THE EFFECTS OF REFERENCE FRAMES ON 3D MENUS IN VIRTUAL ENVIRONMENTS

A Thesis

by

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ABSTRACT

The emergence of affordable Head Mounted Displays (HMD) means Virtual Reality (VR) systems are now available to wider audiences. Other than the key target audience, gamers, groups as diverse as oil and gas industries, medical, military, entertainment and education have created demand for effective Virtual Environments (VE). To be effective certain VEs need to properly convey textual information. This is done using 3D menus. It is very important these menus are displayed in an ergonomic manner and do not obstruct important content. The study collected measures of user experience, comfort and memory recall. The study found that reference frames for 3D menus presenting textual information do not influence user experience or memory recall. However, there was a significant difference in user behavior between the reference frames, which has implications for repeated stress injury.

CONTRIBUTORS AND FUNDING SOURCES

This work was supervised by a dissertation committee consisting of Professor Ann McNamara and Professor Eric Ragan of the Department of Visualization and Professor Stephen Caffey of the Department of Architecture.

All work for the thesis was completed independently by the student. No other external contributions were made.

NOMENCLATURE

HMD	Head-Mounted Display
SSQ	Simulator Sickness Questionnaire
VE	Virtual Environment
VR	Virtual Reality

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1. INTRODUCTION

Every day we acquire information via text displayed through our phones or computers [16]. Within VE's, text is presented using 3D menus, which act as a container to hold the textual information in the VE. To understand how text affects users in VE, we must investigate 3D menu placement in the VE. Since training and learning within VE have been shown to enhance user's learning capabilities, many companies and educational institutions are now looking to use VR for education. [18, 28]. Many of these educational VEs allow for a more immersive experience and simulate real world situations that are beneficial to training scenarios. There are a variety of factors that can affect learning in VE's [18, 28, 31, 11]. Previous research has evaluated text parameters such as text size, convergence, view box dimensions and positioning, and reading task performance [13, 7]. However, the effects of text placement using 3D menus on users in VEs has not been thoroughly researched, and the educational experience provides a suitable scenario to analyze these effects. [13]

With VR being explored as a new medium, there currently exists a vast amount of usability problems for how 3D menus work. 3D menus can be influence by their functionality, purpose, visual appearance, structural layout, and even its hierarchical nature [6]. Simple tasks in VR can be made confusing or frustrating to the user by requiring more effort than is deemed necessary to complete them. Since menus are often placed at various coordinate positions in a VE than the main task, focus switching is a result. When a menu is opened the content in the main interaction space can become impeded causing occlusion and clutter from the 3D menu. Placement, occlusion, and focus switching is often difficult to balance for 3D menus [15]. It is important to pay attention to how 3D menus containing abstract information are placed in VE since it can impede the user. To better understand how text affects users in VEs we must examine how the placement of 3D menus affect user experience, comfort and memory recall for abstract information.

Assessing user experience is important since the user can become frustrated with the system from usability problems or finding the material not challenging enough in a VE [17, 30]. Recent research shows that users that were more successful in learning tasks also perceived quality, flow and immersion of the system as better [17].

Within VEs, the user's physical comfort is another area that must be taken into consideration. Comfort within VEs can affect the user by becoming too sick to continue or cause fatigue/strain, to the point that the user stops the VE altogether. Simulator sickness or cybersickness is a common known problem within VEs [27, 26, 8]. For designers it is important to consider these issues for VE since it could prevent a user from completing the training or learning objective. Physical fatigue such as, gorilla arm, which is experienced when a user tenses their muscles over long periods of time and causes fatigue or pain, should also be taken into consideration [32]. With controllers now being widely available with HMD's, the risk of gorilla arm and physical strain is and increasingly important consideration for learning VEs.

Taking these concerns into consideration, effectively presenting new information to users in VEs is a universal challenge, especially for educational VEs. Many educational VE objectives also inherently require abstract information, contextual information that is not normally perceptible in the physical world, to be presented in the most effect manner. In this study, I am investigating how the placement of 3D menus containing abstract information affects users in VEs to provide insight into how text can better be designer to supplement VEs.

2. RELATED WORK

Classifications of 3D menus have been investigated since the early 1990's. In 1993, Feiner et al. presented world-fixed, display-fixed, object-fixed, and user-fixed for placement in augmented reality [9]. Following research continued using these classifications. In the 2000's, Information Rich Virtual Environments (IRVE) research focused on the presentation of abstract information, in VEs including: display location, association, and level of aggregation [3]. For display location they used Feiner et al. work from 1993. Bowman et al investigated the effects of varying amounts of text with travel techniques and how it impacted usability and task performance. The testbed they created allowed for scenarios to be quickly and easily tested with classification for text known as Text Layout Techniques [3, 21, 20]. Text Layout Techniques classifies text in four ways: quantitatively, qualitatively, spatially, and temporally. Quantitatively is the amount of information being displayed in the VE. This is important since there can be a difference in presenting small amounts of text versus large amounts of text. Qualitatively is the visual attributes and spatially is where the information is located, based on location and orientation [3].

Chen et al. investigated navigation techniques with Text Layout Techniques from Bowman et al. [5]. Navigation consisted of hand-centered manipulation extending ray-casting (HOMER) and go-go navigation. While the text layout techniques consisted of within-the-world display (WWD) and heads-up-display (HUD). Users performed four search tasks measuring their performance. Results showed that the HUD allowed for significantly better performance than the

WWD, while the go-go technique allowed for better performance than the HOMER technique. The combination of the HUD and go-go techniques was preferred by users for all tasks [5].

Following this research Polys et al. focused-on search and comparison tasks using layout spaces for their placement of abstract information. In this study depth cue/visibility tradeoffs between annotations schemes were evaluated using object space and viewport space [21]. The role of depth and gestalt cues in IRVE were also investigated to articulate crucial tradeoffs in text label layouts. The results aided developers with a set of design guidelines for new and advantageous interfaces [22]. The design and layout of supplemental information for desktop VEs has also been evaluated, demonstrating an object-oriented approach that solved fundamental challenges for information design across display locations. A set of design solutions was also described including: object fixed, world fixed, user fixed, and display fixed annotations [20].

In 2007 Dechselt et al. surveyed the research field for classifications of 3D menus. He summarizes the 3D menu classification criteria into a defined taxonomy shown in figure 1 [6]. The taxonomy not only considers placement but also intentions of use, appearance and structure, invocation and availability, interaction and I/O setting, usability, and combinability (Figure 1). For placement of 3D menus, he breaks it down into three categories: reference, orientation and repositioning. For reference of placement Dechselt et al. [6] uses the extended placement options by Bowman et al which are referenced originally from Feiner et al. work from the early 1990’s. These include: world-reference, object-referenced, head-referenced, body-referenced, and device-referenced.

Intention of use	
Number of displayed items	limited or not, range or definite value
Hierarchical nature	temporary option menu, single menu, menu system, menu hierarchy
Appearance and Structure	
Geometric structure	none, list, disc, sphere, cylinder, cube…
Structural layout	acyclic list, cyclic list (ring), matrix, free arrangement, geometric structure
Type of displayed data	3D-objects, text entries, images, images & text, 3D-objects & text
Size & spacing of items	
Placement	
Reference	world, object, head, body, device
Orientation	
Repositioning	
Invocation and availability	
Visibility	whole time, temporarily, user-dependent
Invocation	icon/miniature, context dependent, free, none
Animation	various ways
Collapsibility	
Interaction and I/O setting	
Interaction device dependence	mouse, gloves, pen & tablet, 6-DOF devices, computer vision, multiple etc.
Application type & setting	VR, AR, Desktop VR, 3D-Mobile
Dimensionality	mapping of interaction device and task
Feedback/highlighting	various ways
Visualization of selection path	
Usability	
Evaluation Criteria	selection speed, error rate, efficiency, user comfort, ease of use and learning
Comparison	of different layouts, selection methods, menu solutions
Combinability	

Figure 1: Reprinted from Dechselt et al. 3D menu taxonomy [4].

In more current research on 3D menus, LaViola et al. considers 3D menus in world-referenced, object-referenced, head-referenced, body-referenced, or device-referenced in his book [15]. Once again, these are adapted from Feiner et al. 1993 classification [9]. With newer technology and devices used with HMD's and VE, there are missing placement references such as eye-reference frame that are included in Jason Jerald reference frame classification [14]. Reference frames are a coordinate system that serve as a basis to locate and orient objects [14]. They are specifically used for VR systems and complement the pre-existing design features. It also takes into consideration of tracking technology which result in different placement of where objects or 3D menus within a VE would appear. Even with these classifications, there has not been current research that focuses solely on the placement of 3D menus for VEs using large amounts of abstract information.

Annotations have been regularly used and investigated for VE [5, 21, 22, 20, 3]. Annotations are short pieces of information about an object of interest, these can include labels, diagrams, or pictures. A main difference between annotations and text is that text can be paragraphs long, whereas annotations are meant to be small pieces of information to be obtained quickly by the user. In some research, annotations are descriptive meta data about scientific data, which aids the data analysis process. In Pick et al. research, they focus on automating the position of annotation location in immersive VEs [19]. While Pick et al. research is meant to aid in data analysis, my research is focused on being able to present large amounts of abstract information about a subject to a user to learn and understand, not to analyze data.

The previously mentioned related work use annotations and not paragraphs of text [3, 20, 21, 22, 19]. Very little research has considered large amounts of text or reading in VE [13]. The performance of reading tasks in VE have been studied comparing VE HMD's and a traditional display, evaluating day-to-day computing tasks. Results show that reading tasks were performed with near equivalent performance in the VE HMD compared to the traditional display [13]. Comfortable reading settings for text have also been explored investigating user interfaces for reading in VE. Focusing on text size, convergence, and view box dimensions and positions [7]. The research created a guideline for vergence distance in VE (Figure 2).

Research in augmented reality has investigated text style usability on see-through HMD's. Four text colors and styles were examined finding that both presentation mode and background influences readability of text [10]. This is however for see-through HMD's for augmented reality, overlaying on top of the real world and not VE, which are computer generated environments.

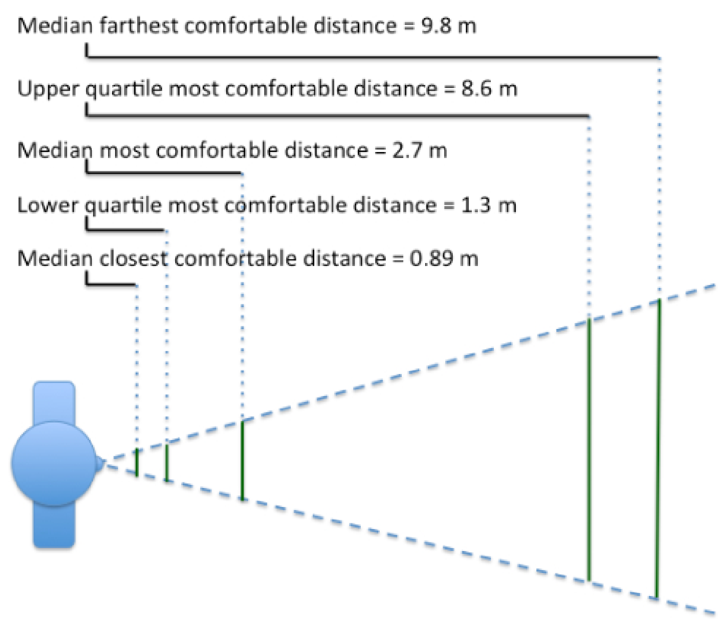

Figure 2: Reprinted from Merchant et al vergence distance guideline for text display in VE [18].

Past and current research has shown that using VE for education has enhanced learning, it also shows the use of textual information being presented with in the VE. In the late 1990's The

Virtual Zoo Exhibit taught college students about habitat design, understanding the philosophy of environmental design. Information was given to the students by audio clips and annotations which were placed as signs in the VE. Annotations were chosen for important information for students to be able to scan back over and reread (Figure 3). This research suggested that IRVE did indeed enhance the learning experience [1]. However, it did not evaluate how the user would be affected by larger amounts of abstract information or how the placement of that information would affect the user in VE.

Figure 3: Reprinted from Bowman et al. text annotations in the virtual habitat [1].

More recent research now focuses on how design features impact learning in VE. The effects of spatial presentations have been evaluated for how it affects learning, memory recall, and problem solving. The results suggested that supplemental spatial information can affect mental strategies and improves performance in VEs, but the effectiveness of the spatial presentations is dependent on the task and a meaningful use of the space [24]. This study focuses on how spatial information supports the user but does not look at the design feature of the placement of text.

Other design features that have been investigated are level of environment detail and method of navigation. They were investigated to understand how these design features influence learner strategies, and the effectiveness of learning [23]. The results showed that neither the environmental detail nor method of navigation affected learning. Once again, this research did not focus on where the abstract information was placed in the VE. It focused on other design features and how they affect learning.

Research regularly uses 3D menus to present annotations in VE. However, very little recent research has been done for how large amounts of text using a 3D menu affect the user in VE. Our study evaluates the placement of 3D menus for large amounts of abstract information with new technology and with an updated taxonomy that includes current coordinate systems that work within VR, such as reference frames. There is a lack of research for how large amounts of text can occlude a VE. When text is presented in research it is normally presented based on the object reference frame, world reference frame, or head reference frame (HUD). Are these the best locations to present large amounts of text? These have issues for occlusion, focus switching, and clutter for the user. How do reference frames affect the user when presenting large amounts of textual information in a VE?

3. METHODOLOGY

This thesis aims to provide insight into how reference frames either complement or obstruct the structure of VE, to better understand how 3D menus with abstract information in VEs affect users. The placement of a 3D menu can cause problems when shown in VE by occlusion, focus switching, and clutter. How do reference frames affect users in VE? To address this question, three experiments were ran focusing on user experience, comfort, and memory recall.

Art History was used as a testbed for our learning objective in these experiments because it requires abstract information to be effectively presented to the user in a VE. When a student views a painting they have no understanding of its significance, abstract information is needed to inform the user of important content. This content is given to the user using a 3D menu. Reference frames were used to coordinately place the 3D menus. Reference frames are a coordinate system that serve as a basis to locate and orient objects [8]. They are specifically used for VR systems and complement the pre-existing design features.

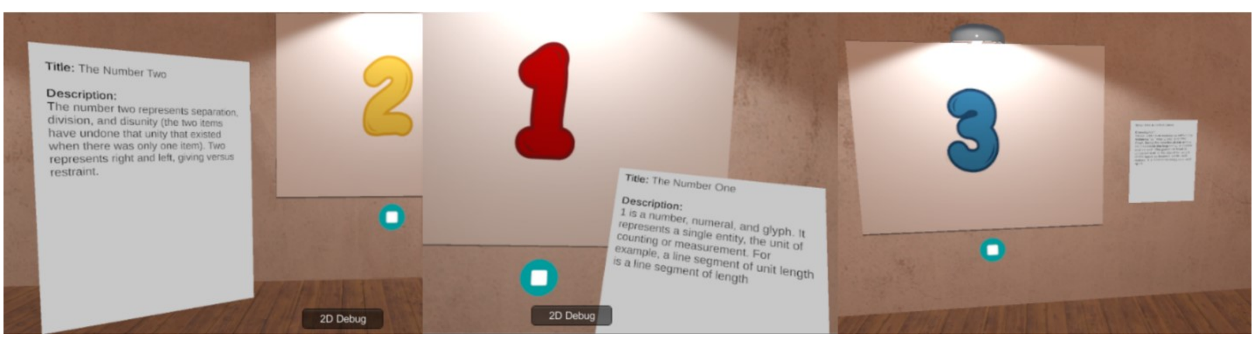

Figure 4: Reference frames from left to right; body relative, hand, and object reference.

The three reference frames that are investigated are body relative, hand, and object (Figure 4).

- Body relative reference frame refers to 3D menu appearing in correlation to the HMD forward direction. It is based on the user's position when it is opened. Once positioned in the VE it stays static in the environment and does not follow the user [8].
- Hand reference frames are defined by the position and orientation of the user's hand or controller. The 3D menu would be tracked to the user's hand or controller by its position and orientation [8].
- Object reference frames are confined to the object's position and orientation within the VE. If the object is moved within the VE the reference frame would follow its position and orientation [9].

I hypothesize that the hand reference frame will have significantly higher user experience scoring and higher comfort. It allows the user freedom to control where the information is shown within the VE by movement of the controller. I expect the body relative reference frame to do the worst in user experience expecting the reference frame to impede the user when it is presented, causing frustration to the user.

3.1 Task

In each experiment, participants were asked to learn about a set of 12 paintings and their associated abstract information. The paintings chosen were non-popular historical paintings to avoid problems with familiarity, the paintings included content such as: nature, portraits, biblical and historical scenes. Varying sizes of paintings were also chosen from small, medium, to large. For each painting the participant was able to open the 3D menu to display the abstract information of the painting. The abstract information included: title, artist, date, culture, and a short description. The short description was kept to a minimum and maximum word count to keep consistency across all paintings. Only one paintings information was available at a time, this was determined by pre-designated areas for each painting.

The source population consisted of 100 current or recent graduate college students who were above the age of 18. Our target populations were college students above the age of 18. Participants were tasked with memorizing the abstract information about each painting and its visual features in the VE. They were given a total time of 20 minutes to complete this task with a time update halfway through. The participant could choose to take less time to learn the material or they could use the max time allowed.

3.2 Apparatus

The VE, was created within the Unity game engine using the HTC Vive HMD and Controller. Through the Unity Asset Store the Showroom Environment was downloaded and altered for the study [29]. Participants were able to stand within the space and have slight movement such as leaning to view the painting for a stand only experience. A virtual barrier would appear when participants were too close to the outside barrier of the designated area, this prevented participants from bumping into walls in the real-world space.

The layout of the showroom was set up to mimic an art gallery, a long hallway with space for participants to easily navigate (Figure 5). Participants were able to travel around the environment using a teleportation VR technique through the HTC Vive controller. Predesignated locations are identified in the environment through highlighted markers on the ground to show where the user can teleport to. These designated areas allowed for participants to freely teleport closer, farther, left, or right from the painting. The participants were able to interact with the artwork by pulling the trigger button on the controller to display the 3D menu. In all three experiments, participants used the same VE layout. Once each participant completed the task or time was up they removed the HMD.

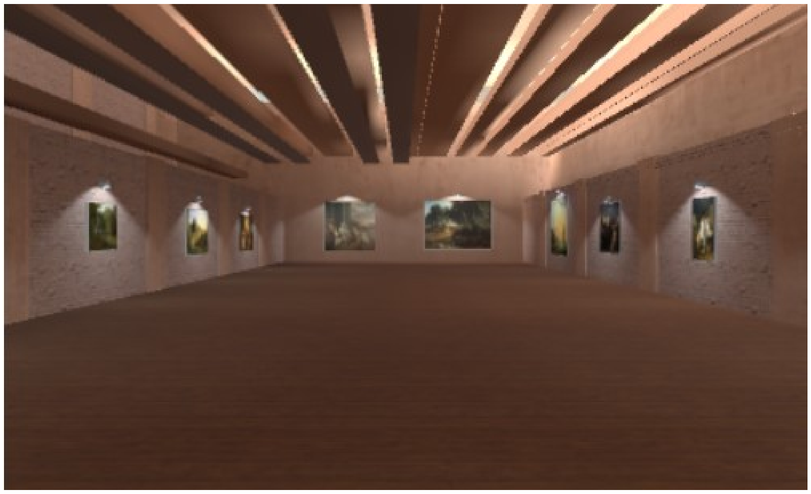

Figure 5: Experiment VE.

The demo room VE is a smaller version of the experiment VE. It held only 6 demo paintings for participants to demo, which included images of numbers on one side and shapes on the opposite wall (Figure 6). This allowed users to become comfortable with the interactions but also become familiar with how to move around in the VE. Once removed from the HMD, participants completed all questionnaires and assessment tests outside the HMD on a laptop computer, using a mouse and keyboard.

Screen recording of the participant's play-through was also recorded to obtain information about where the user was looking. Data was also collected through the Unity game engine that calculated the time participants gaze was on each painting and each paintings menu. Participants were also observed during the experiment to record body language and gestures.

Figure 6: Demo VE.

3.3 Observation

While in the experiment VE, participants body language was observed for each painting within each experiment. The upper body was the focus of observation, looking at how the participant used their head and arms. Casual observation was conducted which followed with a thematic analysis of the coded data. Coded data was collected by taking detailed notes of every movement the participant did for each painting while in the VE. Examples include:

- looked at painting then menu,
- arm is outstretched,
- arm is raised above eye level,
- moved to the right to view painting,
- holds menu close to body,
- menu is at book level,
- body is relaxed with arms at sides,
- leans into painting,

- views painting and menu together,
- tilts head at extreme angle to read menu,
- head tilt up to read menu,

Themes were collected by highlighting key terms which included: arm position, gaze, and moving/leaning. Arm position was further broken down into different themes based on its position: outstretched, raised high, book level, close to body, and relaxed.

Following the casual observation with the categorized themes a semantic observation was conducted. Casual observation was still collected coding new body language if any and payed close attention to any signs of fatigue from the user. Some of the signs of fatigue included the height of where the participant held the controller and whether their opposite hand started supporting the controller arm.

3.4 Procedure

A pre-questionnaire was given at the beginning of each study. The questionnaire asked general background questions and their immersive tendency. Afterwards, participants familiarized themselves with the VE interactive controls in a demo scene. They were given enough time to become comfortable using the controls and allowed time for any questions before beginning the experiment. Once the experiment began participants were put into the experiment VE. Observation notes were taken of the participant during their experience. A time update was given to the participant when they reached halfway through the VE. After their experience in the VE, participants were given a series of questionnaires and tests specific to each experiment.

3.5 Experiment I

The first experiment focused on the user experience, memory recall, and comfort across all three reference frames. The experimental design is a 2x3x3 mixed design, that contains a between subject factor, gender, and a within subject's factor, paintings and reference frames.

A total of 12 paintings were used in the study. Each painting was evaluated based on content and subject matter and were divided into groups based off these. Paintings were divided into three groups with 4 paintings each, these are called groups A, B, and C. Each group of paintings contained 1 large, 2 medium, and 1 small size of paintings. The abstract information was also taken into consideration, which included the paintings: title, artist, date, culture, and short description. Three reference frames were used to position the 3D menus: Body Relative, Hand, and Object. Each of these were grouped with each of the painting groups, making sure there was the same sizing across all three. In all three conditions counterbalance measures were put in place to prevent one grouping being more difficult than another.

I hypothesized that the hand reference frame would do the best for user experience and memory recall since it allows the user more control over where the information will be located.

3.5.1 Participants

Thirty participants participated in this experiment, fifteen females and fifteen males, which were balanced across the 3 conditions as well as possible. Participants ranged from ages 20-29, with an educational background of current undergraduate and graduate students, or recent graduates. 29 of the participants had prior experience using HMD's. Majority of the participants had a background in art history, meaning they had taken art history courses at their university. Some of these courses included Art History Survey I, II, and Modern Art History.

3.5.2 Procedure

After exiting the VE and removing the HMD, participants were given a test and set of questionnaires. The test was a memory recall assessment, which asked one question for each of the paintings. The questions were multiple choice and asked about the abstract information provided in the 3D menu or of what was visually shown in the paintings, such as subjects.

Afterwards, participants filled out a post questionnaire for each reference frame. It evaluated the participant's user experience and comfort while in the VE for each reference frame. An image of the referred reference frame was included for each of the post-questionnaires.

3.5.3 Results and Discussion

A factorial mixed ANOVA was conducted to compare the main effects of type of reference frames and the interaction effect between gender on memory recall. Reference frames included three levels (body relative, object, and hand) and gender consisted of two levels (male, female). All effects were statistically not significant at the .05 significance level. The main effect for reference type yielded an F ratio of $F(2,48) = 1.00$, $p < .375$, indicating there is no significant difference between reference frames for memory recall. The main effect for gender yielded an F ratio of $F(1,24) = 4.347$, $p < .631$, indicating that the effect of gender was not significant, male ($M = 45.56$, $SD = 21.511$) and female ($M = 60$, $SD = 26.328$). The interaction effect was not significant, $F(2,48) = 0.77$, $p < .927$.

I believe that the assessment test was not strong enough to evaluate memory recall with only one question for each painting, meaning there were only 4 questions for each reference frame. In the following experiment, this issue is addressed by making a stronger assessment test that would appropriately evaluate memory recall for each reference frame.

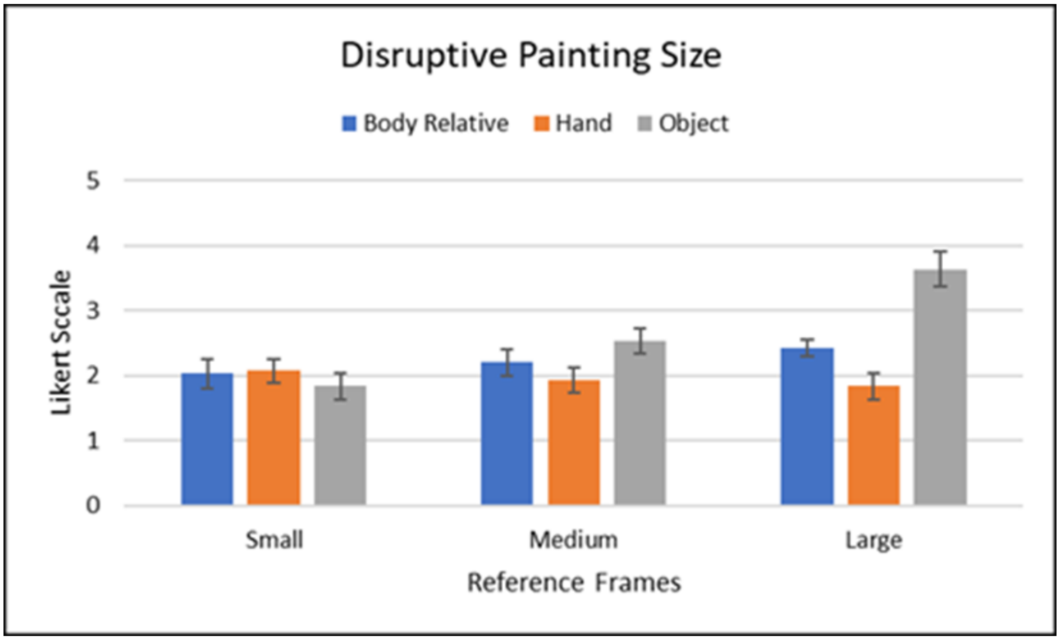

Figure 7: The menu was disruptive when viewing x size of painting.

The post-questionnaire asked users a set of Likert questions pertaining to whether the menu was disruptive or uncomfortable with different painting sizes. In Figure 7, the object reference frame has a noticeable difference when viewing large paintings. There was a significant effect of reference frames for being disruptive when viewing large paintings at $p<.05$ level for the three conditions [$F(2,87) = 18.10$, $p= .000$]. Post hoc comparisons using the Bonferroni correction indicated that the mean score for object reference frame (M=3.63, SD=1.497) was significantly different than body relative condition (M= 2.43, SD=1.165) and hand condition (M=1.83, SD=1.085). This shows that the object reference frame was more disruptive than the other two conditions for viewing large paintings.

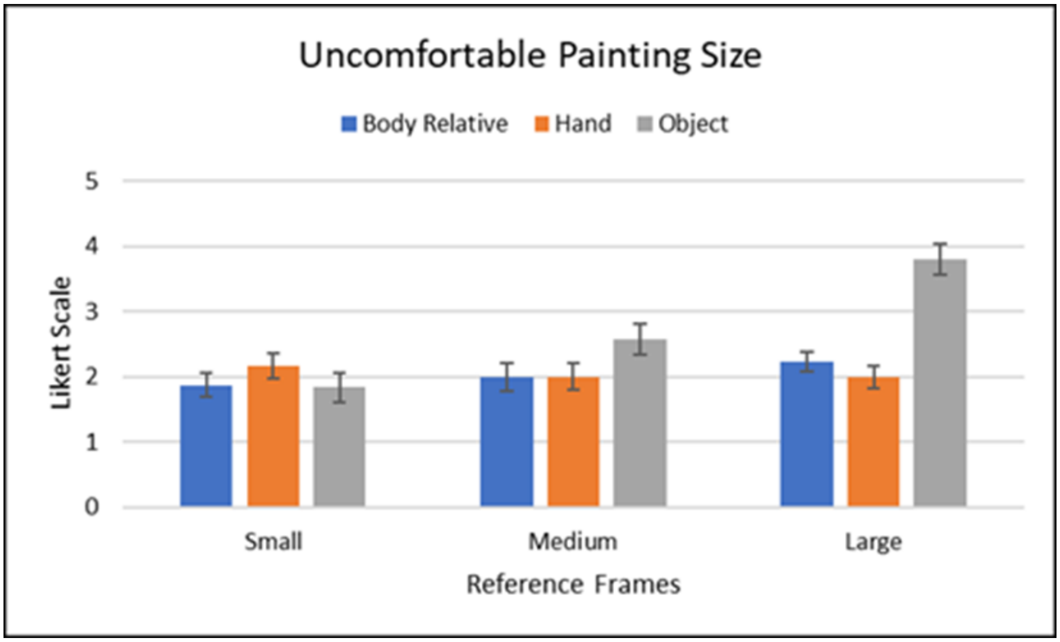

Figure 8: The menu was uncomfortable when viewing x size of painting.

In Figure 8 there is a noticeable difference on user comfort when using the object reference frame with large paintings. There was a significant effect of reference frames for comfort when viewing large paintings at $p<.05$ level for the three conditions [$F(2,87) = 18.10$, $p= .000$]. Post hoc comparisons using the Bonferroni correction indicated that the mean score for object reference frame (M=3.80, SD=1.324) was significantly different than body relative condition (M= 2.00, SD=1.194) and hand condition (M=2.00, SD=1.259). This shows that the object reference frame was more uncomfortable than the other two conditions for viewing large paintings. From these two charts I can deduce that the object reference frame should not be used for viewing large paintings since it becomes disruptive and uncomfortable for the user in the VE.

A casual observation was performed on the participants posture and body movement. This data coded what the user was doing with their body for each painting rather then why the user was doing it. Observation focused specifically on the participants upper body. From the coded observed data, I created categories of the user habits by thematic analysis. Afterwards a decision rule was created for a total of six different user habits.

These user habits were classified into two levels: non-fatiguing positions: A, B, and F, and fatiguing positions: C, D, and E (Figure 9).

A. Relaxed position, with hand at sides or crossed in front of body.

B. User positions menu at phone/book reading level. Elbow is bent while still connected to the center of the body.

C. User overextends their neck looking down at the controller, while the shoulder to elbow is parallel to the main body.

D. User extends arm/controller straight out, extending the elbow to be straight instead of bent. Arm is no longer parallel to the main body and instead is perpendicular.

E. User raises arm/menu up, elbow can be bent or extend so that the elbow is straight. Arm is not parallel to the main body.

F. User leans in to view painting. This is the only broad category. There are many different variations of how the user can lean in to view a painting.

I found the user's habits were very interesting and decided to take a further look at the them in the following experiments. Since fatigue can limit how much information users learn in the VE by the user quitting the experience early, this is an important area to further investigate for comfort.

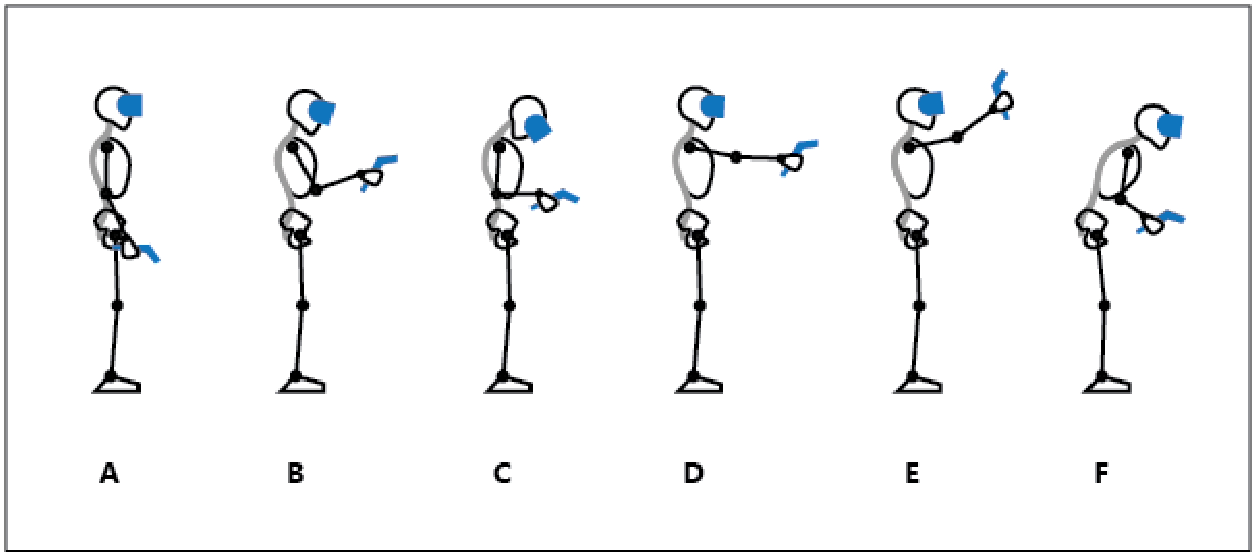

Figure 9: User habits.

3.6 Experiment II

The second experiment investigated how reference frames affect memory recall, user experience and comfort in VE. To be able to obtain more accurate data of the user's comfort for each reference frame a between subject's design was conducted. The experimental design is a between subject factor, with independent variable reference frames: body relative, hand, and object. Each participant only used one of the three reference frames with a total of 12 paintings.

Comfort was evaluated by an SSQ and observation with the use of decision rules for the participant's user habits. Observed data from experiment I outlined what was observed during experiment II. These categories were broken down into 6 habits (Figure 9). Using these six categories, I systematically observed user behavior and marked whether the user demonstrated that habit for each painting. A participant could have a score of 0-12 for each habit once the VE experience was complete. Casual observation for each painting was still conducted as well as coding whether the user's behavior throughout the VE changed. These changes specifically looked for signs of fatigue for the casual observation. They included changes in the height of where the participant held the controller and whether their opposite hand started supporting the other.

3.6.1 Participants

Thirty participants participated in this experiment, fifteen female and fifteen male, which were balanced across the 3 conditions. Participants ranged from ages 20-28, with educational background of current undergraduate and graduate students, or recent graduates. More than half of the participants were graduate students. All participants had prior experience with using HMD's, with 26 participants being familiar with the HTC Vive HMD. Majority of the participants had a background in art history, meaning they had taken art history courses at their university. Some of these courses included Art History Survey I, II, and Modern Art History.

3.6.2 Procedure

Once the VE experience was done participants removed the HMD and were given post questionnaires. They filled out an SSQ and a NASA TLX form before beginning the assessment test. A subject-matter expert was contacted to evaluate and assist in creating the assessment test questions. The multiple-choice assessment test consisted of 65 questions, with each painting having 5 questions. These questions asked about the title, artist, culture, date, and description or visual features of the painting. A painting that was not shown in the VE was also presented. This painting included 5 questions pertaining to the abstract information and visual features of the painting. For each of the 65 questions a confidence question was also associated asking, how confident they were in answering the question. This gave insight into whether the participant was guessing or whether they confidently knew the answer. After the assessment test followed a post questionnaire asking about the user's experience.

3.6.3 Results and Discussion

A One-way between subjects ANOVA was conducted to compare the effect of reference frames on memory recall with body relative, object, and hand conditions. There was not a significant effect of reference frames on memory recall at the $p < .05$ level for the three conditions $F(2,27) = 1.043$, $p = .366$.

A System Usability Scale was used to evaluate each reference frames usability. There was no significant effect of reference frames on usability at the $p < .05$ for the three conditions [$F(2,27) = .476$, $p = .627$]. This shows that all three conditions were equally as usable. For simulator sickness there was not a significant effect of reference frames on total SSQ score at the $p < .05$ level for the three conditions $F(2,27) = .011$, $p = .989$. There was not a significant effect of reference frames on Nausea at the $p < .05$ level for the three conditions $F(2,27) = 1.392$, $p = .266$. There was not a significant effect of reference frames on Oculomotor at the $p < .05$ level for the three conditions $F(2,27) = .012$, $p = .988$. There was not a significant effect of reference frames on Disorientation at the $p < .05$ level for the three conditions $F(2,27) = .322$, $p = .727$. Because there was not a significance in SSQ, Nausea, Oculomotor and Disorientation I can conclude there is no difference between simulator sickness between the three conditions. Because there was no significant difference between memory recall, user experience and simulator sickness I reject the hypothesis that the hand reference frame would overall do the best for users in VE.

A systematic observation was conducted with the 6 listed user habits from the previous study. Decision rules were defined ahead of time based off experiment I to reduce inferences. For each painting, a quantitative mark was used whether the user did any of the 6 user habits. A mark was given only based on whether the user did the habit or not for each painting, the amount of how many times the user did each habit was not collected. Casual observation was still collected and coded, this data included habits not included in the decision rule. I ran a thematic analysis and categorized them as signs of fatigue. These included:

- The opposite arm would start supporting the user.
- The height of where the controller was placed based off the user changed.
    - Eye level
    - Shoulder level
    - Stomach level.

The hand reference frame significantly used the 3 fatiguing user habits more than the body relative and object reference frames (Figure 8). I ran a One-way ANOVA to compare the effect of reference frames on the 3 fatiguing user habits using a Bonferroni correction to account for the chances of a false positive. There was a significant effect of reference frames on observed user habit C, at the $p<.05$ level for the three conditions $F(2,27) = 8.854$, $p= .001$. Post hoc comparisons using the Bonferroni correction indicated that the mean score for hand ($M=2.70$, $SD=2.869$) was significantly different than the body relative condition ($M=.00$, $SD=.000$) and object condition ($M=.00$, $SD=.000$). This shows that participants would likely have neck strain when using the hand reference frame by over extending their neck downward.

The other two user habits affect the user's arm by either being stretched straight out or lifted high. There was a significant effect of reference frames on observed user habit D, at the $p<.05$ level for the three conditions $F(2,27) = 13.760$, $p= .000$. Post hoc comparisons using the Bonferroni correction indicated that the mean score for hand ($M=4.60$, $SD=3.921$) was significantly different than the body relative condition ($M=.00$, $SD=.000$) and object condition ($M=.00$, $SD=.000$). This shows that using the hand reference frame users have a higher chance of fatigue in their arm due to it being outstretched in front of them.

There was a significant effect of reference frames on observed user habit E, at the $p<.05$ level for the three conditions $F(2,27) = 22.455$, $p= .000$. Post hoc comparisons using the Bonferroni correction indicated that the mean score for hand (M=2.953, SD=.934) was significantly different than the body relative condition (M=.00, SD=.000) and object condition (M=.316, SD=.100). This shows that using the hand reference frame user's are more likely to position the controller high up causing possible fatigue in the user's arm.

These results show that the hand reference frame is more fatiguing than the other two conditions, requiring the user to strain their arm or neck by using C, D, and E user habits (Figure 8). I further investigated the hand reference frame with the coded casual observation data. With this data a thematic analysis was conducted of the coded information for the hand reference frame. The trends found showed that users would change their user habits halfway through the VE at the 5th or 8th painting when using the hand reference frame. Investigating this trend further, collected data from the Unity game engine was analyzed. This data timed how long the user was gazing at each menu. From this data the average time the user would start showing signs of fatigue was around 4 minutes of gazing at a menu.

Because there was a significant difference in user fatigue using the hand reference frame a pilot study was conducted to see if there was a way to minimize these effects. Based off our observation of the user and the screen recording of participants playthrough the data suggests that the user would perform fatiguing habits when trying read textual information. I believe these fatiguing user habits happened when the user was reading text outside of the clear area on the HMD lens. However, there is not data to confirm this.

3.7 Experiment III

Experiment II found significant data in user habits when using the hand reference frame. These habits were classified as straining or fatiguing for the user, C-E. Design features should be considered for minimizing fatigue for the user for hand reference frames. Based off the previous two studies, I conducted a pilot study to investigate how to minimize strain and fatigue in the hand reference frame. Through observation of the second experiment I concluded that minimizing the amount of motion of the participants arm, specifically at the shoulder and elbow, would be effective in eliminating or minimizing these effects. When using the hand reference frames, participants would extend their arm out from the body and up or they would hold the controller close and over extend their neck to look down (Figure 10). For this experiment, I propose a way that would minimize these straining affects to only the user's wrist.

The new design of the hand reference frame was to mimic where the body relative reference frame resides, in world space. I offset the hand reference frame by location and restricted its rotation (Figure 11). A metaphor for this in the real world is fencing. When a fencer moves their wrist the sword's tip will follow giving a larger range of motion with little effort from the user. Whereas if you move the sword from the shoulder, there is a little movement with a lot of effort. With this new design I evaluated it with the hand and body relative reference frame. I hypothesized that offsetting the hand reference frame would minimize the range of motion of the user and lower observed strain and fatigue.

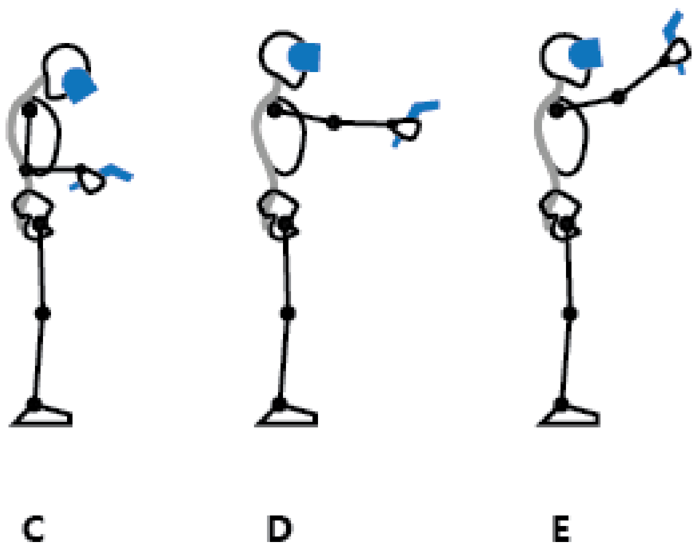

Figure 10: Fatiguing user habits C, D, and E.

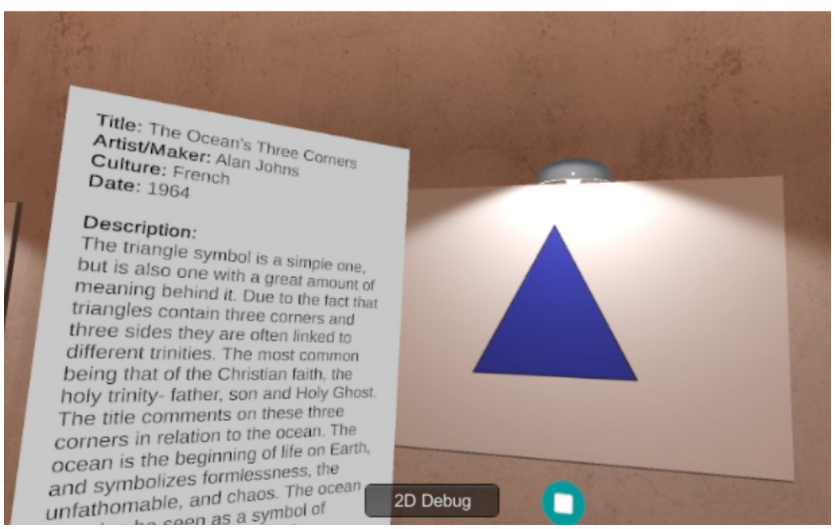

Figure 11: Offset hand reference frame.

3.7.1 Experimental Design

The third experiment was a between subject's design presenting the hand, body relative, and the offset-hand reference frame. The new design, offset-hand, was created by restricting and offsetting coordinates. Normally for the hand reference frame the menu is 1:1 with the controller coordinates, instead I locked the rotation of x and z axis based off Unity's coordinate system (Figure 12) and the y axis was constrained to always face the player. The placement of where the menu appeared was locked to a distance directly in front of the controller. As the controller moved the menu would follow its location based off x, y, z coordinates (Figure 12).

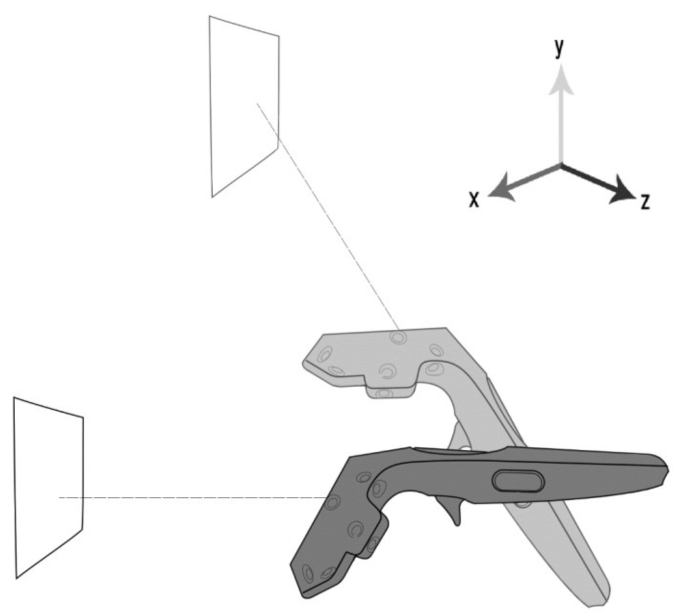

Figure 12: Offset hand reference frame menu, Unity coordinate axis.

I investigated comfort, SSQ and observation, for the new designed menu, offset-hand reference frame and compared it against the body relative and hand reference frames. I hypothesize that the offset-hand will minimize fatiguing habits known to the hand reference frame. Like the previous experiments, a total of 12 paintings were used in the study.

3.7.2 Participants

Nine participants participated in the third experiment, 5 females and four males, which were balanced across the 3 conditions as well as possible. Participants ranged from ages 19-29, with educational background of current undergraduate and graduate students, or recent graduates. More than half of the participants were undergraduate students. All participants had prior experience with using HMD's, with 6 having practical application experience using HMD's. Majority of the participants had a background in art history, meaning they had taken art history courses at their university. Some of these courses included Art History Survey I, II, and Modern Art History.

3.7.3 Procedure

After the VE experience, participants immediately filled out an SSQ and a NASA TLX form. A multiple-choice assessment test was also given right after these two forms. The assessment test consisted of 26 questions, with each painting having 2 questions. These questions asked about the paintings title and their description or visual information. A painting that was not shown in the VE was also presented, which included 2 of these questions. For each of the 26 questions a confidence question was also associated asking, how confident they were in answering the question. This gave insight into whether the participant was guessing or whether they confidently knew the answer. After the assessment test, a post questionnaire was given asking about the user's experience.

3.7.4 Results and Discussion

The third study suggests that the offset reference frame was effective in minimizing the fatiguing user habits: C, D, and E. However, I am not able to confirm this with the limited number of participants that were ran. A more in-depth study should be conducted with more users and video recording to strengthen our observation of user habits. The observation of user habits suggests that further design features to the hand reference frames could minimize fatigue and strain. This is important for VE since fatigue could cause the user to stop the VE experience.

4. IMPLICATIONS AND DESIGN

Through our research comfort is an important factor in effectively presenting abstract information when using 3D menus. User's have a higher risk of repeated stress injury when using the hand reference frame than object and body relative reference frames. Paying attention to how long users will be positioned in fatiguing habits is important since it can cause repeated stress injury or prevent the user from completing the learning objective. Designers can design experience that can either take advantage of the fatigue for specific use as in for rehabilitation purposes or for getting a specific population such as the elderly to move around more.

A few designs to investigate to minimize fatigue is combining reference frames, such as body relative and hand. This is based off the third study but also user's free response from the previous two experiments. Development of this could allow for the menu to quickly switch between one reference frame to another, becoming a multi-use reference frame. An example is, starting the menu on the hand controller, then when holding down a button the menu switches to body relative reference frame and the user can place the menu within world space and leave it there. If the user wanted, they could reposition where the menu is floating in the world space. Could this combination increase user's experience and improve users fatigue from the hand menu?

When HMD's become more robust and the lens are clear in the user's peripheral vision, the hand reference frame should be reevaluated for comfort. From our research there were many comments about the HMD or lens being blurry. I believed this distorted area of the lens prevented users from glancing down at information with just their eyes and forced users to move their head or arm to be able to clearly see the textual information, resulting in strain and fatigue from the user.

The range of area to read in an HMD is limited to a small section of the lens, front and centered. In real life, we regularly use eye gaze to quickly pick up information and once we switch our point of interest it becomes clear. Currently, HMD's are not able to mimic this, but as technology and hardware improve this would be something to reinvestigate in how it effects fatigue in the hand reference frame for 3D menus.

5. CONCLUSIONS

This study is a first step in exploring how reference frames for 3D menus affect user habits. Even though I found nothing that statistically supplements user experience or memory recall I discovered an area of research that should be further investigated for user fatigue in reading textual information in 3D menus. This paper acts as a reference point for future research to evaluate and categorize user habits for placement of 3D menus. It gives insight in how to design for user comfort but also how to possibly take advantage of fatiguing effects for rehabilitation purposes.

I only investigate how reference frames for 3D menus can affect a specific kind of VE. Investigating learning VE's that are time sensitive or that require more interaction should also be evaluated. A topic not covered, is the use of head reference frames (HUD) and eye reference frames. This was due to eye tracking not being widely available to consumers and HUD's being known in the VR development community for causing simulator sickness with a large amount of textual information. These could be useful in specific learning VE's depending on the task, such as using annotations.

Our participant population had previous Art History background, from taking multiple art history course at their university. Majority of participants also were familiar with using HMD's, in most training or learning scenarios this will not be the case. Due to the population of participant coming from the College of Architecture in the university, who have more experience in using HMD, I do not know how this would affect users with no experience using HMDs.

Future research for reference frames should not only investigate textual information but also evaluate how reference frames influence time sensitive tasks, navigation, spatial awareness, collaborative learning or dual tasks paradigms. Other aspects of 3D menus should also be investigated with the use of reference frames other than text. This can include graphical menus for system control such as: TULIP menu, pie menu, ring menu, etc. [15, 2]. These can continue to set guidelines for designers to quickly and efficiently create intuitive VE for training and education.

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