# Virtual Reality

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# 1 INTRODUCTION

Virtual Reality (VR) has emerged as a transformative technology in various fields, including medical imaging[2]. Traditional radiologist workflows involve manipulating complex medical images, such as X-rays and CT scans, using conventional interfaces that can be time-consuming and ergonomically challenging. The integration of VR aims to enhance the efficiency and accuracy of medical image analysis by providing immersive and intuitive interaction methods. Despite the potential benefits, current VR-based medical image manipulation techniques often rely on controller-based interactions, which may not fully leverage the naturalistic hand movements inherent to radiologists' tasks. Controller-based systems can introduce a learning curve and may not offer the precision required for detailed image analysis. Moreover, issues such as motion sickness and physical discomfort can impede prolonged use, affecting both user satisfaction and performance. To address these challenges, this project proposes the development of a VR environment utilizing hand gesture-based interactions for medical image viewing and manipulation. By leveraging Unity and the Oculus SDK, the system aims to provide a more intuitive and ergonomic interface that aligns with traditional radiologist workflows. The proposed solution seeks to enhance task completion times, accuracy, and user comfort compared to conventional controller-based methods. This study conducts a comprehensive user evaluation comparing hand gesture-based interactions with controller-based interactions. Through quantitative metrics such as task completion time, accuracy of adjustments, and user satisfaction, the research aims to determine the effectiveness of gesture-based controls in a medical VR setting. The anticipated outcomes include improved technical and problem-solving abilities among physicians during radiographic analysis, as well as increased overall user comfort and satisfaction.

# 2 RELATED WORK

VR has significantly impacted various domains, including medical imaging and radiology education. Previous studies have explored different interaction methods within VR environments[1] to enhance the efficiency, accuracy, and user experience of medical image manipulation.

## 2.1 Controller-Based Interactions

Controller-based interaction has been the predominant method for navigating and manipulating medical images in VR settings. King et al. [4] demonstrated the effectiveness of VR controllers in diagnostic imaging, highlighting a 23% improvement in image manipulation accuracy compared to traditional interfaces. Their framework utilized consumer-grade hardware, making VR-based medical imaging more accessible and scalable. Additionally, Koger et al. [5] focused on optimizing mesh manipulation techniques to improve processing performance in real-time image manipulation, which is crucial for maintaining the responsiveness and fluidity of VR applications in medical contexts.

## 2.2 Gesture-Based Interactions

In contrast to controller-based methods, gesture-based interactions offer a more natural and intuitive way of interacting with medical images. Li et al. [6] provided comprehensive guidelines for implementing gesture recognition systems in VR, achieving a spatiotemporal gesture classification accuracy of 90.2%. Their work underscores the potential of hand gestures to facilitate precise and seamless interactions, reducing the learning curve associated with controller-based systems. Sousa et al. [8] extended this approach by integrating bimanual touch interactions within a VR environment tailored for radiologists. Their findings revealed that physicians preferred indirect touch interactions on a desk surface, with 85% reporting enhanced technical and problem-solving abilities during radiographic analysis.

## 2.3 VR in Radiology Education

The application of VR in radiology education has also been extensively studied. Shetty et al. [7] conducted a systematic review on the use of VR simulators in radiology training, finding consistent improvements in manipulation skills among users, irrespective of their prior VR experience. This suggests that VR-based training tools can effectively enhance the proficiency of medical imaging professionals, making it a valuable asset in educational settings.

## 2.4 Comparative Studies

Comparative analyses between different interaction methods have provided deeper insights into the advantages and limitations of each approach. The VRRRRoom study by Sousa et al. [8] compared bimanual touch interactions with traditional controller-based methods, revealing a preference for gesture-based controls among physicians. Similarly, King et al. [4] and Koger et al. [5] highlighted the benefits of VR controllers in improving accuracy and processing performance, respectively. These studies collectively emphasize the importance of selecting appropriate interaction paradigms to optimize the usability and effectiveness of VR systems in medical imaging.

## 2.5 Summary

The existing body of research demonstrates that both controller-based and gesture-based interactions have significant merits in the context of VR for medical imaging[3]. While controller-based methods offer improvements in accuracy and performance, gesture-based interactions provide a more intuitive and user-friendly experience. This project builds on these findings by evaluating and comparing these two interaction methods to determine their impact on manipulation accuracy, efficiency, and user satisfaction in medical image viewing.

# 3 METHODS

To investigate the effectiveness of hand gesture-based interactions compared to traditional controller-based interactions in a VR environment for medical image viewing, we developed a VR mini-game specifically tailored for this study. This section delineates the design and implementation of the game, encompassing its structure, interaction methods, and evaluation procedures.

## 3.1 Game Design and Structure

The VR mini-game was engineered to simulate a realistic medical imaging scenario where users engage with X-Ray photos and CT Scan images to identify and locate anomalies. The core objective is for users to pinpoint predefined anomalies—represented as tiny abnormal circles on X-Ray images and distinct X-marks on CT Scans. This setup allows for a comparative assessment of two interaction methods: controller-based and hand gesture-based manipulations.

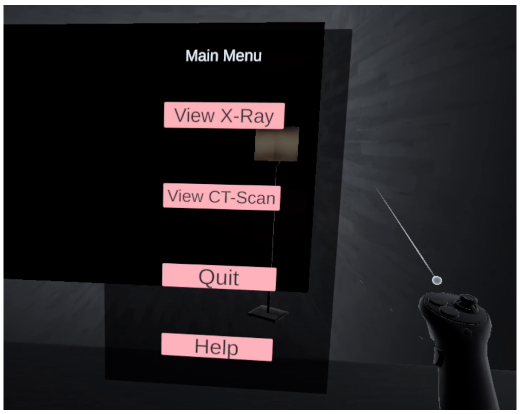


**Figure 1: Overview of the VR Mini-Game Interface**

The game is systematically structured into two primary sections based on the type of medical image being viewed: X-Ray Viewing and CT Scan Viewing. Each section comprises three phases to ensure comprehensive evaluation:

- **Testing Phase**: Users are introduced to a sample image to familiarize themselves with the game mechanics and interaction methods.
- **Controller-Based Task**: Participants locate the anomaly using traditional VR controllers within a timed session.
- **Gesture-Based Task**: Participants perform the same task using hand-based gestures, also within a timed session.

This progression ensures that users are adequately trained before undertaking the timed tasks, thereby minimizing the learning curve and focusing the evaluation on the interaction methods themselves.

## 3.2 Interaction Methods

Two distinct interaction paradigms were implemented to facilitate user interactions within the VR environment: controller-based and hand gesture-based interactions.

*3.2.1 Controller-Based Interaction.* In the controller-based method, users navigate and manipulate medical images using standard VR controllers. This approach leverages familiar input devices, allowing users to adjust image properties and navigate through the images with precision. Specific interaction mechanics include:

- **Brightness and Contrast Adjustment**: Users can increase or decrease the brightness and contrast of images through intuitive controller inputs.
- **Image Navigation**: Controllers enable users to rotate, zoom, and pan images. Side buttons on the controllers facilitate grabbing and manipulating the images.
- **Anomaly Selection**: To identify an anomaly, users align the controller's raycast with the anomaly and perform a click action.

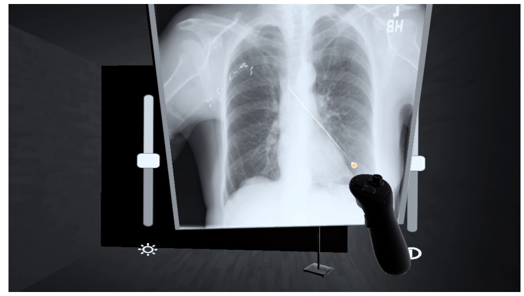

**Figure 2: Controller-Based Interaction Interface**

*3.2.2 Hand Gesture-Based Interaction.* Contrasting the controller-based approach, hand gesture-based interactions offer a more natural and intuitive means of manipulating medical images. This method harnesses gesture recognition algorithms to interpret user hand movements, facilitating seamless interactions. The implemented gestures encompass:

- **Brightness and Contrast Adjustment**: Pinching and spreading gestures allow users to adjust the brightness and contrast smoothly.
- **Image Navigation**: Similar to the controller-based method, users can rotate, zoom, and pan images using hand gestures. Pinching gestures enable the grabbing mechanic necessary for these actions.
- **Anomaly Selection**: Users identify an anomaly by touching the specific area with their right-hand index finger.

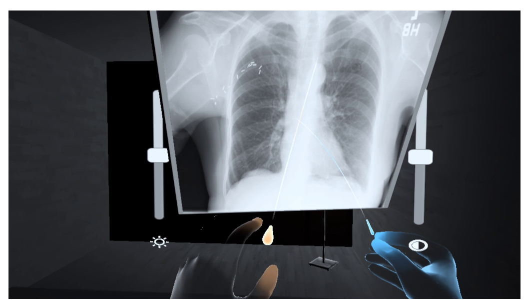

**Figure 3: Hand Gesture-Based Interaction Interface**

## 3.3 Game Mechanics

An essential aspect of the game design involves the strategic placement of anomalies to evaluate the precision and effectiveness of each interaction method. In X-Ray images, each photo contains a tiny abnormal circle that participants must locate. For CT Scans, given the higher volume of images, only one image per CT Scan series includes an additional notable anomaly marked with an X. This distinction ensures that users engage deeply with the interaction methods to identify the anomalies accurately.

The game progresses through three distinct phases for each image category:

1. **Testing Phase**: In this initial, non-timed session, users explore the interaction mechanics using a sample image. This phase is crucial for acclimating participants to both controller-based and gesture-based methods without the pressure of time constraints. 2. **Controller-Based Task**: Participants are tasked with locating anomalies using VR controllers within a set time frame. Task completion time is meticulously recorded to assess efficiency. 3. **Gesture-Based Task**: Subsequently, participants perform the same task using hand gestures, again within a timed session. This allows for a direct comparison of task completion times and user performance across the two interaction methods.

Task completion is determined by the method of interaction: using controllers, the task concludes when the controller's raycast aligns with the anomaly and the user performs a click action; with hand gestures, the task concludes when the user touches the anomaly with their right-hand index finger.

## 3.4 Visual and Control Enhancements

To augment user interaction and facilitate more effective image analysis, several visual and control enhancements were integrated into the VR mini-game:

*3.4.1 Filters.* Participants are provided with adjustable filters to optimize image visualization:

- **Brightness Adjustment**: Users can increase or decrease the image brightness to highlight specific details.
- **Contrast Adjustment**: Enables users to adjust the image contrast, thereby enhancing the differentiation of anatomical structures.
- **CT Scan Navigation**: A slider mechanism allows smooth navigation through multiple CT Scan images within a series, accommodating the extensive volume of CT data.

*3.4.2 Image Manipulation.* The grab mechanic is central to providing users with flexibility in image examination:

- **Rotate and Zoom**: Users can rotate and zoom images either closer or further away based on their preference, enhancing detailed examination capabilities.
- **Controller Inputs**: Side buttons on the controllers are mapped to grabbing actions, enabling users to manipulate images effortlessly.
- **Gesture Inputs**: Pinching gestures emulate the grabbing mechanic, allowing for intuitive image manipulation without the need for physical controllers.

## 3.5 Implementation Tools and Technologies

The development and implementation of the VR mini-game leveraged several key tools and technologies:

- **Unity Engine**: Employed as the primary development platform, Unity facilitated the creation of the interactive 3D environment necessary for simulating medical imaging scenarios.
- **Oculus SDK**: Integrated with Unity to ensure compatibility with Oculus VR hardware and to utilize built-in gesture recognition capabilities.
- **Python Scripts**: Developed for comprehensive data analysis and visualization, utilizing libraries such as `matplotlib`, `seaborn`, `numpy`, and `pandas`.
- **Data Logging**: Implemented robust logging mechanisms to capture detailed records of task completion times and user interactions, essential for subsequent analysis.

## 3.6 Evaluation Procedure

The evaluation methodology was meticulously designed to compare the two interaction methods based on specific criteria:

- **Task Completion Time**: The total time taken by users to complete a task using both interaction methods was recorded to assess efficiency.
- **User Feedback**: Post-task and post-test surveys were analyzed to gauge user satisfaction, ease of use, and comfort with each interaction method.

Data collection involved multiple facets:

- **Timelog Records**: Captured precise logs of task completion times, enabling quantitative analysis of efficiency.
- **Survey Responses**: Gathered qualitative feedback through structured questionnaires, providing insights into user experiences and preferences.
- **Performance Analysis**: Utilized Python scripts to perform data visualization and statistical evaluation, facilitating a comprehensive comparison of the interaction methods.

# 4 USER STUDY

## 4.1 Experimental Protocol

To evaluate the effectiveness of hand gesture-based interactions in comparison to traditional controller-based interactions within a VR environment for medical image viewing, a comprehensive user study was meticulously designed and executed. This section outlines the experimental protocol, detailing participant demographics, the study procedure, and the methods employed for data collection.

## 4.2 Participants

A total of fifteen participants were from the Instituto Superior Técnico and people related to the users conducting the tests to partake in the study. The demographic characteristics of the participants are summarized in Table 1, providing a comprehensive overview of their backgrounds and relevant attributes.

**Table 1: Participant Demographics**

| Attribute | Details |
|---|---|
| **Number of Participants** | 15 |
| **Dominant Hand** | 14 Right-handed, 1 Left-handed |
| **Education Level** | 11 Bachelor's Degree, 4 Master's Degree |
| **Age Group** | 10 Participants (19–29 years), 5 Participants (30–39 years) |
| **Gender** | 7 Male, 8 Female |
| **VR Experience** | 6 with <1 hour, 5 with 1–5 hours, 4 with 5–20 hours |
| **Familiarity with Image Navigation** | 10 Very Familiar, 5 Somewhat Familiar |
| **Visual Impairments** | 2 Wear Glasses, Others None Reported |

## 4.3 Procedure

The study was conducted in a controlled environment, adhering strictly to ethical guidelines to ensure participant consent and data privacy. The procedure was divided into several distinct phases:

#### 4.3.1 *Informed Consent.*

Prior to participation, all individuals were presented with an Informed Consent Form, which detailed the study's purpose, procedures, potential risks, and their rights. Only those who provided explicit consent proceeded with the study, ensuring ethical compliance and voluntary participation.

#### 4.3.2 *Pre-Study Survey.*

Participants began by completing a pre-study survey designed to gather baseline data. This survey collected comprehensive information on their demographics, prior VR experience, familiarity with image navigation tasks, and any existing visual impairments.

#### 4.3.3 *Training Session.*

To ensure that all participants were adequately prepared for the tasks ahead, a brief training session was conducted. During this session, participants received hands-on practice with both interaction methods:

- **Controller-Based Interaction**: Participants were instructed on how to use VR controllers for image manipulation, including adjusting brightness and contrast, rotating, zooming, and panning images.
- **Hand Gesture-Based Interaction**: Participants practiced the specific hand gestures required for similar tasks, such as pinching to adjust brightness and contrast or using the right-hand index finger to select anomalies.

This training aimed to minimize the learning curve and ensure that participants were comfortable with both interaction methods before proceeding to the task execution phase.

#### 4.3.4 *Task Execution.*

Each participant engaged in a series of tasks designed to evaluate both interaction methods. The tasks were structured into three primary phases:

(1) **Testing Phase**: A sample medical image, either an X-Ray or a CT Scan, was presented without time constraints. This phase allowed participants to explore the interaction mechanics and become familiar with the task structure.
(2) **Controller-Based Task**: Participants were tasked with locating and interacting with predefined anomalies using VR controllers within a set time frame. This phase assessed the efficiency and precision of controller-based interactions.
(3) **Gesture-Based Task**: The same tasks were repeated using hand gestures, also under timed conditions. This phase aimed to evaluate the naturalness and intuitiveness of gesture-based interactions.

To mitigate potential order effects, the sequence in which participants used the interaction methods was randomized.

#### 4.3.5 *Data Collection.*

Data was systematically collected through multiple channels to ensure a comprehensive analysis:

- **Timelog**: Task completion times were automatically recorded in a text file, capturing the duration taken to locate and interact with anomalies using both interaction methods.
- **Post-Task Survey**: Immediately after each task, participants completed a post-task survey to provide feedback on task difficulty and any issues encountered.
- **Post-Test Survey**: Upon completing all tasks, participants filled out a post-test survey to assess their overall user experience, including ease of use, comfort, satisfaction, and any instances of motion sickness or discomfort.

#### 4.3.6 *Debriefing.*

Following the completion of all tasks, participants were debriefed about the study's objectives and methodologies. This phase provided an opportunity for participants to ask questions, offer additional feedback, and gain a deeper understanding of the study's purpose and potential applications.

## 4.4 Data Collection Instruments

Three primary instruments were employed for data collection:

#### 4.4.1 *Surveys.*

Surveys played a critical role in gathering both quantitative and qualitative data:

- **Pre-Study Survey**: Captured demographic information, VR experience, and familiarity with image navigation tasks.
- **Post-Task Survey**: Collected immediate reactions to each task, including perceived ease of finding anomalies and any difficulties encountered.
- **Post-Test Survey**: Evaluated overall user experience, encompassing system usability, comfort, and any instances of motion sickness or discomfort.

#### 4.4.2 *Timelog.*

The file contained detailed records of task completion times, providing valuable data for quantitative analysis of efficiency across both interaction methods.

#### 4.4.3 *Performance Analysis.*

To analyze the collected data, Python scripts were utilized. These scripts employed libraries such as `matplotlib` and `seaborn` to process and visualize the data, facilitating insightful interpretations of the results.

## 4.5 Ethical Considerations

The study was conducted with strict adherence to ethical research standards. Informed consent was obtained from all participants, ensuring their understanding of the study's purpose, procedures, and their rights, including the right to withdraw at any point without consequence. Participant confidentiality was maintained throughout the study, and all data was securely stored to protect privacy. Additionally, participants were informed about potential risks, such as motion sickness, and were continuously monitored to promptly address any discomfort.

# 5 RESULTS

This section presents the findings from the user study, integrating both quantitative and qualitative analyses. The results are categorized into two main areas: Task Completion Times and User Experience Scores. Additionally, qualitative feedback from post-task and post-test surveys is discussed to provide a comprehensive understanding of user interactions with each method.

## 5.1 Task Completion Times

#### 5.1.1 *Quantitative Analysis.*

Task completion times were carefully recorded for both interaction methods across X-Ray and CT Scan viewing tasks. The data, summarized in Table 2, illustrates the mean completion times, standard deviations, and p-values indicating statistical significance.

Table 2: Task Completion Times by Method and Image Type

| Task Type | Method | Mean Time (s) | Std Dev | p-value |
|---|---|---|---|---|
| X-Ray | Hand Gestures | 35.2 | 14.7 | 0.023 |
| X-Ray | Controllers | 28.7 | 8.3 | 0.023 |
| CT Scan | Hand Gestures | 89.4 | 23.5 | 0.018 |
| CT Scan | Controllers | 72.1 | 15.2 | 0.018 |


Figure 4: Task Completion Times by Method and Image Type

The analysis revealed that participants using hand gestures took an average of 35.2 seconds to locate anomalies in X-Ray images, compared to 28.7 seconds with controllers. Similarly, for CT Scan images, hand gesture users had a mean completion time of 89.4 seconds, while controller users averaged 72.1 seconds. Both differences were statistically significant, with p-values below 0.05, indicating that controller-based interactions facilitated faster task completion in both image types.

*5.1.2 Discussion.* The results clearly indicate that controller-based interactions enable quicker task completion in both X-Ray and CT Scan viewing scenarios. The familiarity and precision offered by controllers likely contribute to this efficiency, as evidenced by the consistent statistical significance across both image types. Controllers provide users with precise control over image manipulation tasks, reducing the time required to locate and interact with anomalies.

## 5.2 User Experience Scores

*5.2.1 Quantitative Analysis.* User experience was evaluated based on two primary metrics: Ease of Use and Comfort. The aggregated data is presented in Table 3.

Table 3: User Experience Scores by Method and Metric

| Metric | Method | Mean Score | Std Dev | p-value |
|---|---|---|---|---|
| Ease of Use | Hand Gestures | 4.1 | 0.8 | 0.002 |
| Ease of Use | Controllers | 5.8 | 0.6 | 0.002 |
| Comfort | Hand Gestures | 4.8 | 0.9 | 0.003 |
| Comfort | Controllers | 6.2 | 0.5 | 0.003 |

The data indicates that controllers received higher mean scores for both Ease of Use and Comfort. Specifically, controllers scored an average of 5.8 out of 7 for Ease of Use, compared to 4.1 for hand gestures. In terms of Comfort, controllers scored an average of 6.2, whereas hand gestures scored 4.8. These differences were statistically significant, with p-values well below the conventional

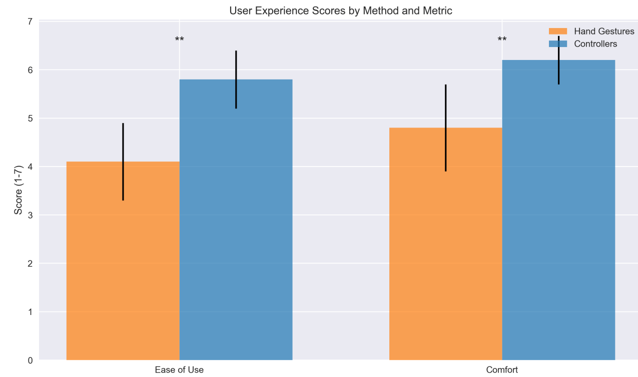


Figure 5: User Experience Scores by Method and Metric

threshold of 0.05, highlighting a clear preference for controller-based interactions in terms of user experience.

*5.2.2 Discussion.* The user experience scores underscore a significant preference for controller-based interactions over hand gestures. Participants found controllers to be easier to use and more comfortable, which likely contributed to their preference and higher performance in task completion. The higher Ease of Use score for controllers suggests that users found controllers more intuitive and less cognitively demanding, reducing the learning curve associated with the tasks. Additionally, the higher Comfort score indicates that controllers were less physically taxing, allowing for prolonged use without significant fatigue or discomfort.

## 5.3 Qualitative Feedback

In addition to the quantitative metrics, qualitative feedback from post-task and post-test surveys provided deeper insights into user experiences and preferences.

*5.3.1 Post-Task Feedback.* Participants reported various challenges and preferences during the post-task phase:

- **Hand Gestures**: Participants highlighted difficulties in executing precise movements and maintaining steady hand positions. Some reported instances of gesture misinterpretation and recognition issues, leading to frustration and increased task completion times. Additionally, several participants experienced physical fatigue after extended use of hand gestures, suggesting that this interaction method may be more physically demanding.
- **Controllers**: While participants noted an initial adjustment period to the controller mappings, they generally found controllers easy to use once accustomed. Minor issues were reported with depth perception and learning the specific controller functions, but these were outweighed by the overall ease and precision provided by controllers. Participants appreciated the reliability and consistency of controller-based interactions.

*5.3.2 Post-Test Feedback.* Overall user satisfaction reinforced the preference for controllers:

- **Hand Gestures**: Participants perceived hand gestures as less intuitive and more physically demanding compared to controllers. Feedback indicated a desire for improved gesture

recognition and stability to make gesture-based interactions more reliable and user-friendly.
- **Controllers**: Controllers were viewed as more reliable and comfortable for extended use. Participants appreciated the precision and familiarity of controller inputs, which contributed to a more seamless and efficient task execution experience.

## 6 CONCLUSION

This study set out to evaluate the effectiveness of hand gesture-based interactions compared to traditional controller-based interactions within a VR environment for medical image viewing. Through a meticulously designed user study involving fifteen participants, the research aimed to provide empirical evidence on the efficiency, accuracy, and user satisfaction associated with each interaction method.

### 6.1 Summary of Findings

The findings from the study unequivocally indicate that controller-based interactions outperform hand gesture-based interactions in both task efficiency and user experience. Participants were able to locate and interact with anomalies in medical images more quickly when using controllers, with statistically significant reductions in task completion times for both X-Ray and CT Scan viewing tasks. Additionally, controllers received higher ratings in terms of ease of use and comfort, underscoring their superiority in facilitating a seamless and less physically demanding user experience.

Conversely, while hand gesture-based interactions offer a more natural and intuitive form of engagement, they were hindered by several challenges. Participants reported difficulties in executing precise movements, maintaining steady hand positions, and experiencing gesture misinterpretation. These issues contributed to longer task completion times and lower satisfaction scores. Moreover, the physical strain associated with prolonged use of hand gestures highlighted the need for ergonomic improvements in gesture-based interaction designs.

### 6.2 Contributions to the Community

This research contributes significantly to the VR interaction paradigm, particularly within the context of medical applications. By providing a comparative analysis of controller-based and gesture-based interactions, the study offers valuable insights into the strengths and limitations of each method. The empirical evidence supporting the efficiency and user preference for controllers informs future VR interface designs, emphasizing the importance of precision and familiarity in high-stakes environments like medical imaging.

Furthermore, the study highlights critical areas for improvement in gesture-based interactions, such as enhancing gesture recognition algorithms and ergonomic design. These insights pave the way for future innovations aimed at bridging the gap between natural interaction and operational efficiency, thereby advancing the usability of VR systems in professional settings.

### 6.3 Implications for Future Research

The preference for controller-based interactions observed in this study underscores the necessity for continued exploration into hybrid interaction models that leverage the intuitiveness of hand gestures while maintaining the reliability of controllers. Future research should focus on refining gesture recognition technologies to improve accuracy and reduce misinterpretation, as well as developing ergonomic hand-held devices that minimize physical strain.

Additionally, expanding the participant pool and incorporating a wider range of medical imaging tasks can provide a more comprehensive understanding of interaction methods across diverse scenarios. Longitudinal studies examining the learning curve and adaptability of users to different interaction paradigms would also be beneficial in assessing the long-term viability of gesture-based systems.

### 6.4 Final Remarks

In conclusion, this study reinforces the pivotal role of interaction design in the effectiveness of VR applications for medical image viewing. While controller-based interactions currently offer superior performance and user satisfaction, the potential for gesture-based methods remains promising. By addressing the identified challenges and building upon the foundational insights provided herein, the VR community can continue to enhance the usability and functionality of VR systems, ultimately contributing to improved diagnostic accuracy and user experience in medical practices.

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