an example of the task analysis completed for each task, while the remainder of the nine tasks are presented in the appendix.

Set B task four was to display the skin of the thoracic wall as opaque, while hiding the superficial musculature. These results include the first and second attempts for participants completing the third and fourth rounds of tasks using both interaction devices; 63 attempts were evaluated for this task. The removed attempt was due to a participant rotating the image prior to identifying the anatomy. The attempt was removed from the mouse category.

The first metric that evaluated was the accuracy of participants completing tasks with the two interaction devices. Participants using the Kinect™ had more correct responses than those using the mouse. Individuals using the Kinect™ completed 25 of the 32 tasks correctly (7 tasks were incorrect). Individuals using the mouse completed 15 of the 32 tasks correctly (16 tasks were incorrect, 1 task was rotated) (See Figure 13). Statistical significance between accuracy and interaction devices is discussed on the next section with respect to the amount of time taken to the complete the task.

Figure 13. Percentages of responses based on accuracy of participants using the Kinect™ compared to the mouse for set B task four. Pink corresponds to incorrect responses, green are correct responses, and blue are tasks that were rotated.

The second metric was the amount of time participants took to complete the tasks. Participants completed this task faster during the fourth round (μ =

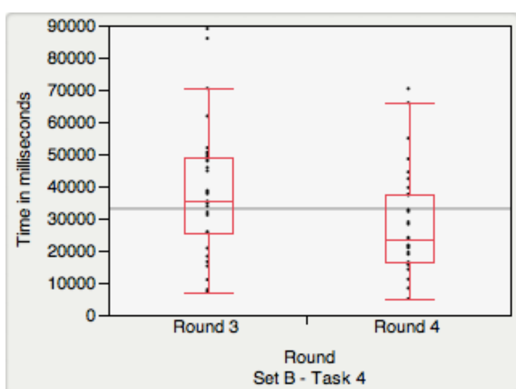


Figure 14. Time for participants to complete tasks between rounds for set B task four.

28.089 seconds, σ = 16.060 seconds) of tasks compared to the third round (μ = 38.138 seconds, σ = 20.271 seconds). Time was statistically significant at 95% ($p < 0.05$) (See Figure 14).

Participants who correctly identified the anatomical region in round two took less time compared to those who correctly identified the anatomical region in round one. Time was statistically significant; values are presented in Table 10. Other correlations between accuracy and round did not show statistical significance.

Table 10. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set B task four comparing accuracy and rounds.

Set B - Task 4 Completion Times	Incorrect	Correct	
Round 3	μ = 40.555 seconds (n = 12, σ = 23.320 seconds)	μ = 36.611 seconds (n = 19, σ = 18.606 seconds)	*Difference was not statistically significant*
Round 4	μ = 32.788 seconds (n = 11, σ = 19.356 seconds)	μ = 25.628 seconds (n = 21, σ = 13.927 seconds)	*Difference was not statistically significant*
	Difference was not statistically significant	*95% at p < 0.05*	*Statistical Significance*

Participants using the Kinect™ completed tasks faster in both the third and fourth round for this task compared to the mouse. Time was statistically significant; values presented in Table 11.

Participants improved their completion time using the mouse and Kinect™ between rounds. Time was statistically significant; values are presented in Table 11.

Table 11. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set B task four comparing interaction device and rounds.

Set B - Task 4 Completion Times	Mouse	Kinect™	
Round 3	μ = 47.710 seconds (n = 15, σ = 21.062 seconds)	μ = 29.164 seconds (n = 16, σ = 15.175 seconds)	*99% at p > 0.05*
Round 4	μ = 35.320 seconds (n = 16, σ = 17.542 seconds)	μ = 20.858 seconds (n =16, σ = 10.667 seconds)	*99% at p > 0.05*
	95% at p < 0.05	*95% at p < 0.05*	*Statistical Significance*

Participants who correctly and incorrectly identified the anatomy did so in less time with the Kinect™ compared to those using the mouse. Time was statistically significant; values are presented in Table 12. Correlation between accuracy for interaction devices did not show statistical significance.

Table 12. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set B task four comparing accuracy and interaction device.

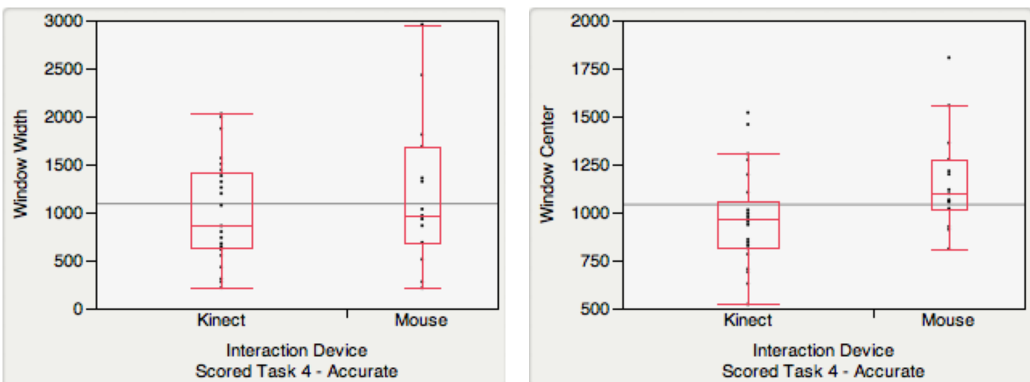
Set B - Task 4 Completion Times	Incorrect Tasks	Correct Tasks	
Mouse	μ = 43.207 seconds (n = 16, σ = 20.962 seconds)	μ = 39.296 seconds (n = 15, σ = 19.467 seconds)	*Difference was not statistically significant*
Kinect™	μ = 22.287 seconds (n = 7, σ = 15.013 seconds)	μ = 25.774 seconds (n =25, σ = 13.375 seconds)	*Difference was not statistically significant*
	99% at p > 0.05	*95% at p > 0.05*	*Statistical Significance*

The third metric was to evaluate each task by the window width and window center values created by each participant. These results are separated by the individual tasks that correctly identified the anatomical feature and the individual tasks that were incorrectly identified.

First, the window width and window center values were evaluated by all correct responses. Participants using the Kinect™ had lower window center values compared to those who used the mouse. Window center was statistically significant; values are presented in Table 13 (See Figure 15). Correlation of window width did not show statistical significance.

Table 13. Number of tasks, mean, standard deviation and statistical significance of window width and window center values split between Kinect™ and mouse users for those who accurately identified the anatomical feature.

Set B - Task 4 Accurate score	Kinect™ (n=25)	Mouse (n=15)	*Statistical Significance*
Window Width	μ = 1024 HU (σ = 531 HU)	μ = 1200 HU (σ = 762 HU)	*Difference was not statistically significant*
Window Center	μ = 966 HU (σ = 243 HU)	μ = 1165 HU (σ = 257 HU)	*95% at $p < 0.05$*



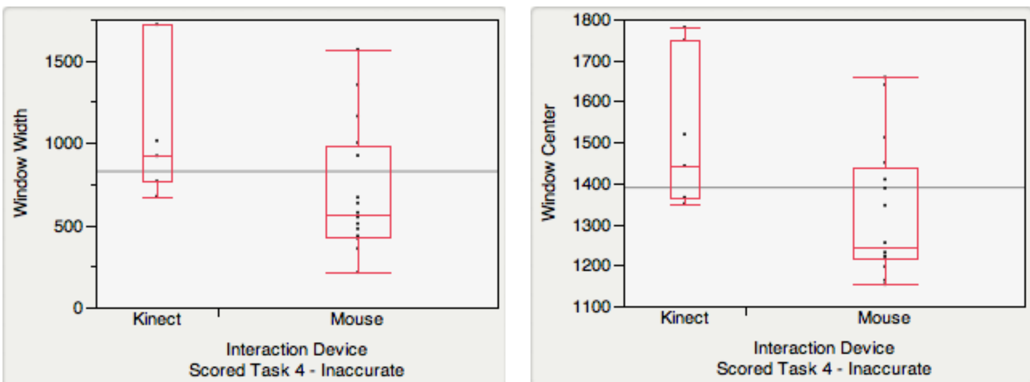
(a) (b)

Figure 15. a) Window width values for set B task four for accurate tasks split by interaction device. b) Window center values for set B task four for accurate tasks split by interaction device.

Second, the window width and window center values were evaluated by all incorrect responses. Participants using the Kinect™ had larger window width and higher window center values compared to those using the mouse, for those tasks where the anatomy was inaccurately identified. Window width and window center was statistically significant; values are presented in Table 14 (See Figure 16).

Table 14. Number of tasks, mean, standard deviation and statistical significance of window width and window center values split between Kinect™ and mouse users for those who inaccurately identified the anatomical feature.

Set B - Task 4 – Inaccurate score	Kinect™ (n=7)	Mouse (n=16)	*Statistical Significance*
Window Width	μ = 1105 HU (σ = 433 HU)	μ = 704 HU (σ = 386 HU)	*95% at p < 0.05*
Window Center	μ = 1522 HU (σ = 175 HU)	μ = 1161 HU (σ = 163 HU)	*95% at p < 0.05*



(a) (b)

Figure 16. a) Window width values for set B task four for inaccurate tasks split by interaction device. b) Window center values for set B task four for inaccurate tasks spilt by interaction device.

4.4.4 Overall Experience with Interaction Devices

Along with analyzing the overall and individual tasks, analysis was completed on the participant's previous experience with medical imaging technology, the attitude measurement, and the final questionnaire given to participants. Comparisons not presented in this section did not show statistical significance.

4.4.4.1 Previous medical imaging experience compared to attitude during study

Mouse participants who reported more experience viewing 2D anatomical images also reported higher levels of excitement during the study. Comparison of previous viewing experience and attitudes was statistically significant at 95% confidence ($p < 0.05$).

Kinect™ participants who reported more experience viewing 3D stereoscopic anatomical images also reported higher levels of frustration during the study. Comparison of previous experience and attitude was statistically significant at 95% confidence ($p < 0.05$).

Mouse participants who reported more experience viewing 3D stereoscopic anatomical images also reported lower levels of anxiety and higher levels of excitement. Comparison of previous experience and attitude was statistically significant at 95% confidence ($p < 0.05$) and 99% confidence ($p < 0.05$), respectively.

Kinect™ participants who reported more experience working with 3D stereoscopic anatomical images also reported higher levels of frustration during the study. Comparison of previous experience and difficulty of task was statistically significant at 99% confidence ($p < 0.05$). These individuals also reported that they felt the device was awkward to use (95% confidence at $p < 0.05$).

Overall, independent of the interaction device, participant's responses indicate that previous experience viewing and working with 3D monoscopic images reduces the boredom felt by participants during the tasks. This was statistically significant at 95% confidence ($p < 0.05$). Excitement was another trend that was viewed as participants had previous additional experience with types of medical imaging technology, they reported increased enjoyment, particularly with 3D stereoscopic experience. This was statistically significant at 95% ($p < 0.05$).

Evaluating attitudes of participants between those who used a particular interaction device showed two attitude differences with statistical significance. Participants reported feeling less anxious when using the Kinect™ as an interaction device compared to those using the mouse. Anxiety was statistically significant at 95% confidence ($p < 0.05$). While, participants using the mouse reported feeling less calm compared to those using the Kinect™. Feeling calm was statistically significance at 95% confidence ($p < 0.05$). These results show consistency in the reporting of feelings as anxious and calm are antonyms of one another, however the attitudes were evaluated separately by the participants and therefore presented separately in this section.

4.4.4.2 Comparing post-surveys with task completion times

This section of results looks at the comparison between the amount of time taken by participants to complete the tasks and their responses during the pre- and post-survey sections of the study. Participants using the Kinect™ who reported more experience working with 3D monoscopic anatomical images took less time to complete the series of 20 tasks for the study. Comparison was statistically significant at 99% confidence ($p < 0.05$).

Participants using the mouse who reported that the interaction device was more complicated to use also spent less time completing the series of 20 tasks. Comparison was statistically significant at 99% ($p < 0.05$). Participants, who reported the interaction to feel more awkward, spent less time completing the series of 20 tasks. Comparison was statistically significant at 95% confidence ($p < 0.05$). While older participants took more time to complete the tasks than younger participants. Comparison was statistically significant at 99% confidence ($p < 0.05$).

4.5 Discussion

The results of this study suggest that with additional time for participants to familiarize themselves with using the Kinect™, they were able to perform better than those using a traditional mouse to do the same interaction manipulations. Participants using both the mouse and Kinect™ were able to complete tasks with an average accuracy of 75%, while the Kinect™ participants took, on average, 2-minutes less to complete the 20 tasks. These findings pose the Kinect™ as a possible interaction device for medical imaging technology.

Participants appeared to be split in their experience with the interaction devices. Those who enjoyed using their assigned interaction device spent more time with the tasks compared to those who did not enjoy using their interaction device. Individuals using the Kinect™ showed less hesitation when using the device compared to those using the mouse. The Kinect™ appeared to be a much more fluent device for interaction.

During the post-survey free response questions, there were two trends that appeared in the participant's responses. Those who used the mouse discussed the windowing feature as the most enjoyable feature. One participant wrote:

> "I liked being able to manipulate the tool to see different areas of the anatomical model. This replicates what we do in real life when we look at the cadavers from different angles. I found this tool to be easier and I wish we would have used it in our lab!"

Participants who used the Kinect™ focused more on the interaction available through the Kinect™, compared to the windowing features. It is likely the Kinect™ and the windowing feature were new and unique features for the participants. One participant using the Kinect™ combined their enjoyment of using the windowing feature and the interaction tool, by writing:

> "The development of an image felt more organic/artistic and less mechanical than conceivable alternatives."

This view indicates the interest students may have in improving the mechanisms for viewing a patient's data. Technology has become a key component in medical student's lives, which has created a desire for seamless technology in every aspect of clinical practice, especially the opportunity for touch-free technology from traditional gaming systems. Many of the participants who had the opportunity to use the Kinect™ showed excitement and less boredom in their overall opinion of the interaction device compared to those using a traditional mouse.

The Kinect™ is able to remove the 2D constraints present with the mouse and allow a more natural interaction. Participants were able to envision their hands directly interacting with the sliders bars as if the user interface was a piece of machinery and their hands were adjusting settings for the next process. Many students would adjust and reposition their hands as if reading the feedback from the machine and acting accordingly. These users utilized a variety of hand positions to complete the interaction. Many participants used open palms as was demonstrated during the introduction to the software, some used fists, while others rotated their hands 90 degrees from the open palm to be able to move the slider bars closer together than what an open palm would allow. Other participants even "held" the sliders bars in a pinching fashion to move them within the interaction space. A mouse participant mentioned they would have preferred to be able to interact with both slider bars simultaneously compared to the single slider bar interaction design available with the mouse. The opportunities for participants to customize their interaction gestures within a very static library of motion was witnessed during the study. The variation in participant's gestures spoke to the need for a gesture vocabulary to be customizable to the individual, as everyone will intuitively interact with the technology in a different manner.

The Kinect™ also offered fewer overall time constraints to complete the tasks and fewer learning obstacles associated with new interface designs.

Doctors and other medical professionals work in a very fast paced and ever changing environment. The Kinect™ promotes the opportunity for medical professionals to access patient data more efficiently and personally compared to an assistant controlled computer. Intuitive interaction design reduces the learning curve to master the technology. One participant enjoyed using the Kinect™ because it removed the interface learning curve. This person remarked:

> "Seeing the different densities on a scale without having to worry about interface tools allowed for anatomical inspection vs. software familiarization."

This participant understood the implications associated with hands-free technology and revealed that there is both a need and a desire for such technology. There appeared to be a desire amongst the participants to have a high-quality design that removed the software familiarization factor and moved straight into interaction and gathering information from the patient's data. Medical professionals need technological solutions that meet their needs on all fronts. Software needs to be designed for better implementation and adoption for successful use to improve the service provided to the communities served by these doctors.

Designing effective technology for medical visualization is difficult, as everyone has a different interpretation of the images they viewed. This was witnessed while the experts graded the results from participants, as the nature of grading these tasks was very subjective for what are already subjective results from participants. A number of factors aside from their direct knowledge contributed to participants selecting a correct response. These additional factors included lack of anatomical terminology, lack of interest, misunderstanding of the task, or a concern for the time allowed per task. Even two images that were confidently selected, could be graded differently due to each participant having a different perception of an appropriate image. Evaluating the results was equally difficult on our experts. Visual interpretation of the images and understanding of their representation can be completely different between two participants, as well as two experts. Medical imaging technology has to be able to adapt and the designers need to be conscious that when viewing images, the representations are very subjective based on the participant. Understanding how the technology can be effectively designed to enable medical professions to effectively access the data is important to provide better diagnoses and outcomes for patients.

4.6 Conclusion

Over the course of the study, the Kinect™ showed potential as an interaction device for medical imaging applications. Those participants using the Kinect™ were able to achieve almost identical levels of accuracy with the tasks compared to those using the mouse, while spending less time to complete the same series of tasks. As designs for interactions with the Kinect™ continue to improve, the device will provide positive alternatives to current lack of access problems faced by medical professionals in sterile environments.

The study showed that additional time with the Kinect™ allows participants to familiarize themselves with the interaction and design of the software. Participants were able to improve their accuracy over the course of the four rounds while spending less time on the individual tasks. A number of Kinect™ participants commented about the ease of use and functionality of the application in the primary experience of the anatomy lab. Although there is variation in precision of accessibility to small window widths this did not present a challenge to participants to be able to see the desired anatomy and achieve the same accuracy over all results.

The participants using the Kinect™ showed much more excitement and thrill when using the Kinect™ compared to those using the mouse. For many of the students, the software itself was a novel experience, while those using the Kinect™ found more excitement and interest in the technology and the opportunities available to improve the medical professional's access to the technology through interaction devices.

4.7 Future Work

Additional work needs to evaluate and determine a library of gestures that could be utilized for medical imaging touch-free interaction. A body of work was presented in the background section that could be built upon to identify and establish a series of gestures that would be appropriate for medical imaging touch-free interaction.

Also, additional work needs to seek solutions for the precision seen by those interacting with the Kinect™. In particular cases, doctors will need to access areas with small window widths. Another area for future work would be additional exploration of the functionality to understand the full capability of the technology for use in medical settings.

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CHAPTER 5: CONCLUSIONS

The Kinect™ as a touch free technology has shown to be a viable interaction tool for medical imaging within operating rooms and clinics. Through additional interaction and experience with the interaction device, as seen in the second study, participants become more comfortable with the tasks and the interaction device. Participants included comments about the artistic nature of the device with respect to being about the view the 3D medical anatomical images to learn more about a patient's anatomy. Very few participants walked away from the study with the opinion of dissatisfaction towards the Kinect™, which showed promise that the Kinect™ could be accepted in the medical community to improve access to technology in sterile environments.

Participants in the second study completed 12 additional tasks for their interaction device, compared to the original 8 from the first study. Through repetition of the tasks, participants were able to focus on the interaction and less on the task completion. This reduced the pressure of correctly identify the anatomy and allowed participants another opportunity to work with the tasks and move their understanding of the interaction tool into usable knowledge of the interaction design.

An observed difference between the two studies was the different demeanors that veterinary medical students and medical students had when completing the study. Veterinary medical students were more concerned with their appearance as they interacted with the device compared to the medical students who seemed more engaged with the task and the novelty of the 3D anatomical image and the form of interaction. These variations in participant groups, speaks to the variations in the results of the two studies and therefore the design opportunities that need to be explored with these interaction devices.

After study one, recommending the Kinect™ as an appropriate interaction tool for medical imaging would have taken serious consideration. Participants did not enjoy using the device and felt very self-conscious about their appearance as they completed the tasks. The Kinect™ showed inefficiencies in window width precision and ability to access the far-lying regions of the windowing slider.

After study two, there is more confidence in the opportunity for the Kinect™ to be implemented in medical facilities, specifically sterile environments. Participants found the tasks more enjoyable and marveled in the novelty of the interaction and possibility of using this technology in the future. The Kinect™ still showed inefficiencies in window width precision, however this did not appear to detract from participants ability to perform the task, as they maintained similar accuracy in task completion compared to those using the mouse. Within this second study, participants more frequently accessed the far-lying regions of the windowing slider bar, which reduced the concern of limited accessibility to all anatomical data.

This second study showed that participants using the Kinect™ were able to achieve similar accuracy when completing the tasks and spent less time completing the tasks. These findings suggest the opportunity for a seamless interaction and transition from other tasks to working with the medical software. However, to achieve this seamless and effortless transition to touch-free technology, an appropriate gesture library needs to be developed for the various operations within a medical software package.

Over the course of these two studies, the potential and opportunity for the Kinect™ as a medical imaging touch-free interaction device was discovered. Additional research needs to evaluate window width precision, effective mapping of a user's hands and gesture libraries. However, with this additional work the effective design and implementation of the Kinect™ can be achieved to offer touch-free environments for medical professionals to improve the care patients receive around the world.

APPENDIX

Set A - Task One: Display an opaque skull, while eliminating all skin and musculature.

These results include the first and second attempts for participants completing tasks during round one and two, while using both interaction devices; 61 attempts were evaluated for this task. Two attempts were removed for reaching the maximum allotted time of two-minutes and one was removed for rotating the anatomical region. All three removed attempts were from participants using the mouse.

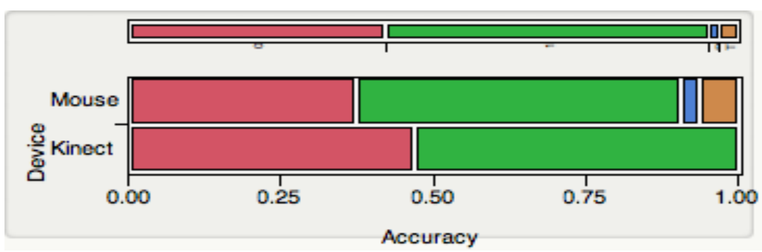


Figure A1. Percentage of responses based on accuracy of participants using the Kinect compared to the mouse for set A task one. Pink corresponds to incorrect responses, green are correct responses, blue are rotated tasks and orange are tasks that reached the allotted time of two-minutes per task.

The first metric of analysis was to compare the accuracy achieved by participants using both interaction devices. Participants using both devices had the same number of tasks correct. Individuals using the Kinect™ completed 17 of the 32 tasks correctly (15 incorrect). Individuals using the mouse completed 17 of the 32 tasks correctly (12 incorrect, 1 was rotated, two reached the allotted time of two-minutes) (See Figure A1). Statistical significance between accuracy and interaction devices is discussed on the next section with respect to the amount of time taken to the complete the task.

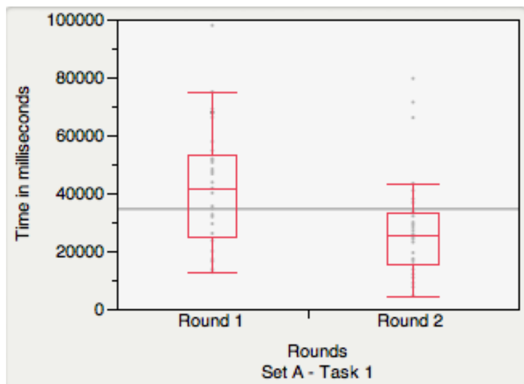


Figure A2. Time for participants to complete tasks between rounds for set A task one.

The second metric was the amount of time participants took to complete the task. Participants took less time to complete a task when carried out for a second attempt (μ = 27.779 seconds, σ = 17.614 seconds), compared to the first attempt (μ = 41.947 seconds, σ = 20.950 seconds) using both interaction devices. Time was statistically significant at a confident level of 95% ($p < 0.05$) (See Figure A2).

Correlating the time to complete tasks separated by accuracy and rounds showed no significance in the amount of time to complete tasks (See Table A1).

Participants improved their task completion time between round one and round two for both the mouse and the Kinect™. Time was statistically significant;

values are presented in Table A2. Correlations between interaction devices per round did not show statistical significance.

Table A1. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set A task one comparing accuracy and rounds.

Set A - Task 1 Completion Times	Incorrect Tasks	Correct Tasks	
Round 1	$\mu = 40.649$ seconds ($n = 15$, $\sigma = 22.526$ seconds)	$\mu = 43.337$ seconds ($n = 14$, $\sigma = 19.871$ seconds)	*Difference was not statistically significant*
Round 2	$\mu = 25.094$ seconds ($n = 12$, $\sigma = 18.546$ seconds)	$\mu = 29.391$ seconds ($n = 20$, $\sigma = 17.315$ seconds)	*Difference was not statistically significant*
	Difference was not statistically significant	Difference was not statistically significant	*Statistical Significance*

Table A2. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set A task one comparing interaction device and rounds.

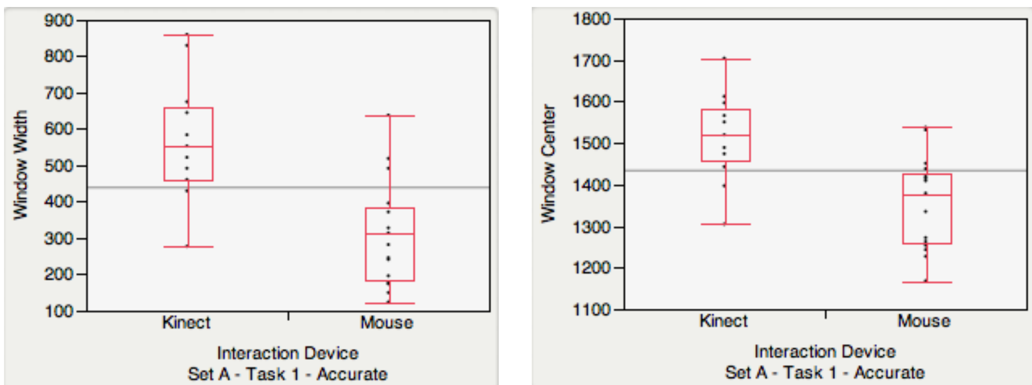
Set A - Task 1 Completion Times	Mouse	Kinect™	
Round 1	$\mu = 46.469$ seconds ($n = 13$, $\sigma = 23.811$ seconds)	$\mu = 38.273$ seconds ($n = 16$, $\sigma = 18.265$ seconds)	*Difference was not statistically significant*
Round 2	$\mu = 28.760$ seconds ($n = 16$, $\sigma = 14.138$ seconds)	$\mu = 26.798$ seconds ($n = 16$, $\sigma = 20.959$ seconds)	*Difference was not statistically significant*
	99% at $p < 0.05$	*95% at $p < 0.05$*	*Statistical Significance*

Table A3. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set A task one comparing accuracy and interaction device.

Set A - Task 1 Completion Times	Incorrect Tasks	Correct Tasks	
Mouse	$\mu = 37.321$ seconds ($n = 12$, $\sigma = 24.928$ seconds)	$\mu = 36.259$ seconds ($n = 17$, $\sigma = 18.041$ seconds)	*Difference was not statistically significant*
Kinect™	$\mu = 30.867$ seconds ($n = 15$, $\sigma = 19.616$ seconds)	$\mu = 34.008$ seconds ($n = 17$, $\sigma = 21.185$ seconds)	*Difference was not statistically significant*
	Difference was not statistically significant	*Difference was not statistically significant*	*Statistical Significance*

Correlating accuracy and interaction devices showed no significance in the amount of time to complete tasks for participants (See Table A3).

The third metric was comparing window width and window center values created by participants during the tasks. These results are separated by the individual tasks that either correctly or incorrectly identified the anatomical feature.



(a) (b)

Figure A3. a) Window width values from set A task one for accurate tasks split by interaction device. b) Window center values from set A task one for accurate tasks split by interaction device.

Table A4. Number of tasks, mean, standard deviation and statistical significance of window width and window center values split between Kinect™ and mouse users for those who accurately identified the anatomical feature.

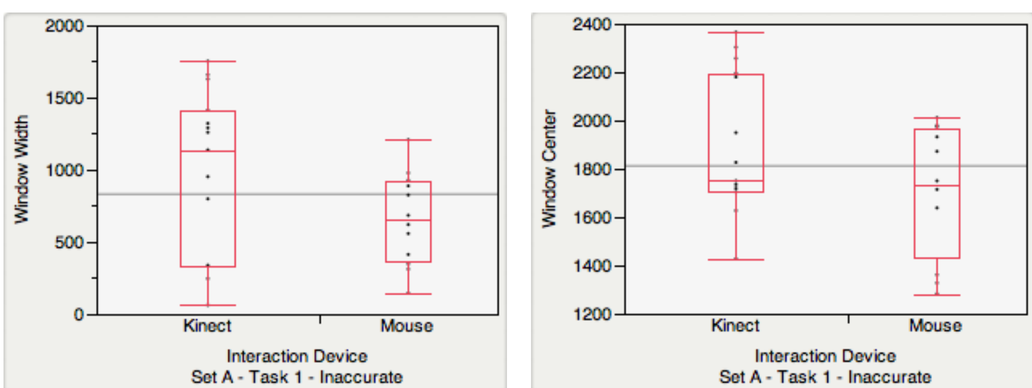
Set A - Task 1 Accurate score	Kinect™ (n = 17)	Mouse (n = 17)	*Statistical Significance*
Window Width	μ = 563 HU (σ = 169 HU)	μ = 314 HU (σ = 221 HU)	*99% at $p < 0.05$*
Window Center	μ = 1515 HU (σ = 97 HU)	μ = 1352 HU (σ = 109 HU)	*99% at $p < 0.05$*

First, was the evaluation of the accurate tasks. Participants using the Kinect™ had larger window width values and higher window center values compared to those who used the mouse, for those tasks where the anatomy was accurately identified. Window width and window center were statistically significant; values are presented in Table A4 (See Figure A3).

Second, was the evaluation of incorrect tasks. Participants using the Kinect™ had larger window width values and higher window center values compared to those who used the mouse, for those tasks where the anatomy was inaccurately identified. Window width and window center were statistically significant; values are presented in Table A5 (See Figure A4).

Table A5. Number of tasks, mean, standard deviation and statistical significance of window width and window center values split between Kinect™ and mouse users for those who inaccurately identified the anatomical feature.

Set A - Task 1 Inaccurate score	Kinect™ (n=15)	Mouse (n=12)	*Statistical Significance*
Window Width	μ = 968 HU (σ = 574 HU)	μ = 658 HU (σ = 317 HU)	*95% at $p < 0.05$*
Window Center	μ = 1896 HU (σ = 290 HU)	μ = 1750 HU (σ = 265 HU)	*95% at $p < 0.05$*



(a) (b)

Figure A4. a) Window width values from set A task one for inaccurate tasks split by interaction device. b) Window center values from set A task one for inaccurate tasks split by interaction device.

Set A Task Two: Display the zygomatic bones visible through the skin.

These results include the first and second attempts for participants completing tasks during round one and two, while using both interaction devices; 60 attempts were evaluated for this task. Four were removed for participants rotating the anatomical region as they identified the anatomy. All four attempts were removed from the participants using the mouse.

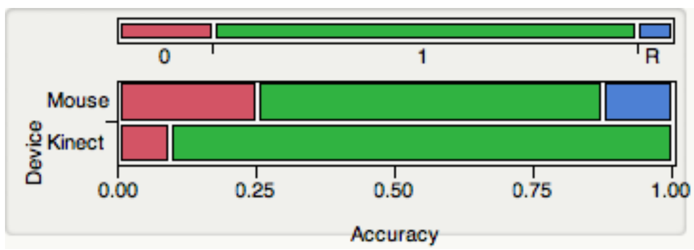


Figure A5. Percentage of response based on accuracy of participants using the Kinect™ compared to the mouse for set A task two. Pink corresponds to incorrect responses, green are correct responses and blue are rotated tasks.

The first metric of analysis was to compare the accuracy achieved by participants using different interaction devices. Participants using the Kinect™ had more correct response than those using the mouse. Individuals using the Kinect™ completed 29 of the 32 tasks correctly (3 tasks were incorrect). Individuals using the mouse completed 20 of the 32 tasks correctly (8 tasks were incorrect, 4 tasks were rotated) (See Figure A5). Statistical significance between accuracy and interaction devices is discussed on the next section with respect to the amount of time taken to the complete the task.

The second metric of analysis was to compare the amount of time taken by participants to complete this task. Participants took less time to complete this task the second time (μ = 13.684 seconds, σ = 8.074 seconds), compared to the first attempt (μ = 24.566 seconds, σ = 13.778 seconds). Time was statistically significant at a confidence level of 99% ($p < 0.05$) (See Figure A6).

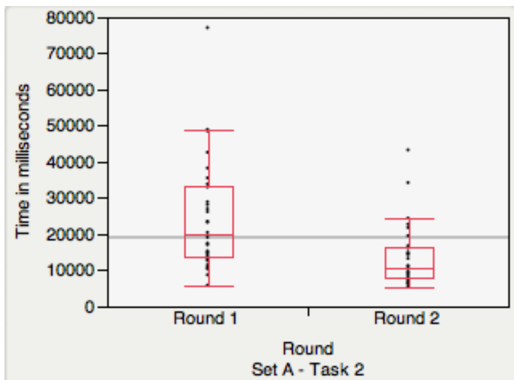


Figure A6. Time for participants to complete tasks for the rounds of set A task two.

Participants completed the second round of tasks faster for both incorrect and correct responses compared to their first round of tasks. Time was statistically significant; values are presented in Table A6. Correlation between accuracy per round did not show statistical significance.

Table A6. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set A task two comparing accuracy and rounds.

Set A - Task 2 Completion Times	Incorrect Tasks	Correct Tasks	
Round 1	μ = 26.864 seconds (n = 5, σ =.9.207 seconds)	μ = 24.106 seconds (n = 25, 16.410 seconds)	*Difference are not statistically significant*
Round 2	μ = 12.521 seconds (n = 6, σ = 5.135 seconds)	μ = 13.975 seconds (n = 24, σ = 9.353 seconds)	*Difference are not statistically significant*
	95% at p < 0.05	*99% at p < 0.05*	*Statistical Significance*

Participants using the Kinect™ were able to complete their tasks quicker than those using the mouse during both the first and second rounds. Time was statistically significant; values are presented in Table A7.

Participants improved their task completion time between round one and round two for both the mouse and the Kinect™. Time was statistically significant; values are presented in Table A7.

Table A7. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set A task two comparing interaction device and rounds.

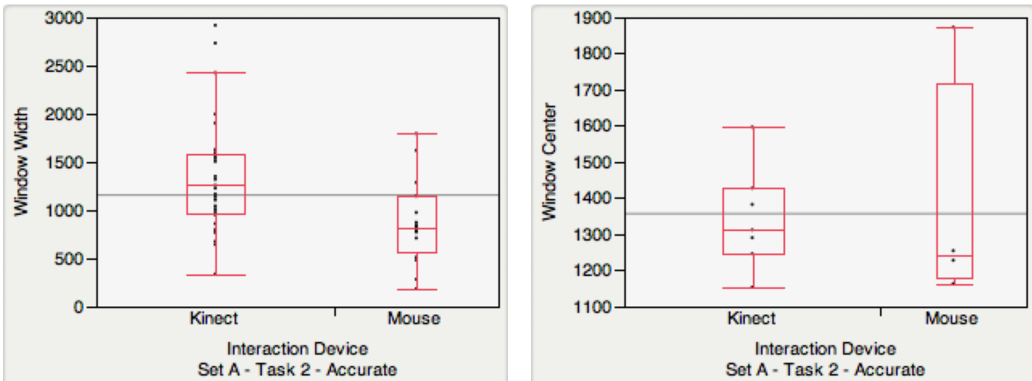
Set A - Task 2 Completion Times	Mouse	Kinect™	
Round 1	μ = 29.934 seconds (n = 14, σ = 17.675 seconds)	μ = 19.869 seconds (n = 16, σ = 11.592 seconds)	*95% at $p < 0.05$*
Round 2	μ = 16.777 seconds (n = 14, σ = 9.704 seconds)	μ = 10.979 seconds (n = 16, σ = 6.727 seconds)	*95% at $p < 0.05$*
	95% at $p < 0.05$	*99% at $p < 0.05$*	*Statistical Significance*

Participants who correctly identified the anatomy did so in less time using the Kinect™ compared to those using the mouse. Time was statistically significant; values presented in Table A8. Other correlations between accuracy and interaction devices did not show statistical significance.

Table A8. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set A task two comparing accuracy and interaction device.

Set A - Task 2 Completion Times	Incorrect Tasks	Correct Tasks	
Mouse	μ = 17.922 seconds (n = 8, σ = 9.852 seconds)	μ = 25.529 seconds (n = 20, σ = 16.994 seconds)	*Difference was not statistically significant*
Kinect™	μ = 22.021 seconds (n = 3, σ = 12.568 seconds)	μ = 14.741 seconds (n = 29, σ = 10.118 seconds)	*Difference was not statistically significant*
	Difference was not statistically significant	*99 % at $p < 0.05$*	*Statistical Significance*

The third metric was to compare the window width and window center values that were created by the participants during the study. These results are separated by the individual tasks that correctly identified the anatomical feature and the individual tasks that were incorrectly identified.



(a) (b)

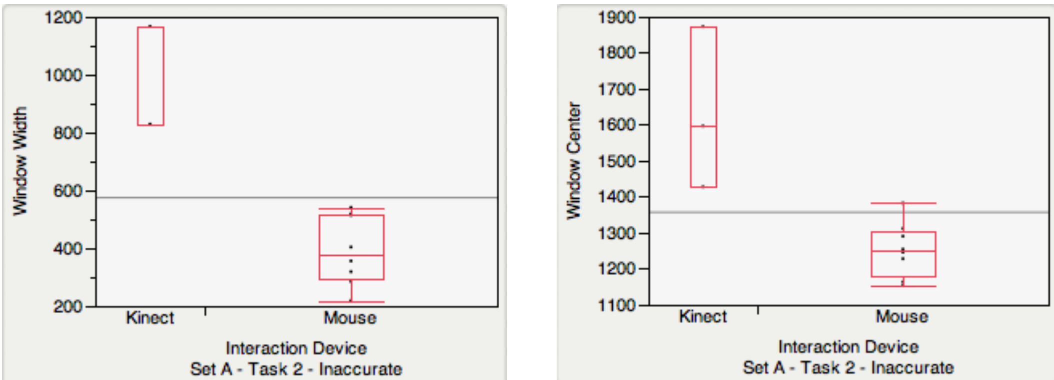
Figure A7. a) Window width values from set A task two for accurate tasks split by interaction device. b) Window center values from set A task two for accurate tasks split by interaction device.

First is the comparison of tasks that were graded correctly. Participants using the Kinect™ had larger window width values compared to those using the mouse, for those tasks where the anatomy was accurately identified. Window width values were statistically significant; values are presented in Table A9 (See Figure A7). Window center did not show statistical significance.

Table A9. Number of tasks, mean, standard deviation and statistical significance of window width and window center values split between Kinect™ and mouse users for those who accurately identified the anatomical feature.

Set A - Task 2 Accurate score	Kinect™ (n=29)	Mouse (n=20)	Statistical Significance
Window Width	μ = 1347 HU (σ = 598 HU)	μ = 880 HU (σ = 411 HU)	*99% at p < 0.05*
Window Center	μ = 1300 HU (σ = 205 HU)	μ = 1237 HU (σ = 123 HU)	*Difference was not statistically significant*

Second was the comparison of tasks that were graded as incorrect. Participants using the Kinect™ had larger window widths and higher window center values compared to those using the mouse, for those tasks where the anatomy was inaccurately identified. Window width and window center was statistically significant; values are presented in Table A10 (See Figure A8).



(a) (b)

Figure A8. a) Window width values from set A task two for inaccurate tasks split by interaction device. b) Window center values from set A task two for inaccurate tasks split by interaction device.

Table A10. Number of tasks, mean, standard deviation and statistical significance of window width and window center values split between Kinect™ and mouse users for those who inaccurately identified the anatomical feature.

Set A - Task 2 Inaccurate score	Kinect™ (n=3)	Mouse (n=8)	Statistical Significance
Window Width	μ = 1054 HU (σ = 195 HU)	μ = 394 HU (σ = 120 HU)	99% at $p < 0.05$
Window Center	μ = 1632 HU (σ = 224 HU)	μ = 1253 HU (σ = 76 HU)	95% at $p < 0.05$

Set A Task Three: Display the facial artery visible through the skin.

These results include the and second attempts for participants completing tasks during round one and two, while using both interaction devices; 59 attempts were evaluated for this task. Three were removed for reaching the maximum allotted time of two-minutes and two were removed for rotating the anatomical region. Four of the five removed attempts were from participants using the mouse, while the remaining one was from a participant using the Kinect™.

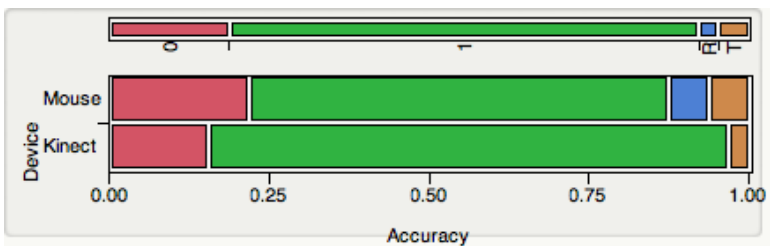


Figure A9. Percentage of response based on accuracy of participants using the Kinect™ compared to the mouse for set A task three. Pink corresponds to incorrect responses, green are correct responses, blue are tasks that were rotated and orange are tasks where the participants reached the allotted time of two-minutes.

The first metric was to compare the accuracies achieved by participants by interaction device. Participants using the Kinect™ had more correct responses than those using the mouse. Individuals using the Kinect™ completed 26 of the 32 tasks correctly (5 tasks were incorrect and 1 task reached the allotted time). Individuals using the mouse completed 21 of the 32 tasks correctly (7 tasks were incorrect, 2 tasks were rotated and 2 tasks reached the allotted time) (See Figure A9). Statistical significance between accuracy and interaction devices is discussed on the next section with respect to the amount of time taken to the complete the task.

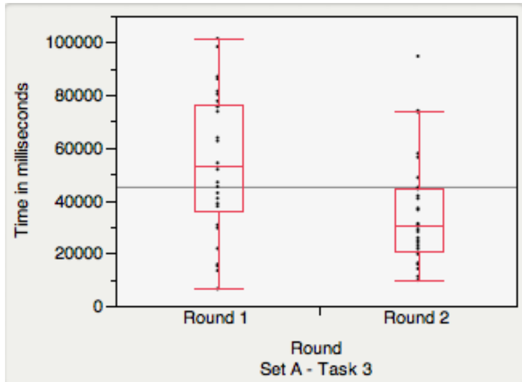


Figure A10. Time for participants to complete tasks for the rounds of set A task three.

The second metric was the amount of time taken by participants to complete this task. Participants took less time to complete this task the second attempt (μ = 35.236 seconds, σ = 20.718 seconds) compared to the first attempt (μ = 54.330 seconds, σ = 26.506 seconds). Time was statistically significant at a confidence level of 99% ($p < 0.05$) (See Figure A10).

Participants during round one spent less time completing the task correctly than those who incorrectly completed the task. Time was statistically significant; values are presented in Table A11. Correlations between accuracy during round two did not show statistical significance.

Participants improved their task completion time between round one and round two for both incorrect and correct responses. Time was statistically significant; values presented in Table A11.

Table A11. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set A task three comparing accuracy and rounds.

Set A - Task 3 Completion Times	Incorrect Tasks	Correct Tasks	
Round 1	μ = 80.395 seconds (n = 5, σ = 22.492 seconds)	μ = 49.117 seconds (n = 25, σ = 24.387 seconds)	*95% at p < 0.05*
Round 2	μ = 42.737 seconds (n = 7, σ = 28.706 seconds)	μ = 32.849 seconds (n = 22, σ = 17.669 seconds)	*Differences are not statistically significant*
	95% at p < 0.05	*99% at p < 0.05*	*Statistical Significance*

Participants improved their task completion time between round one and round two using the mouse. Time was statistically significant; values presented in Table A12. Other correlations between interaction device and round were not statistically significant.

Table A12. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set A task three comparing interaction devices and rounds.

Set A - Task 3 Completion Times	Mouse	Kinect™	
Round 1	μ = 61.259 seconds (n = 15, σ = 23.285 seconds)	μ = 47.401 seconds (n = 15, σ = 28.463 seconds)	*Difference are not statistically significant*
Round 2	μ = 38.120 seconds (n = 13, σ = 23.078 seconds)	μ = 27.523 seconds (n = 16, σ = 19.030 seconds)	*Difference are not statistically significant*
	99% at p < 0.05	*Difference are not statistically significant*	*Statistical Significance*

Table A13. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set A task three comparing accuracy and interaction devices.

Set A - Task 3 Completion Times	Incorrect Tasks	Correct Tasks	
Mouse	μ = 62.536 seconds (n = 7, σ = 30.094 seconds)	μ = 46.510 seconds (n = 21, σ = 23.376 seconds)	*Difference was not statistically significant*
Kinect™	μ = 52.676 seconds (n = 5, σ = 36.696 seconds)	μ = 37.458 seconds (n = 26, σ = 21.951 seconds)	*Difference are not statistically significant*
	Difference was not statistically significant	*Difference was not statistically significant*	*Statistical Significance*

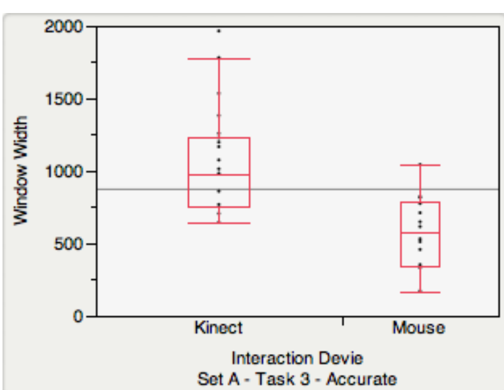
Correlating accuracy and interaction device showed no significance in the amount of time to complete tasks for participants (See Table A13).

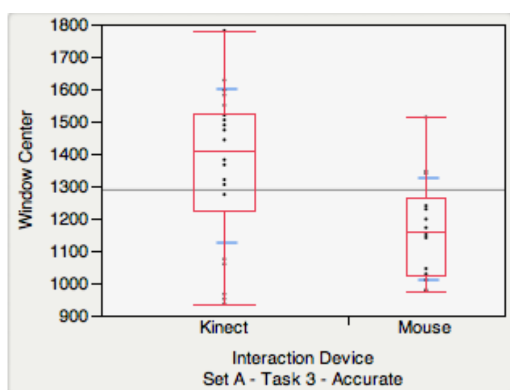
The third metric is comparing the window width and window center values generated by participants during the study. These results are separated by the individual tasks that correctly identified the anatomical feature and the individual tasks that were incorrectly identified.

Table A14. Number of tasks, mean, standard deviation and statistical significance of window width and window center values split between Kinect™ and mouse users for those who accurately identified the anatomical feature.

Set A - Task 3 Accurate score	Kinect™ (n=22)	Mouse (n=14)	*Statistical Significance*
Window Width	μ = 1059 HU (σ = 359 HU)	μ = 580 HU (σ = 241 HU)	*99% at p < 0.05*
Window Center	μ = 1364 HU (σ = 237 HU)	μ = 1168 HU (σ = 157 HU)	*99% at p < 0.05*

First was the comparison of correct tasks. Participants using the Kinect™ had larger window widths and higher window centers values compared to those using the mouse, for those tasks where the anatomy was accurately identified.





(a) (b)

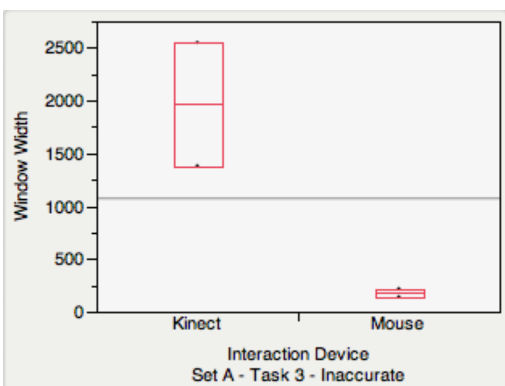
Figure A11. a) Window width values from set A task three for accurate tasks split by interaction device. b) Window center values from set A tasks three for accurate tasks split by interaction device.

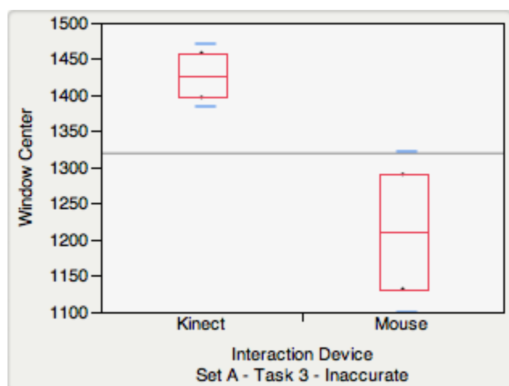
Window width and window center were statistically significant; values are presented in Table A14 (See Figure A11).

Second was comparison of incorrect tasks. Correlating between interaction devices for window width and window center values showed no significance in the Hounsfield Units of tasks for participants (See Table A15 and Figure A12).

Table A15. Number of tasks, mean, standard deviation and statistical significance of window width and window center values split between Kinect™ and mouse users for those who inaccurately identified the anatomical feature.

Set A - Task 3 Inaccurate score	Kinect™ (n=2)	Mouse (n=2)	*Statistical Significance*
Window Width	μ = 1965 HU (σ = 825 HU)	μ = 180 HU (σ = 54 HU)	*Difference was not statistically significant*
Window Center	μ = 1427 HU (σ = 43 HU)	μ = 1211 HU (σ = 112 HU)	*Difference was not statistically significant*





(a) (b)

Figure A12. a) Window width values from set A task three for inaccurate tasks split by interaction device. b) Window center values from set A tsk three for inaccurate tasks split by interaction device.

Set A Task Four: Display the pulmonary arterial trees visible within the lungs

These results include the first and second attempts for participants completing tasks during round one and two, while using both interaction devices; 58 attempts were evaluated for this task. One was removed for reaching the maximum allotted time of two-minutes and five were removed for rotating the anatomical region. All of these attempts were from participants using the mouse.

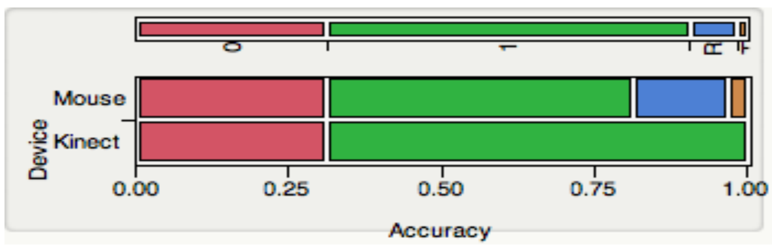


Figure A13. Percentage of responses based on of participants using the Kinect™ compared to the mouse for set A task four. Pink corresponds to incorrect responses, green are correct responses, blue are tasks that were rotated and orange are tasks where the participants reached the allotted time of

The first metric was to compare the accuracy achieved by participants using different interaction devices. Participants using the Kinect™ had more correct responses than those using the mouse. Individuals using the Kinect™ completed 22 of the 32 tasks correctly (10 tasks were incorrect). Individuals using the mouse completed 16 of the 32 tasks correctly (10 tasks were incorrect, 5 tasks were rotated and 1 task reached the allotted time) (See Figure A13). Statistical significance between accuracy and interaction devices is discussed on the next section with respect to the amount of time taken to the complete the task.

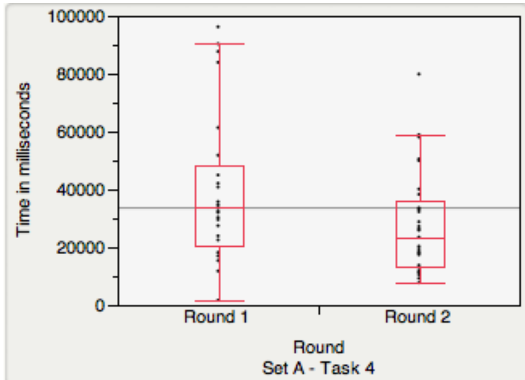


Figure A14. Time for participants to complete tasks for the rounds of set A task four.

The second metric was to compare the amount of time participants took to complete this task. Participants took less time to complete this task the second attempt (μ = 27.788 seconds, σ = 17.693 seconds), compared to the first attempt (μ = 39.321 seconds, σ = 24.778 seconds). Time was statistically significant at a confidence level of 95% ($p < 0.05$) (See Figure A14).

Participants during round two spent less time completing the task correctly than those who incorrectly completed the task. Time was statistically significant; values are presented in Table 18. Correlations between accuracy during round one did not show statistical significance.

Participants who correctly identified the anatomy did so in less time during the second round compared to those who correctly identified the anatomy in round one. Time was statistically significant; values are presented in Table A16.

Correlations for incorrect responses between rounds did not show statistical significance.

Table A16. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set A task four comparing accuracy and rounds.

Set A - Task 4 Completion Times	Incorrect Tasks	Correct Tasks	
Round 1	μ = 35.477 seconds (n = 10, σ = 23.782 seconds)	μ = 41.345 seconds (n = 19, σ = 25.685 seconds)	*Difference was not statistically significant*
Round 2	μ = 38.270 seconds (n = 10, σ = 24.022 seconds)	μ = 22.271 seconds (n = 19, σ = 10.260 seconds)	*95% at p < 0.05*
	Difference was not statistically significant	*99% at p < 0.05*	*Statistical Significance*

Participants using the Kinect™ were able to complete their tasks in less time than those using the mouse during both the first and second rounds. Time was statistically significant; values presented in Table A17.

Participants improved their task completion time between round one and round two for the Kinect™. Time was statistically significant; values are presented in Table A17. Correlation for the mouse response between rounds did not show statistical significance.

Table A17. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set A task four for round one and two for interaction devices, including standard deviation for those results.

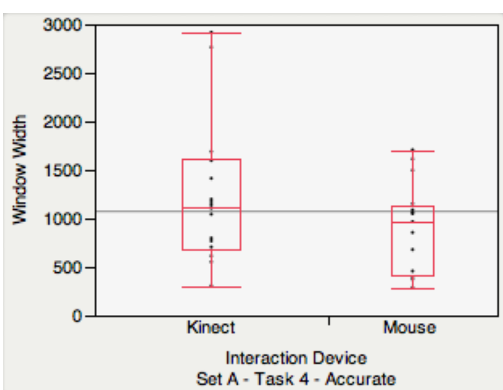
Set A - Task 4 Completion Times	Mouse	Kinect™	
Round 1	μ = 52.620 seconds (n = 13, σ = 28.469 seconds)	μ = 27.704 seconds (n = 16, σ = 13.285 seconds)	*99% at p > 0.05*
Round 2	μ = 36.705 seconds (n = 13, σ = 21.369 seconds)	μ = 20.543 seconds (n = 16, σ = 9.702 seconds)	*95% at p > 0.05*
	Difference was not statistically significant	*95% at p < 0.05*	*Statistical Significance*

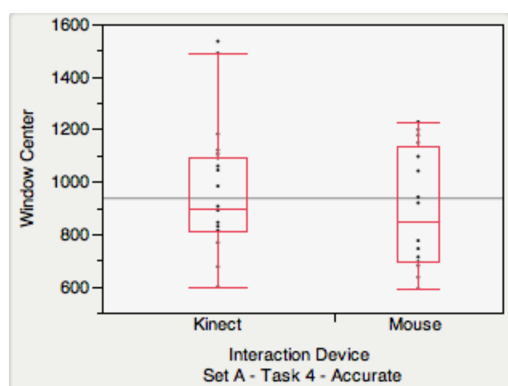
Participants who correctly identified the anatomy did so in less time using the Kinect™ compared to those using the mouse. Time was statistically significant; values are presented in Table A18. Other correlations between accuracy and interaction device did not show statistical significance.

Table A18. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set A task four for round one and two for interaction devices, including standard deviation for those results.

Set A - Task 4 Completion Times	Incorrect Tasks	Correct Tasks	
Mouse	μ = 46.086 seconds (n = 10, σ = 26.370 seconds)	μ = 44.585 seconds (n = 16, σ = 26.824 seconds)	*Difference was not statistically significant*
Kinect™	μ = 27.661 seconds (n = 10, σ = 16.217 seconds)	μ = 22.515 seconds (n = 22, σ = 9.564 seconds)	*Difference was not statistically significant*
	Difference was not statistically significant	*99% at p > 0.05*	*Statistical Significance*

The third metric was to compare the window width and window center values that were created by participants during the study. These results are separated by the individual tasks that correctly identified the anatomical feature and the individual tasks that were incorrectly identified.





(a) (b)

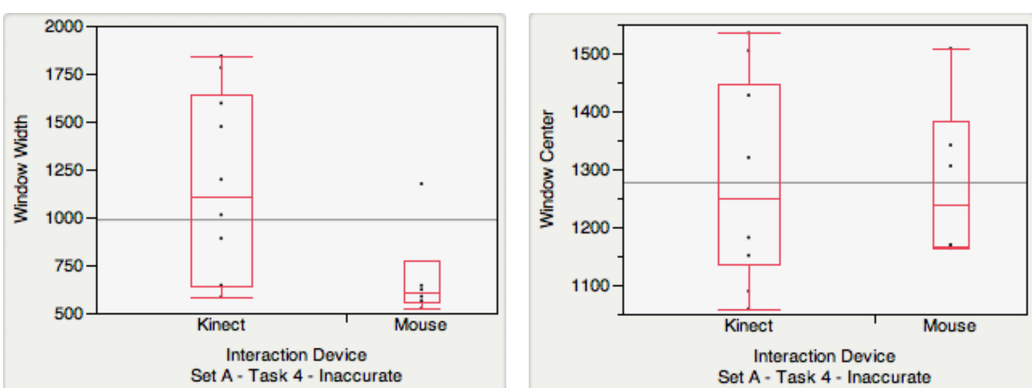
Figure A15. a) Window width values from set A task four for accurate tasks split by interaction device. b) Window center values from set A task four for accurate tasks split by interaction device.

First was the comparison of correct tasks. Correlating between interaction devices for window width and window center values showed no significance in the window width or window center values to complete tasks for participants (See Table A19 and Figure A15).

Table A19. Number of tasks, mean, standard deviation and statistical significance of window width and window center values split between Kinect™ and mouse users for those who accurately identified the anatomical feature.

Set A - Task 4 Accurate score	Kinect™ (n=22)	Mouse (n=16)	*Statistical Significance*
Window Width	μ = 1192 HU (σ = 674 HU)	μ = 907 HU (σ = 455 HU)	*Difference was not statistically significant*
Window Center	μ = 964 HU (σ = 232 HU)	μ = 897 HU (σ = 222 HU)	*Difference was not statistically significant*

Second was the comparison of incorrect tasks. Participants using the Kinect™ had larger window widths compared to those using the mouse, for those tasks where the anatomy was inaccurately identified. Window width was statistically significant; values are presented in Table A20 (See Figure A16). Correlation of window center did not show statistical significance.



(a) (b)

Figure A16. a) Window width values from set A task four for inaccurate tasks split by interaction device. b) Window center values from set A task four for inaccurate tasks split by interaction device.

Table A20. Number of task, mean, standard deviation and statistical significance of window width and window center values split between Kinect™ and mouse users for those who inaccurately identified the anatomical feature.

Set A - Task 4 Inaccurate score	Kinect™ (n=10)	Mouse (n=6)	*Statistical Significance*
Window Width	μ = 1166 HU (σ = 483 HU)	μ = 686 HU (σ = 243 HU)	*99% at $p < 0.05$*
Window Center	μ = 1277 HU (σ = 170 HU)	μ = 1275 HU (σ = 138 HU)	*Difference was not statistically significant*

Set A Task Five: Display the spinous process surrounded by muscle

These results include the first and second attempts for participants completing tasks during round one and two, while using both interaction devices; 61 attempts were evaluated for this task. All three attempts were removed for rotation of the anatomical region. All of these attempts were from participants

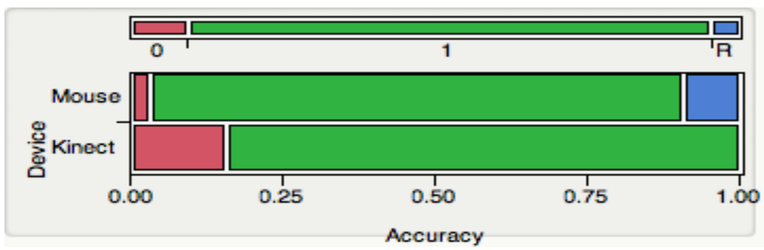


Figure A17. Percentage of response based on accuracy of participants using the Kinect™ compared to the mouse for set A task five. Pink corresponds to incorrect responses, green are correct responses, and blue are tasks that were rotated.

using the mouse.

The first metric is comparing the accuracy achieved by participants using difference interaction devices. Participants using the Kinect™ had less correct responses than those using the mouse. Individuals using the Kinect™ completed 27 of the 32 tasks correctly (5 tasks were incorrect). Individuals using the mouse completed 28 of the 32 tasks correctly (1 task was incorrect, 3 tasks were rotated) (See Figure A17). Statistical significance between accuracy and interaction devices is discussed on the next section with respect to the amount of time taken to the complete the task.

The second metric is comparing the amount of time participants took to complete this task. Participants took less time to complete this task the second attempt (μ = 27.240 seconds, σ = 16.892 seconds), compared to the first attempt (μ = 43.656 seconds, σ = 22.785 seconds). Time was statistically significant at a confidence level of 99% ($p < 0.05$) (See Figure A18).

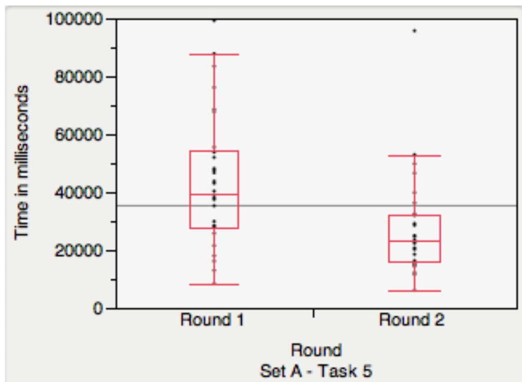


Figure A18. Time for participants to complete tasks for the rounds of set A task five.

Participants during round two spent less time completing the task incorrectly than those who correctly completed the task. Time was statistically significant; values are presented in Table A21. Correlation between accuracy during round one did not show statistical significance.

Table A21. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set A task five comparing accuracy and rounds.

Set A - Task 5 Completion Times	Incorrect Tasks	Correct Tasks	
Round 1	μ = 37.417 seconds (n = 4, σ = 28.320 seconds)	μ = 44.616 seconds (n = 26, σ = 22.334 seconds)	*Difference was not statistically significant*
Round 2	μ = 18.285 seconds (n = 2, σ = 2.726 seconds)	μ = 27.858 seconds (n = 29, σ = 17.302 seconds)	*95% at $p > 0.05$*
	Difference was not statistically significant	*99% at $p < 0.05$*	*Statistical Significance*

Participants who correctly identified the anatomy did so in less time during the second round compared to those who correctly identified the anatomy in round one. Time was statistically significant; values are presented in Table A21. Correlations between incorrect responses between rounds did not show statistical significance.

Participants improved their performance during the second round compared to the first round for both the mouse and the Kinect™. Time was statistically significant; values are presented in Table A22. Correlation between interaction devices per round did not show statistical significance.

Table A22. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set A task five comparing interaction devices and rounds.

Set A - Task 5 Completion Times	Mouse	Kinect™	
Round 1	μ = 48.520 seconds (n = 14, σ = 25.195 seconds)	μ = 39.400 seconds (n = 16, σ = 20.301 seconds)	*Difference was not statistically significant*
Round 2	μ = 31.099 seconds (n = 15, σ = 19.851 seconds)	μ = 23.623 seconds (n = 16, σ = 13.193 seconds)	*Difference was not statistically significant*
	95% at $p < 0.05$	*99% at $p < 0.05$*	*Statistical Significance*

Table A23. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set A task five comparing accuracy and interaction devices.

Set A - Task 5 Completion Times	Incorrect Tasks	Correct Tasks	
Mouse	μ = 35.286 seconds (n = 1)	μ = 39.660 seconds (n = 28, σ = 24.304 seconds)	*Not determinable because n = 1*
Kinect™	μ = 30.190 seconds (n = 5, σ = 26.832 seconds)	μ = 31.756 seconds (n = 27, σ = 17.424 seconds)	*Difference was not statistically significant*
	Not determinable because n = 1	*Difference was not statistically significant*	*Statistical Significance*

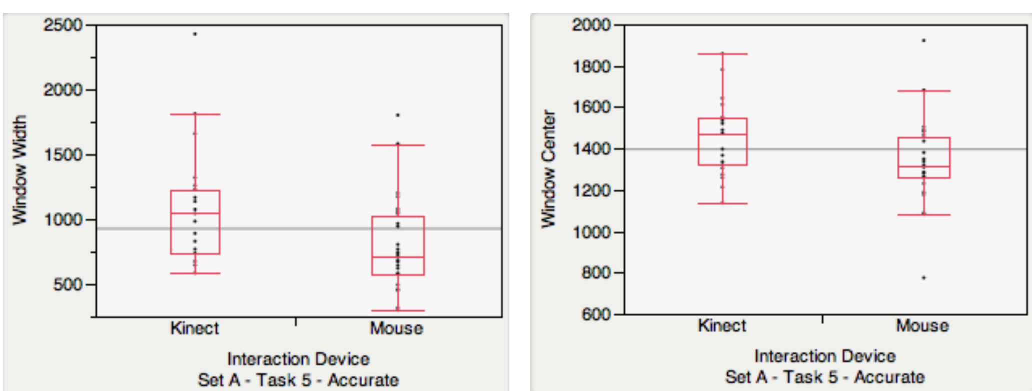
Correlating accuracy and interaction device showed no significance in the amount of time to complete tasks for participants (See Table A23).

The third metric is comparing the window width and window center values created by the participants during the study. These results are separated by the individual tasks that correctly identified the anatomical feature and the individual tasks that were incorrectly identified.

Table A24. Number of tasks, mean standard deviation and statistical significance of window width and window center values split between Kinect™ and mouse users for those who accurately identified the anatomical feature.

Set A -Task 5 Accurate score	Kinect™ (n=27)	Mouse (n=28)	*Statistical Significance*
Window Width	μ = 1051 HU (σ = 415 HU)	μ = 803 HU (σ = 350 HU)	*95% at p < 0.05*
Window Center	μ = 1458 HU (σ = 168 HU)	μ = 1336 HU (σ = 204 HU)	*99% at p < 0.05*

First was comparing the correct tasks. Participants using the Kinect™ had larger window widths and higher window centers values compared to those using the mouse, for those tasks where the anatomy was accurately identified. Window



(a) (b)

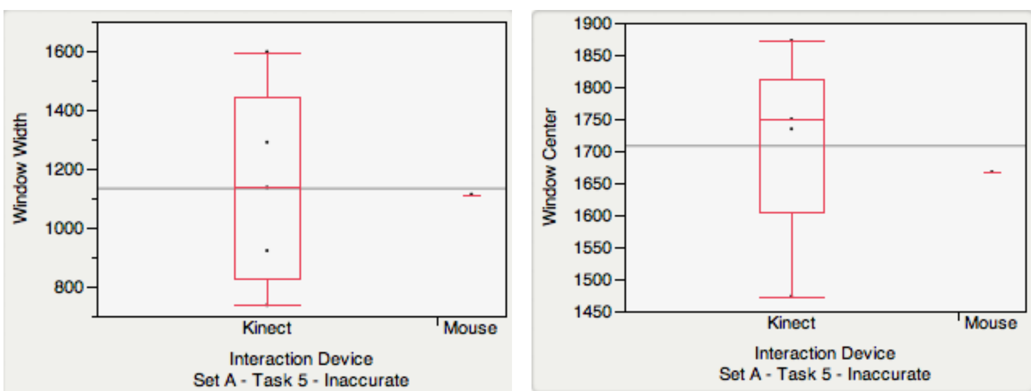
Figure A19. a) Window width values from set A task five for accurate tasks split by interaction device. b) Window center values from set A task five for accurate tasks split by interaction device.

widths and window center were statistically significant; values are presented in Table A24 (See Figure A19).

Table A25. Number of tasks, mean, standard deviation and statistical significance of window width and window center values split between Kinect™ and mouse users for those who inaccurately identified the anatomical feature.

Set A - Task 5 Inaccurate score	Kinect™ (n=5)	Mouse (n=1)	*Statistical Significance*
Window Width	μ = 1137 HU (σ = 332 HU)	μ = 1113 HU	*Not determinable because n = 1*
Window Center	μ = 1716 HU (σ = 147 HU)	μ = 1668 HU	*Not determinable because n = 1*

Second was comparing the incorrect tasks. Correlation of window width and window center values for those who incorrectly identified the anatomy did not show statistical significance. (See Table A25 and Figure A20).



(a) (b)

Figure A20. a) Window width values from set A task five for inaccurate tasks split by interaction device. b) Window center values from set A task five for inaccurate tasks split by interaction device.

Set B Task One: Display the best view of the costal cartilages

These results include the first and second attempts for participants completing tasks during round three and four, while using both interaction devices; 60 attempts were evaluated for this task. Three of the attempts were removed for reaching the allotted time of two-minutes per task. One attempt was removed for rotation of the anatomical region. All removed attempts were from participants using the mouse.

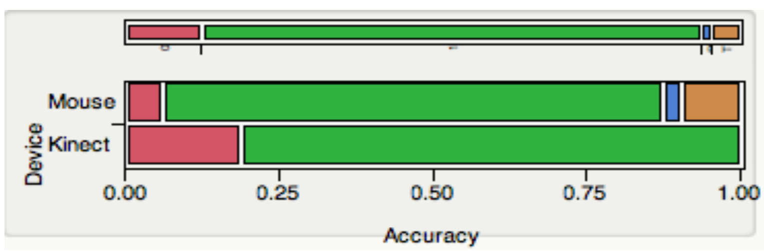


Figure A21. Percentage of responses based on accuracy of participants using the Kinect™ compared to the mouse for set B task one. Pink corresponds to incorrect responses, green are correct responses, blue are rotated tasks and orange are tasks that reached the allotted time of two-minutes per task.

The first metric was to compare the accuracy in tasks achieved by participants. Participants using the Kinect™ had a lower level of accuracy compared to participants using the mouse. Individuals using the Kinect™ completed 26 of the 32 tasks correctly (6 tasks were incorrect). Individuals using the mouse completed 26 of the 32 tasks correctly (2 tasks were incorrect, 1 task was removed for rotation and 3 tasks were removed from participants reaching the allotted time of two-minutes) (See Figure A21). Statistical significance

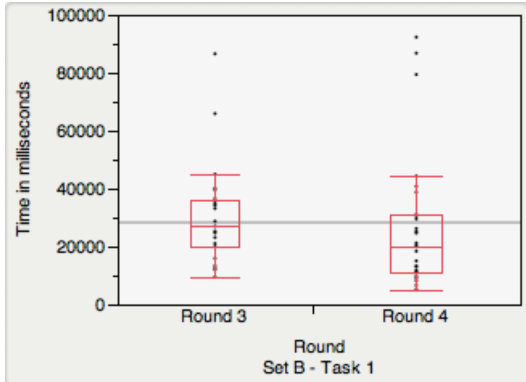


Figure A22. Time for participants to complete tasks for the rounds of set B task one.

between accuracy and interaction devices is discussed on the next section with respect to the amount of time taken to the complete the task.

The second metric was comparing the amount of time participants took to complete this task. Participants took less time to complete this task during the fourth round attempt (μ = 26.662 seconds, σ = 22.587 seconds) compared to the third round attempt (μ = 30.069 seconds, σ = 16.251 seconds), however the results were not statistically significant (See Figure A22).

Table A26. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set B task one comparing accuracy and rounds.

Set B - Task 1 Completion Times	Incorrect Tasks	Correct Tasks	
Round 3	μ = 60.706 seconds (n = 2, σ = 36.539 seconds)	μ = 27.799 seconds (n = 27, σ = 12.471 seconds)	*Difference was not statistically significant*
Round 4	μ = 18.107 seconds (n = 6, σ = 7.649 seconds)	μ = 28.716 seconds (n = 25, σ = 24.553 seconds)	*95% at p > 0.05*
	Difference was not statistically significant	*Difference was not statistically significant*	*Statistical Significance*

Participants took more time to complete tasks correctly during round two compared to those who incorrectly completed the task. Time was statistically significant; values are presented in Table A26. Other correlations between accuracy and round did not show statistical significance.

Participants who used the Kinect™ during round four completed tasks faster than those who used the mouse. Time was statistically significant; values are presented in Table A27. Correlation between interaction devices during round three did not show statistical significance.

Participants who used the Kinect™ completed the task faster during round four compared to round three. Time was statistically significant; values are presented in Table A27. Correlation between rounds for the mouse did not show statistical significance.

Table A27. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set B task one comparing interaction devices and rounds.

Set B - Task 1 Completion Times	Mouse	Kinect™	
Round 3	$\mu = 28.823$ seconds ($n = 13$, $\sigma = 7.407$ seconds)	$\mu = 31.081$ seconds ($n = 16$, $\sigma = 21.134$ seconds)	*Difference was not statistically significant*
Round 4	$\mu = 34.201$ seconds ($n = 15$, $\sigma = 28.835$ seconds)	$\mu = 19.595$ seconds ($n = 16$, $\sigma = 11.584$ seconds)	*95% at $p > 0.05$*
	Difference was not statistically significant	*95% at $p < 0.05$*	*Statistical Significance*

Table A28. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set B task one comparing accuracy and rounds.

Set B - Task 1 Completion Times	Incorrect Tasks	Correct Tasks	
Mouse	$\mu = 24.977$ seconds ($n = 2$, $\sigma = 15.261$ seconds)	$\mu = 32.291$ seconds ($n = 26$, $\sigma = 22.038$ seconds)	*Difference was not statistically significant*
Kinect™	$\mu = 30.316$ seconds ($n = 6$, $\sigma = 28.489$ seconds)	$\mu = 24.189$ seconds ($n = 26$, $\sigma = 14.869$ seconds)	*Difference was not statistically significant*
	Difference was not statistically significant	*Difference was not statistically significant*	*Statistical Significance*

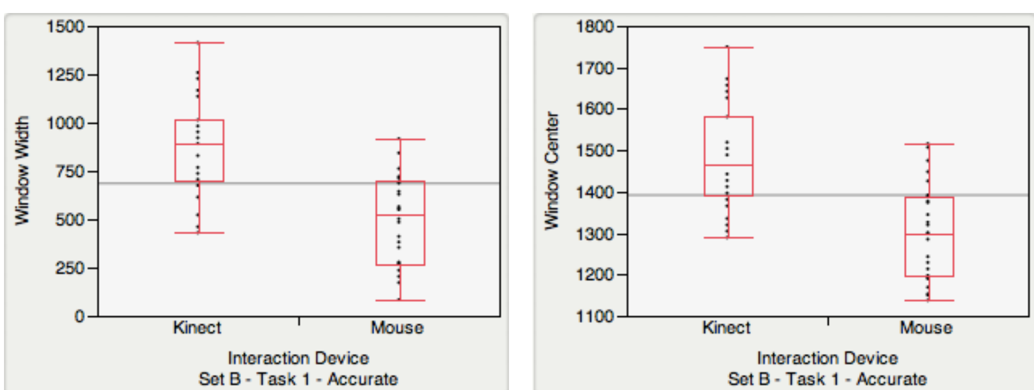
Correlating accuracy and interaction device showed no significance in the amount of time to complete tasks for participants (See Table A28).

The third metric was comparing window width and window center values that were created by participants during the study. These results are separated by the individual tasks that correctly identified the anatomical feature and the individual tasks that were incorrectly identified.

Table A29. Number of tasks, mean, standard deviation and statistical significance of window width and window center values split between Kinect™ and mouse users for those who accurately identified the anatomical feature.

Set B - Task 1 Accurate score	Kinect™ (n=26)	Mouse (n=26)	*Statistical Significance*
Window Width	μ = 875 HU (σ =246 HU)	μ = 495 HU (σ = 231 HU)	*99% at p < 0.05*
Window Center	μ = 1479 HU (σ = 123 HU)	μ = 1303 HU (σ = 115 HU)	*99% at p < 0.05*

First was comparing the tasks that were graded correctly. Participants using the Kinect™ had larger window widths and higher window center values compared to those using the mouse, for those tasks where the anatomy was



(a) (b)

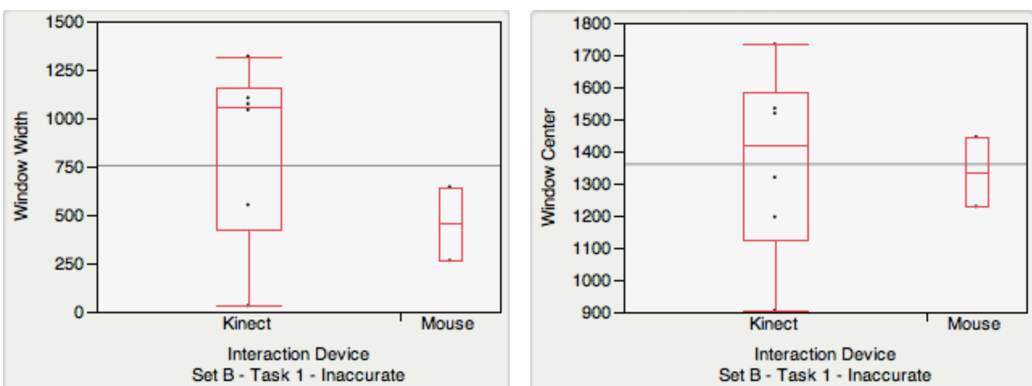
Figure A23. a) Window width values from set B task one for accurate tasks split by interaction devices. b) Window center values from set B task one for accurate tasks split by interaction devices.

accurately identified. Window width and window center were statistically significant; values are presented in Table A29 (See Figure A23).

Second was comparing the tasks that were graded incorrectly. Correlation of window width and window center values for those who incorrectly identified the anatomy did not show statistical significance. (See Table A30 and Figure A24).

Table A30. Number of tasks, mean, standard deviation and statistical significance of window width and window center values split between Kinect™ and mouse users for those who inaccurately identified the anatomical feature.

Set B - Task 1 – Inaccurate score	Kinect™ (n=6)	Mouse (n=2)	*Statistical Significance*
Window Width	μ = 854 HU (σ = 475 HU)	μ = 455 HU (σ = 268 HU)	*Difference was not statistically significant*
Window Center	μ = 1368 HU (σ = 293 HU)	μ = 1337 HU (σ = 153 HU)	*Difference was not statistically significant*



(a) (b)

Figure A24. a) Window width values from set B task one for inaccurate tasks split by interaction device. b) Window center values from set B task one for inaccurate tasks split by interaction device.

Set B Task Two: Display the best discrimination of the sternal angle joint

These results include the first and second attempts for participants completing tasks during round three and four, while using both interaction devices; 63 attempts were evaluated for this task. One attempt was removed due to the participants reaching the allotted time of two-minutes. The attempt was removed from participants using the Kinect™.

The first metric was comparing accuracy in tasks completed by participants. Participants using the mouse had more correct responses than those using the Kinect™. Individuals using the Kinect™ completed 22 of the 32 tasks correctly (9 tasks were incorrect, 1 task reached the allotted allowed time of two-minutes). Individuals using the mouse completed 24 of the 32 tasks correctly (8 tasks were incorrect) (See Figure A25). Statistical significance between accuracy and interaction devices is discussed on the next section with respect to the amount of time taken to the complete the task.

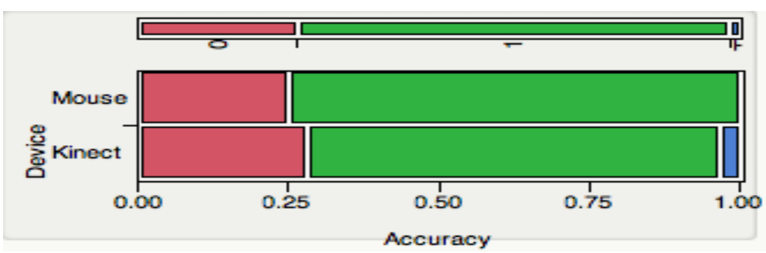


Figure A25. Percentages of responses based on accuracy of participants using the Kinect compared to the mouse for set B task two. Pink corresponds to incorrect responses, green are correct responses, and blue are tasks that reached the allotted time of two-minutes.

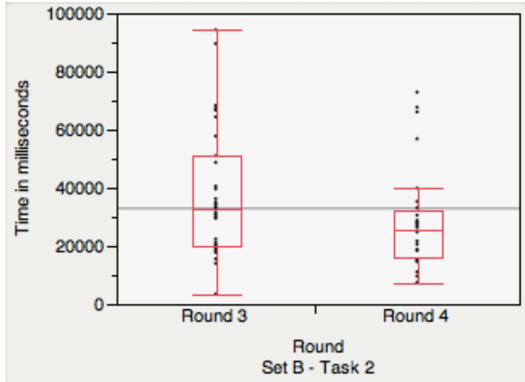


Figure A26. Time for participants to complete tasks during the third and fourth rounds for the set B task two.

The second metric was comparing the amount of time participants took to complete this task. Participants completed this task faster during the fourth round attempt (μ = 28.053 seconds, σ = 16.574 seconds) of set B tasks compared to the third round of attempts (μ = 37.881 seconds, σ = 22.370 seconds). Time was statistically significant at 95% ($p < 0.05$) (See Figure A26).

Participants completed tasks correctly during third round in less time compared to those who incorrectly identified the anatomical feature. Time was statistically significant; values are presented in Table A31. Other correlations between accuracy and rounds did not statistical significance.

Table A31. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set B task two comparing accuracy and rounds.

Set B - Task 2 Completion Times	Incorrect Tasks	Correct Tasks	
Round 3	μ = 53.559 seconds (n = 10, σ = 22.607 seconds)	μ = 30.416 seconds (n = 21, σ = 18.419 seconds)	*99% at p < 0.05*
Round 4	μ = 36.623 seconds (n = 7, σ = 19.123 seconds)	μ = 25.654 seconds (n = 25, σ = 15.362 seconds)	*Difference was not statistically significant*
	Difference was not statistically significant	*Difference was not statistically significant*	*Statistical Significance*

Correlating accuracy and interaction device showed no significance in the amount of time to complete tasks for participants (See Table A32).

Table A32. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set B task two comparing interaction device and rounds.

Set B - Task 2 Completion Times	Mouse	Kinect™	
Round 3	μ = 39.691 seconds (n = 16, σ = 23.411 seconds)	μ = 35.950 seconds (n = 15, σ = 21.849 seconds)	*Difference was not statistically significant*
Round 4	μ = 31.070 seconds (n = 16, σ = 16.666 seconds)	μ = 25.037 seconds (n =16, σ = 16.449 seconds)	*Difference was not statistically significant*
	Difference was not statistically significant	*Difference was not statistically significant*	*Statistical Significance*

Participants using both interaction devices took less time to correctly identify the anatomy compared to those who incorrectly identified the anatomy. Time was statistically significant; values are presented in Table A33. Correlation between interaction devices for accuracy did not show statistical significance.

Table A33. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set B task two comparing accuracy and interaction device.

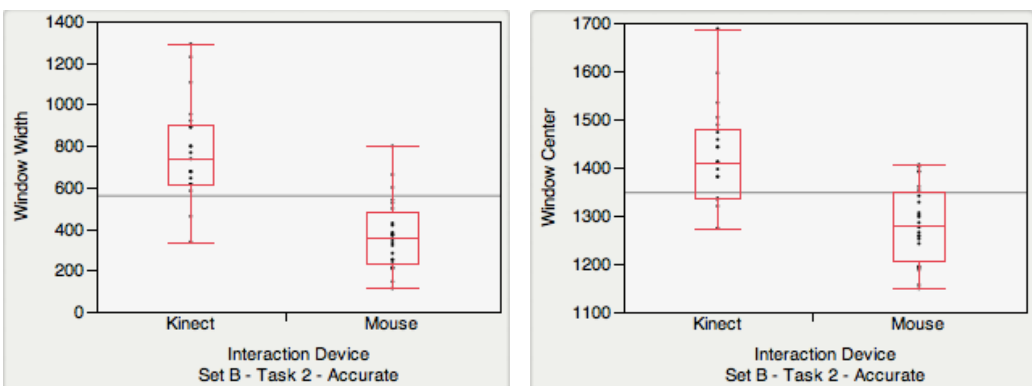
Set B - Task 2 Completion Times	Incorrect Tasks	Correct Tasks	
Mouse	μ = 50.602 seconds (n = 8, σ = 19.023 seconds)	μ = 30.307 seconds (n = 24, σ = 18.624 seconds)	*95% at $p < 0.05$*
Kinect™	μ = 43.015 seconds (n = 9, σ = 25.490 seconds)	μ = 25.123 seconds (n =22, σ = 14.510 seconds)	*95% at $p < 0.05$*
	Difference was not statistically significant	*Difference was not statistically significant*	*Statistical Significance*

The third metric was comparing the window width and window center values created by participants completing this task. These results are separated by the individual tasks that correctly identified the anatomical feature and the individual tasks that were incorrectly identified.

First was comparing the tasks that were graded correct. Participants using the Kinect™ had larger window widths and higher window center values compared to those using the mouse, for those tasks where the anatomy was accurately identified. Window width and window center were statistically significant; values are presented in Table A34 (See Figure A27).

Table A34. Number of tasks, mean, standard deviation and statistical significance of window width and window center values split between Kinect™ and mouse users for those who accurately identified the anatomical feature.

Set B - Task 2 Accurate score	Kinect™ (n=21)	Mouse (n=21)	*Statistical Significance*
Window Width	μ = 775 HU (σ = 236 HU)	μ = 369 HU (σ = 167 HU)	*99% at p < 0.05*
Window Center	μ = 1422 HU (σ = 103 HU)	μ = 1283 HU (σ = 78 HU)	*99% at p < 0.05*



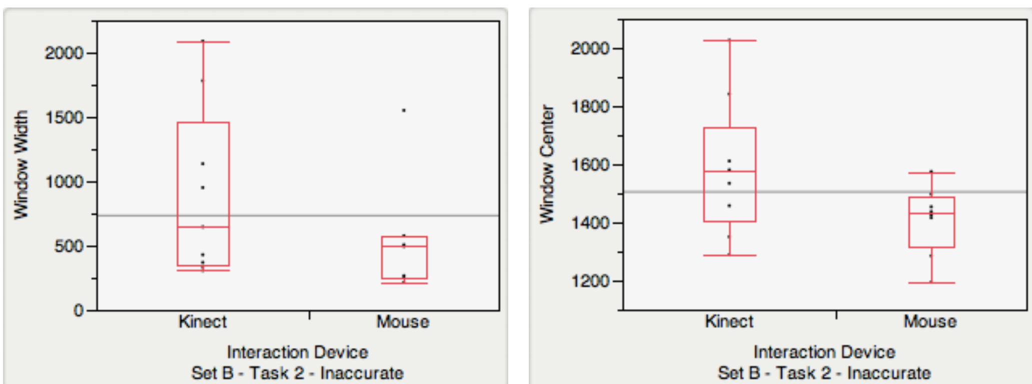
(a) (b)

Figure A27. a) Window width values from set B task two for accurate tasks split by interaction device. b) Window center values from set B task two for accurate tasks split by interaction device.

Second was comparing tasks that were graded incorrectly. Participants using the Kinect™ had higher window center values compared to those using the mouse, for those tasks where the anatomy was inaccurately identified. Window center was statistically significant; values are presented in Table A35 (See Figure A28). Correlation of window width did not show statistical significance.

Table A35. Number of tasks, mean, standard deviation and statistical significance of window width and window center values split between Kinect™ and mouse users for those who inaccurately identified the anatomical feature.

Set B - Task 2 Inaccurate score	Kinect™ (n=9)	Mouse (n=8)	*Statistical Significance*
Window Width	μ = 894 HU (σ = 659 HU)	μ = 553 HU (σ = 429 HU)	*Difference was not statistically significant*
Window Center	μ = 1589 HU (σ = 230 HU)	μ = 1410 HU (σ = 119 HU)	*95% at $p < 0.05$*



(a) (b)

Figure A28. a) Window width values from set B task two for inaccurate tasks split by interaction device. b) Window center values from set B task two for inaccurate tasks split by interaction device.

Set B Task Three: Display the pulmonary artery

These results include the first and second attempts for participants completing tasks during round three and four, while using both interaction devices; 62 attempts were evaluated for this task. The removed tasks were due to participants reaching the allotted time of two-minutes. Both tasks were removed from the mouse.

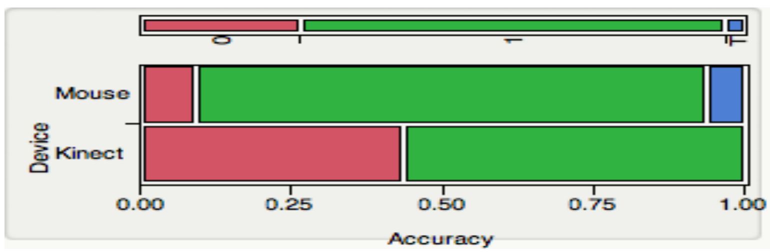


Figure A29. Percentages of responses based on accuracy of participants using the Kinect™ compared to the mouse for set B task three. Pink corresponds to incorrect responses, green are correct responses, and blue are tasks that reached the allotted time of two-minutes.

The first metric is comparing the accuracy achieved during this task during the study. Participants using the mouse had more correct responses than those using the Kinect™. Individuals using the Kinect™ completed 18 of the 32 tasks correctly (14 tasks were incorrect). Individuals using the mouse completed 27 of the 32 tasks correctly (3 tasks were incorrect, 2 tasks reached the allotted time of two-minutes) (See Figure A29). Statistical significance between accuracy and interaction devices is discussed on the next section with respect to the amount of time taken to the complete the task.

The second metric was comparing the time taken by participants to complete this task. Participants completed this task faster during the fourth round attempt (μ = 30.681 seconds, σ = 20.909 seconds) compared to the third round

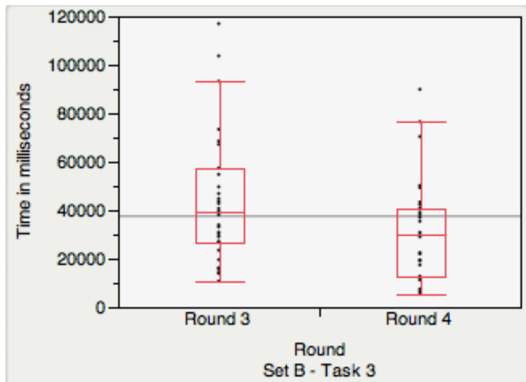


Figure A30. Time for participants to complete tasks during the third and fourth rounds for the set B task three.

attempt (μ = 44.293 seconds, σ = 26.510 seconds). Time was statistically significant at 99% ($p < 0.05$) (See Figure A30).

Correlating accuracy and rounds showed no significance in the amount of time to complete tasks for participants (See Table A36).

Table A36. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set B task three comparing accuracy and rounds.

Set B - Task 3 Completion Times	Incorrect Tasks	Correct Tasks	
Round 3	μ = 47.611 seconds (n = 8, σ = 30.111 seconds)	μ = 43.139 seconds (n = 23, σ = 25.788 seconds)	*Difference was not statistically significant*
Round 4	μ = 29.109 seconds (n = 9, σ = 13.518 seconds)	μ = 31.324 seconds (n = 22, σ = 23.526 seconds)	*Difference was not statistically significant*
	Difference was not statistically significant	*Difference was not statistically significant*	*Statistical Significance*

Participants using the Kinect™ improved their task completion time between round three and round four. Time was statistically significant; values are presented in Table A37. Other correlations between interaction device and rounds did not show statistical significance.

Table A37. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set B task three comparing interaction device and rounds.

Set B - Task 3 Completion Times	Mouse	Kinect™	
Round 3	μ = 40.046 seconds (n = 15, σ = 14.205 seconds)	μ = 48.275 seconds (n = 16, σ = 34.385 seconds)	*Difference was not statistically significant*
Round 4	μ = 34.870 seconds (n = 15, σ = 18.428 seconds)	μ = 26.755 seconds (n =16, σ = 22.880 seconds)	*Difference was not statistically significant*
	Difference was not statistically significant	*95% at p < 0.05*	*Statistical Significance*

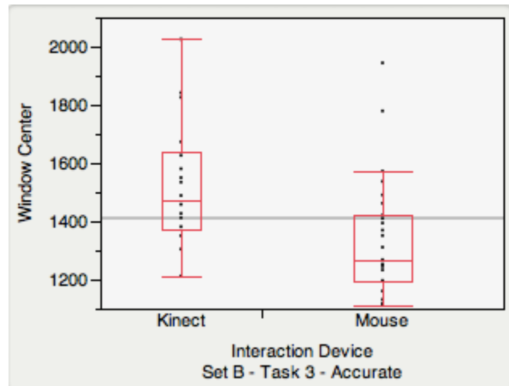
Correlating accuracy and interaction device showed no significance in the amount of time to complete tasks for participants (See Table A38).

Table A38. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set B task three comparing accuracy and interaction device.

Set B - Task 3 Completion Times	Incorrect Tasks	Correct Tasks	
Mouse	μ = 32.898 seconds (n = 3, σ = 5.422 seconds)	μ = 37.964 seconds (n = 27, σ = 17.156 seconds)	*Difference was not statistically significant*
Kinect™	μ = 38.870 seconds (n = 14, σ = 26.475 seconds)	μ = 36.461 seconds (n =18, σ = 34.415 seconds)	*Difference was not statistically significant*
	Difference was not statistically significant	*Difference was not statistically significant*	*Statistical Significance*

The third metric was comparing the window width and window center values created by participants during the study. These results are separated by the individual tasks that correctly identified the anatomical feature and the individual tasks that were incorrectly identified.

First was the comparison of tasks that were graded correctly. Participants using the Kinect™ had larger window width values and larger window center values compared to those using the mouse, for those tasks where the anatomy



(a) (b)

Figure A31. a) Window width values from set B task three for accurate tasks split by interaction device. b) Window center values from set B task three for accurate tasks spilt by interaction device.

was accurately identified. Window width and window center were statistically significant; values are presented in Table A39 (See Figure A31).

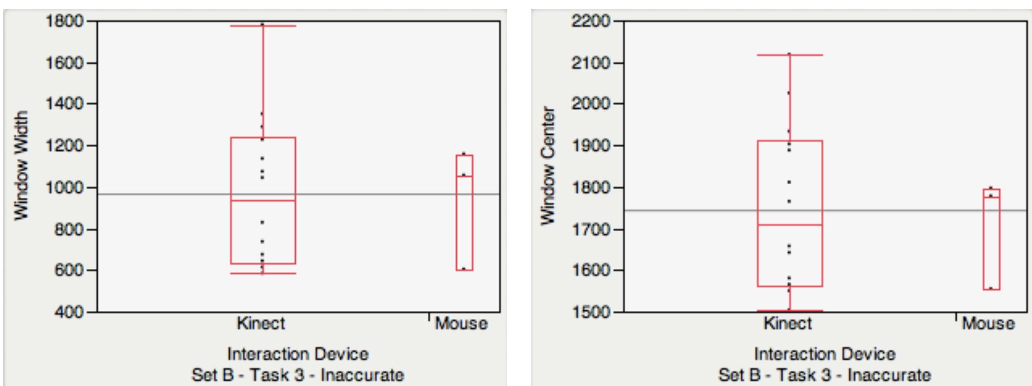
Table A39. Number of tasks, mean, standard deviation and statistical significance of window width and window center values split between Kinect™ and mouse users for those who accurately identified the anatomical feature.

Set B - Task 3 Accurate score	Kinect™ (n=18)	Mouse (n=27)	*Statistical Significance*
Window Width	μ = 1023 HU (σ = 431 HU)	μ = 631 HU (σ = 504 HU)	*99% at $p < 0.05$*
Window Center	μ = 1523 HU (σ = 212 HU)	μ = 1336 HU (σ = 201 HU)	*99% at $p < 0.05$*

Second was the comparison of tasks that were graded incorrectly. Correlation of window width and window center values for those who incorrectly identified the anatomy did not show statistical significance. (See Table A40 and Figure A32).

Table A40. Number of tasks, mean, standard deviation and statistical significance of window width and window center values split between Kinect™ and mouse users for those who inaccurately identified the anatomical feature.

Set B - Task 3 Inaccurate score	Kinect™ (n=14)	Mouse (n=3)	*Statistical Significance*
Window Width	μ = 969 HU (σ = 362 HU)	μ = 939 HU (σ = 294 HU)	*Difference was not statistically significant*
Window Center	μ = 1749 HU (σ = 199 HU)	μ = 1710 HU (σ = 134 HU)	*Difference was not statistically significant*



(a) (b)

Figure A32. a) Window width values from set B task three for inaccurate tasks split by interaction device. b) Window center values from set B task three for inaccurate tasks split by interaction device.

Set B Task Four: Display the skin of the thoracic wall as opaque, while hiding the superficial musculature.

This task was presented in the main body of this thesis during chapter 4.

Set B Task Five: Display the ribcage so that heart is clearly visible through the ribs

These results include the first and second attempt for participants completing tasks during round three and four, while using both interaction devices; 61 tasks were evaluated for this task. Two tasks were removed for reaching the allotted time of two-minutes. The third task was rotated prior to the participant completing the task. The three tasks were removed form the mouse category.

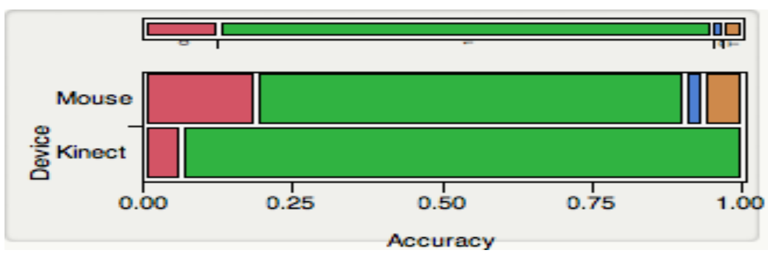


Figure A33. Percentages of responses based on accuracy of participants using the Kinect™ compared to the mouse for set B task five. Pink corresponds to incorrect responses, green are correct responses, blue are rotated tasks and orange are tasks that exceeded the time limit of two-minutes.

The first metric was to compare the accuracy achieved by participants when completing the tasks. Participants using the Kinect™ had more correct responses than those using the mouse. Individuals using the Kinect™ completed 30 of the 32 tasks correctly (2 tasks were incorrect). Individuals using the mouse completed 23 of the 32 tasks correctly (6 tasks were incorrect, 1 task was rotated, and two tasks reached the allotted time of two-minutes) (See Figure A33). Statistical significance between accuracy and interaction devices is discussed on the next section with respect to the amount of time taken to the complete the task.

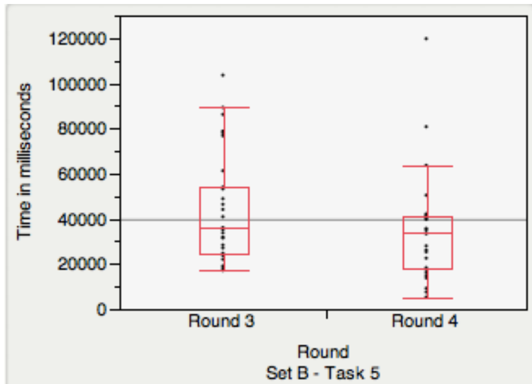


Figure A34. Time for participants to complete tasks between rounds for set B task five.

The second metric was to compare the amount of time participants took to complete this task. Participants completed this task faster during the fourth round attempt (μ = 33.911 seconds, σ = 23.175 seconds) compared to the third round attempt (μ = 44.883 seconds, σ = 23.851 seconds). Time was statistically significant at 95% ($p < 0.05$) (Figure A34).

Table A41. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set B task five comparing accuracy and rounds.

Set B - Task 5 Completion Times	Incorrect Tasks	Correct Tasks	
Round 3	μ = 49.242 seconds (n = 5, σ = 39.068 seconds)	μ = 44.044 seconds (n = 26, σ = 20.831 seconds)	*Difference was not statistically significant*
Round 4	μ = 52.816 seconds (n = 3, σ = 24.403 seconds)	μ = 31.810 seconds (n = 27, σ = 22.526 seconds)	*Difference was not statistically significant*
	Difference was not statistically significant	*95% at p < 0.05*	*Statistical Significance*

Participants improved their task completion time from round three to round four for those who accurately identified the anatomy. Time was statistically significant; values are presented in Table A41. Other correlations between accuracy and round did not show statistical significance.

Participants using the Kinect™ were able to complete their tasks quicker than those using the mouse during the fourth round. Time was statistically significant; values are presented in Table A42. Other correlations between interaction devices and rounds were not statistically significant.

Table A42. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set B task five comparing interaction device and rounds.

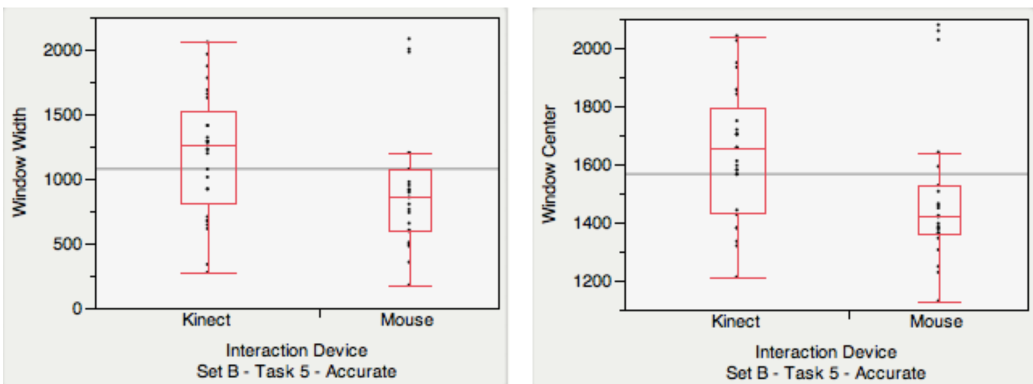
Set B - Task 5 Completion Times	Mouse	Kinect™	
Round 3	μ = 51.918 seconds (n = 15, σ = 25.030 seconds)	μ = 38.287 seconds (n = 16, σ = 21.380 seconds)	*Difference was not statistically significant*
Round 4	μ = 41.760 seconds (n = 14, σ = 27.209 seconds)	μ = 27.043 seconds (n =16, σ = 16.996 seconds)	*95% at p > 0.05*
	Difference was not statistically significant	*Difference was not statistically significant*	*Statistical Significance*

Participants who correctly identified the anatomy did so in less time with the Kinect™ compared to those using the mouse. Time was statistically significant; values are presented in Table A43. Other correlation between accuracy for interaction devices did not show statistical significance.

The third metric was to compare the window width and window center values that were created by participants during the study. These results are separated by the individual tasks that correctly identified the anatomical feature and the individual tasks that were incorrectly identified.

Table A43. Average completion times, number of tasks evaluated, standard deviation and statistical significance for set B task five comparing accuracy and interaction device.

Set B - Task 5 Completion Times	Incorrect Tasks	Correct Tasks	
Mouse	μ = 57.879 seconds (n = 6, σ = 34.491 seconds)	μ = 44.179 seconds (n = 23, σ = 23.647 seconds)	*Difference was not statistically significant*
Kinect™	μ = 28.692 seconds (n = 2, σ = 9.701 seconds)	μ = 32.930 seconds (n =30, σ = 20.404 seconds)	*Difference was not statistically significant*
	Difference was not statistically significant	*95% at p > 0.05*	*Statistical Significance*



(a) (b)

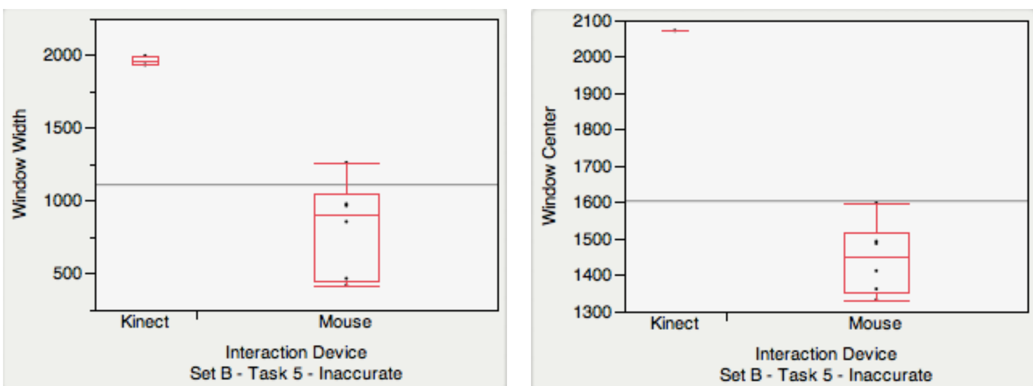
Figure A35. a) Window width values from set B task five for accurate tasks split by interaction device. b) Window center values from set B task five for accurate tasks split by interaction device.

Table A44. Number of tasks, mean, standard deviation and statistical significance of window width and window center values split between Kinect™ and mouse users for those who accurately identified the anatomical feature.

Set B - Task 5 Accurate score	Kinect™ (n=29)	Mouse (n=23)	*Statistical Significance*
Window Width	μ = 1198 HU (σ = 468 HU)	μ = 923 HU (σ = 504 HU)	*95% at p < 0.05*
Window Center	μ = 1630 HU (σ = 228 HU)	μ = 1486 HU (σ = 252 HU)	*95% at p < 0.05*

First was to compare the tasks that were graded correct. Participants using the Kinect™ had larger window width values and higher window center values compared to those who used the mouse, for those tasks where the anatomy was accurately identified. Window width and window center were both statistically significant; values are presented in Table A44 (See Figure A35).

Second was comparing the tasks that were graded incorrect. Participants using the Kinect™ had larger window width and higher window center values compared to those using the mouse, for those tasks where the anatomy was inaccurately identified. Window width and window center was statistically significant; values are presented in Table A45 (See Figure A36).



(a) (b)

Figure A36. a) Window width values from set B task five for inaccurate tasks split by interaction device. b) Window width values from set B task five for inaccurate tasks split by interaction device.

Table A45. Number of tasks, mean, standard deviation and statistical significance of window width and window center values split between Kinect™ and mouse users for those who inaccurately identified the anatomical feature.

Set B - Task 5 Inaccurate score	Kinect™ (n=2)	Mouse (n=6)	*Statistical Significance*
Window Width	μ = 1965 HU (σ = 43 HU)	μ = 824 HU (σ = 324 HU)	*99% at $p < 0.05$*
Window Center	μ = 2072 HU (σ = 0 HU)	μ = 1447 HU (σ = 98 HU)	*99% at $p < 0.05$*