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Effects of Egocentric Versus Exocentric Virtual Object Storage Technique on Cognition in Virtual Environments

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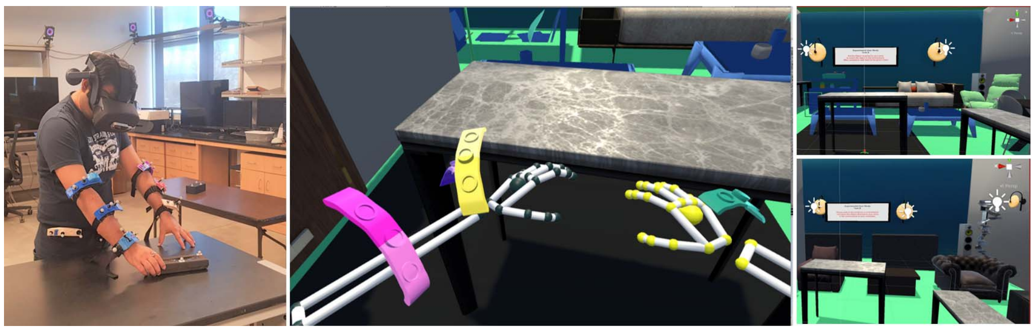

Figure 1: (Left) In Egocentric technique, a user wears tracked props attached to the limbs to interact with virtual objects (center image). In Exocentric the props are placed on the table in both real and virtual environment. (Center) A user's view through VR headset while interacting with the virtual object storage. (Right) A view of the virtual environment rooms: the first room for same context condition (Top) and the second room for change of context condition (Bottom)

Abstract

As tasks in Virtual and Augmented Reality applications become increasingly complex, there is a need to better organize information or virtual objects within the virtual environment. For example, 3D Widget or menus may need to hide information from the user until it is needed. Users may need to organize their own virtual objects or tools by storing them until usage is needed or carry with them to another location. For these scenarios and others, there may be benefits to associating or storing virtual objects in relation to one's own avatar (Egocentric) or in relation to the other virtual objects in the environment (Exocentric). This paper presents the results of a user study comparing the effects of Egocentric and Exocentric Virtual Object Storage Techniques on cognition in a virtual environment. Participants performed a task that enabled them to store virtual objects using different Virtual Object Storage Techniques. As participants completed their tasks, we measured task and cognition performance. We found that the egocentric technique improves task performance, increases accuracy, and reduces cognitive workload during memory task for virtual object storage in comparison to the exocentric technique in a virtual environment.

Index Terms: Human-centered computingVirtual Reality Human-centered computingUser studies

1 Introduction and Motivation

Virtual and Augmented Reality (VR/AR) applications are increasingly being developed to provide more immersive and informative experiences to improve the areas of education [32], health [12], design [5], training [40], and data science exploration and discovery [39]. VR has been shown to provide and support the exploration of higher dimensionality and abstraction, increased understanding of datasets, life-size interaction, and body-centric judgment of the 3D spatial relations, while interacting with the datasets [33, 39, 42]. Tasks in these VR/AR applications are increasingly complex, creating a need for more effective 3D User Interface design of menu items, tools, and other virtual components [7]. More virtual tools, menus, and widgets are visually provided to a user. As a result, a user's visual field becomes obstructed or the result may hinder a sense of presence. To improve this, it is better to hide these virtual components from view. However, working memory has been shown to have a minimum capacity to remember items and information presented visually or verbally to anyone [3, 8]. In this paper, we ask the following research question- how can we design Virtual Environment (VE) tools to facilitate a user's working memory of those hidden elements? There is a need to design better organization and storage of virtual objects.

Cognitive psychology literature has shown that a user can associate objects with information to better remember the object's location, features, attributes, and relationships [3, 14]. It has been shown that body-object interaction represented for spatial memory evidenced increased performance as a user would optimally use body-cue and object-cue to recognize and interpret the information in the scene, but have not explored distinguishing factors between body-cue and object-cue as separate aids and their effects on cognition [28]. To apply this theory, previously researchers have used BodyProp [18] as an interaction technique to understand the body-object interaction while working with large and complex datasets using VR. BodyProp has been defined as a 3D printed physical prop/object which has been designed and developed to interact with a different set of models, datasets, or virtual objects by attaching it to a different body parts location like limbs, head, torso, chest [18]. However, there is little research that has investigated the usage of such associated objects to aid interaction and cognition in a VE.

In this paper, we present the results of an experimental user study that investigated the effects of associating physical objects with

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virtual objects on cognition. Our study explored two interaction conditions: egocentric (objects associated with a user's own body) and exocentric (objects associated with other objects in a VE).

2 BACKGROUND & RELATED WORK

2.1 Frames of Reference

Spatial reference frames are used to represent the position and orientation of objects in the space [19]. It is essential to know the arrangement of the objects in the environment to perform any task. It is equally important to understand how this information is expressed in memory and what frame of reference is used by the memory to specify the spatial organization [25].There are different approaches to describe and analyze spatial reference system, but to understand the purpose of spatial memory, egocentric reference frame relates to the representation of location and orientation to the perspective of the observer (eye, head, or body coordinates) whereas the exocentric reference frame represents spatial relations external and independent of the observer's position [19, 25].

2.2 Cognition

Researchers have shown evidence to expand the capacity of Working Memory through targeted training to enhance cognitive performance. This cognitive enhancement through training includes attention [37], dual-task [6], speed of processing [10], and perceptual training [23]. Focus of attention in working memory is the element that is processed latest and has increased privileged than the older element which was processed earlier [41]. An increase in working memory capacity will increase work efficiency leading to increased performance during a cognitive task such as interpretation, learning, reasoning [2]. However, the focus of our research is to identify interaction modalities that augment working memory.

Previous researchers [11] discovered and suggested that for the spatial navigation, spatial judgment, and target-directed movements, the spatial representation might be dependent on the egocentric reference frames. Furthermore, it was also presented that not all spatial observations rely on the egocentric reference frame but also could involve mental transformations of the objects. Egocentric cues are dominant compared to the exocentric during the wayfinding task as the task does not have direction or axes as that is notable from the defined point of view [9].Using one or two reference directions, the inter-object spatial relation is defined by using an egocentric reference system [27].

A previous research study has shown that distance estimation using egocentric is more accurate than the exocentric reference frames [21, 35]. It was found that exocentric cues were better for size judgment than egocentric cues [24]. Another research experiment [16] using immersive virtual reality for spatial memories showed that the egocentric reference frame played an important role when it lacked extrinsic or intrinsic structure. Spatial memories for the VEs are similarly organized to memory for the real environments and furthermore similar to the egocentric experience [17]. Researcher found that using hand position affects the attention of the region in the peripersonal space [34]. They found that spatial attention is influenced by the representation of space near the hand.

Previous research related to visualizing information suggests that an exocentric view helps people to see global information better (general trends in the data) and egocentric view helps people to see local information (details about the information) [4]. It was found that egocentric distance judgment can be improved more using the feedback mechanism to target on the ground plane in a virtual environment [26]. It has been shown that using real objects in VE to manipulate virtual objects during a spatial cognitive task will help to increase task performance similar to real-world performance [20]. However, it is not clear how cognition is affected when interacting with those objects in relation to one's own body compared to interacting with the objects in the VE.

3 EXPERIMENTAL STUDY

The purpose of this experiment was to evaluate the effectiveness of egocentric versus exocentric interaction modalities to augment working memory in a VE when storing virtual objects. The University of Wyoming Institutional Review Board approved this study design for data collection with human subjects.

3.1 Experimental Design

The user study had a 2x2 within-subjects experimental design. A user may associate virtual tools, menus, or other objects with their body or with the world. The first set of conditions was whether used their own body to associate or store virtual objects (Egocentric) compared with using the environment to associate or store virtual objects (Exocentric). For example in Egocentric, users may use the stretegy to associate objects with left/right or upper/lower arms. In Exocentric, users may associate objects with left/right or closer/further away on a table or in relation to other static objects on the table (book) or in the environment (picture on wall). In certain usage scenarios, a user may put away those virtual tools, menus, or objects away and bring them up in a different room or environment. The next set of conditions investigates if there is a difference when the user is in the same room or environment (Same Context) compared with accessing those objects later in different room or environment (Change of Context). For example, if they learned where the objects were but the environment around them changed- such as furniture in the room. The reference objects stayed constant for both Egocenteric (the arms) and Exocentric (the tables), when a user went to a different room for the change of context condition. There were four different conditions that were investigated: Egocentric-Same Context (Ego-Same), Egocentric- Change of Context or Different Environment (Ego-Diff), Exocentric-Same Context (Exo-Same), and Exocentric-Change of Context or Different Environment (Exo-Diff).

3.2 Virtual Environment

Participants completed their tasks in a single room VE. There were two different room designs, one room for the same context condition and a second room was provided for the change of context condition. To navigate from one room to the next, participants physically walked through an open door in the first room, through a virtual hallway, and into the second virtual room. The virtual door did not open until the tasks to be completed were finished. The virtual rooms consisted of an apartment or lounge environment with couches, chairs, art on the walls, cups, books, etc. in the environment. These differed in placement and design across the two rooms. Three virtual tables were set up in the environment that persisted across both virtual rooms and real tables provided haptic feedback for a user. Other elements like doorways and windows remained in the same location and orientation across the two rooms, having landmarks that were consistent across both rooms.

3.3 Set-up and Apparatus

We used the Unity3D game development platform (v.2018.3.14f) with C#. Participants wore a HTC Vive Pro head-mounted display (HMD) with 2160 by 2160 pixel resolution to view the VE. An HP Z4 G4 Workstation computer with an Intel Xeon W-2102 at 2.90 GHz and an NVIDIA Quadro P5000 was used. Each object was tracked using an OptiTrack Tracking system [29]. The set-up includes fourteen Prime 41 high-speed tracking cameras for tracking rigid body markers [30]. To enable virtual objects attached to or associated with locations of the body for the purposes of this experiment, each participant wore a set of straps around their limbs fig.1. LeapMotion [22] was used to track and view each participant's hands because it has been shown that providing the participant with self-avatar or hand in the VE will help to increase body ownership, sense of presence, interaction, cognition, and perception of the space [36].

3.4 Measures and Procedure

Participants initially completed a pre-questionnaire and the Butterfly Stereoscopic test to assess stereopsis ability [15]. Before beginning the task, the participant was provided with training in the VE. This training was provided to the participant so that they are comfortable in the VE. The training was provided to the participant to make them familiar with a physical prop in the VE. The training VE is not similar to the experimental VE. We assigned four different experimental conditions to the participant using the Latin square method to complete the task. For each condition, the participant completed five trials. The experiment involved two types tasks completed sequentially, a memory task and a manipulation task, that were completed by each participant. First the memory exposure task, then the manipulation task, then the memory testing task. The purpose of the manipulation task was to distract the user sufficiently from the memory task to represent typical VE interaction in between tool usage. We also collected task completion times. Position and orientation of virtual objects were logged before and after the manipulation task. After completion of each condition, the participant was asked to complete the NASA TLX [13], and SUS presence questionnaire [38]. The participant was asked to complete the post-questionnaire. All questions provided to a participant was answered in either simple multiple-choice, or Likert scales. Finally, the investigator asked open-ended interview questions to understand their experience using the egocentric versus exocentric interaction technique for the memory task.

3.5 Experimental Tasks

3.5.1 Memory Task

The purpose of this task was to evaluate how a method of virtual object storage (egocentric versus exocentric) affects memory. The memory task involved two parts: 1) exposure and 2) testing. During the exposure part, a participant performed a gesture (raise hand) to make the objects visible. Then a set of nine virtual objects (see fig.1, right) were presented to a participant each in random positions and orientations relative to either the physical props on a participant's body (Egocentric condition) or relative to physical props in relation to other objects in the VE (Exocentric condition). This is based on a memory guideline of 7 +- 2 chunks of information [1] so that the task would be challenging enough to reveal differences among the conditions (to not risk a ceiling effect) but not too challenging that participants would not be able to complete the task in the time allotted. Each object or chunk of information has position and orientation information that a participant has to remember. For each trial of this task, a participant was given a period of five minutes to study the objects. A participant then completed a secondary manipulation task which is detailed in the next section. After completing the secondary task, a participant was tasked with remembering the position and orientation of each of these objects. A participant had to move the target virtual objects to their appropriate positions and orientations by physically moving the associated physical markers or props into place. Then after the manipulation task, each participant was asked to relocate the virtual objects using physical props to match previous positions and orientations.

3.5.2 Manipulation Task

The purpose of this task was to provide sufficient distraction from the initial exposure portion of the memory task involving some interaction with the VE, similar to usage scenarios where a user puts away virtual menus and tools, interacts with the VE and then brings those tools back into view. The manipulation task (used for providing a distraction) presented a set of virtual objects that looked like ordinary real-world objects, such as a mug or a book, and fit in with the theme of the VE. A participant was tasked with moving each of the highlighted virtual objects to match the position and orientation of their corresponding target object, marked by a transparent form of the same object. For example, a mug was highlighted and a participant could see the same transparent mug in a different position and orientation. A participant would then physically move the marker of the virtual mug to match the virtual representation of the mug to the transparent visual target.

3.6 Experimental Conditions

In the egocentric-same context condition (see Fig. 1), all of the physical prop which we designed as described earlier, were attached to the limbs of each participant, each using adjustable straps with buckles so that they can use their body as a reference frame for the egocentric task. A different physical prop was attached to nine different locations of the body (three in each arm and three in the waist). Participants completed the memory task with the virtual objects associated with the physical props attached to their body.

In egocentric-change of context condition (see Fig. 1, left), each of the props are also attached to nine different positions of a participant's body using adjustable straps. The only difference in this condition is that participants completed part 1 of the memory task and the manipulation task in the first virtual room. Then each participant walked through an open door in the virtual room, followed along a hallway in the VE as directed to reach the second virtual room . After reaching the new VE, the randomly swapped virtual objects were visible on each participant's avatar, which was associated to each of the different physical props on the participant's body.

In exocentric-same context condition, the virtual objects which are augmented on top of a physical prop are placed around the room in the VE, not attached to the limbs. The virtual objects are made available in the VE to provide the exocentric reference frame. Nine different abstract virtual objects were visible in the VE. Participants completed part 1 of the memory task, the manipulation task, and part 2 of the memory task all in the same virtual room. For part 2 of the memory task, each participant was asked to move the virtual objects to its previous location in the virtual room to match the position and orientation as remembered from part 1 of the memory task.

In the exocentric-change of context condition, each participant participant performed part 1 of the memory task and the manipulation task in the first virtual room. After completing the manipulation task, each participant walked through an opened door and followed along the hallway to reach the second virtual room. Each participant completed part 2 of the memory task in the second virtual room, utilizing consistent objects (ie. three tables) or landmarks (doorway, window, etc.) as references in the room to facilitate the task.

4 Results

We conducted a repeated measures ANOVA on data collected during the experimental user study. A Bonferroni test was used for post-hoc analysis. We present the analysis on task completion time, accuracy (virtual objects placed at the correct location), and pre/post-experimental data for each condition.All the participants recruited were from the University of Wyoming. We had a total of 12 participants (1 female, 11 males, M=24.95yo, SD = 5.46). All participants passed the stereopsis test and reported that they were not color blind. Participation was voluntary and no compensation was provided.

Completion times were analyzed and an ANOVA showed a significant difference between conditions on completing the task, $F(3,44) = 26.09$, $p < 0.001$, $n^2 = .64$. A Bonferroni post-hoc test found that the participants took less time during egocentric-same context (M=47.69s, SD=8.36s) and egocentric-change of context (M=53.15s, SD = 5.01s) in comparison to exocentric-same context (M=73.44s, SD = 14.02s) and exocentric-change of context (M=84.41s, SD = 15.88s) as shown in Fig.2. The result suggests that the egocentric virtual object storage technique takes less time to complete a task in comparison to the exocentric technique.

Accuracy was measured by counting the number of virtual objects placed to its original position during the memory task for each con-

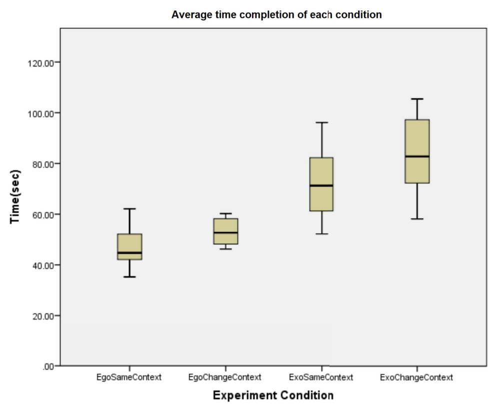

Figure 2: Average task completion time during memory task.

dition. There were nine virtual objects available in the VE for virtual object storage. An ANOVA revealed a significant main effect across the conditions for completing the task, F (3,43) = 14.16, p <0.001, n^2 = 0.50, power=0.97. The accuracy for placing the virtual object using egocentric-same context (M=7.50, SD = 1.00) and egocentric-change of context (M=7.00, SD=1.27) higher in comparison to the exocentric-same context (M=5.50, SD= 1.00) and exocentric-change of context (M=5.00, SD = 1.00). This result suggests that using the egocentric technique will increase the accuracy for storing the virtual object in a VE compared to exocentric.

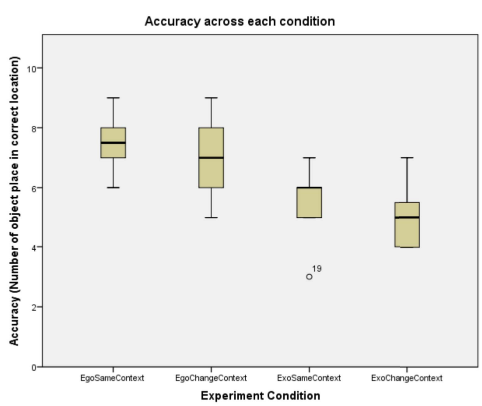

Figure 3: Accuracy across each condition during memory task.

Error was measured by calculating the positional data of a physical prop before and after the memory task across each condition. An ANOVA revealed a significant main effect across the conditions, F (3,32) = 44.87, p <0.01, n^2 = 0.81. The error rate for placing the virtual object using egocentric-same context (M=0.19, SD = 0.09) and egocentric-change of context (M=0.35, SD=0.10) lesser in comparison to the exocentric-same context (M=0.60, SD= 0.095) and exocentric-change of context (M=0.81, SD = 0.17). This result suggests that using the egocentric technique will have reduced error rate during memory task in comparison to the exocentric.

Rotational error was measured by calculating the orientation of a physical prop before and after the memory task across each condition using the euclidean distance formula [9]. An ANOVA revealed a significant main effect across the conditions, F (3,32) = 80.28 p <0.01, n^2 = 0.88. The error rate for orientation of the virtual object using egocentric-same context (M=3.07°, SD =2.35°) and egocentric-change of context (M=22.26°,SD=6.82°) is lower in comparison to the exocentric-same context(M=42.51°,SD = 7.51°) and exocentric-change of context(M=60.73°,SD = 13.06°). This result suggests that using the egocentric technique will reduce rotation error during a memory task compared to exocentric.

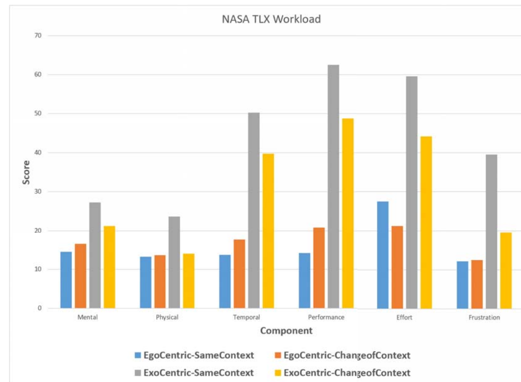

Figure 4: NASA TLX workload analysis across conditions.

NASA-TLX is a subjective measure of mental workload. An ANOVA found a significant main effect for NASA TLX overall workload across the conditions, F(3,44) = 11.86, p <0.001, n^2 = 0.45. Fig.4 suggests that the overall workload assessment for NASA TLX indicates that the egocentric-same context (M=15.88, SD=5.75) and egocentric-change of context (M=17.05.34, SD =3.60) has least amount of physical and cognitive workload in comparison to the exocentric-same context (M=43.79, SD=16.35) and exocentric-change of context (M=31.25, SD= 14.70) during the virtual object storage task in the VEs. We collected memorability data to understand how participants felt about how much they remembered the location of the virtual objects in the VE. The question for the memorability was referenced from the book titled "Usability Engineering" [31]. The question was a Likert-scale ranging from 0 to 9, where higher value indicated good memory. Data suggests that the participant provided feedback that they could remember better during the egocentric-same context (M=7.41, SD=0.79) and egocentric-change of context (M=6.91, SD=1.26) in comparison to exocentric-same context (M=5.167, SD=0.90) and exocentric-change of context (M=4.91, SD=0.99).

The system usability scale (SUS) score data was collected after each condition was completed to measure the usability perception. The SUS score for egocentric-same context (score=77.29) and egocentric-change of context (score=75.83) falls within the range of good scale whereas the SUS score for exocentric-same context (score =62.91) and exocentric-change of context (score=58.95) falls within the range of poor scale. Participants also preferred using the egocentric (N=10) against the exocentric (N=2) technique using the egocentric (N=10) against the exocentric (N=2) technique for virtual object storage association. One participant commented "I thought that egocentric let me memorize things a lot better!" and another commented "I was surprised how egocentric was so easy to remember than the exocentric. It was easy for me to remember the objects and lot more faster to reach the object for storing information".

5 Summmary and Conclusion

Our results suggest that the egocentric is more effective in increasing the task performance in comparison to the exocentric technique for storing virtual objects in a VE. This is supported by the decrease in task completion time and increase in accuracy for egocentric. Our result supports in a VE, findings from the cognitive psychology literature [3, 14], which suggested that a user can associate objects with information to better remember it's location, features, and attributes in relation to their body during cognitive tasks. Participants were able to remember better and associate the information with virtual objects by referencing it with parts of their body (Egocentric) than parts of the table, objects on table, or environment (Exocentric).

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