Comparing Voodoo Dolls and HOMER: Exploring the Importance of Feedback in Virtual Environments

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ABSTRACT

When creating techniques for manipulating objects at a distance in immersive virtual environments, researchers have primarily focused on increasing selection range, placement range, and placement accuracy. This focus has led researchers to create and formally study a series of "arm-extension" techniques, which dynamically scale the user's arm to allow him to manipulate distant objects. Researchers have also developed representation-based techniques, which allow users to manipulate a distant object by manipulating a copy of it in a handheld representation. However, researchers have not yet formally established the relative value of these techniques. In this paper we present a formal study comparing Voodoo Dolls, a best-practice representation-based technique, with HOMER, a best-practice arm-extension technique. We found that the Voodoo Dolls technique, which provides better feedback by allowing users to view a manipulated object both up close and at a distance, allowed users to both position and orient objects more accurately. Our results suggest that researchers should focus on improving feedback for 3D manipulation techniques.

Keywords

Virtual reality, 3D interaction, object manipulation

INTRODUCTION

When creating techniques for manipulating objects at a distance in immersive virtual environments, researchers have primarily focused on increasing selection range, placement range, and placement accuracy. This focus has led researchers to create a series of "arm-extension" techniques, which dynamically scale the user's arm to allow him to manipulate distant objects. The HOMER [1], Go-Go [11], and World-scaling [8] techniques are best-practice examples of this type of technique.

The World-In-Miniature [14] and Voodoo Dolls [10] techniques take a different approach: they provide users with handheld representations of distant locations. Users manipulate a distant object by manipulating a copy of it in a handheld representation. In addition to allowing users to work at a distance, a representation allows users to get a better view of the manipulated object by viewing it both up close and at a distance. These techniques thus provide users with better feedback than arm-extension techniques, which only allow users to view manipulated objects at a distance.

Despite this potential advantage, researchers have yet to formally compare representation-based and arm-extension techniques. Formal studies of techniques for manipulating objects at a distance (e.g. [2][13]) have primarily focused on comparing arm-extension techniques. To determine the value of the representation-based approach relative to the arm-extension approach, we decided to formally compare the Voodoo Dolls technique with a best-practice arm-extension technique.

We chose the Voodoo Dolls technique because it overcomes a problem with the World-In-Miniature (WIM) technique. While a WIM provides better feedback, it does not always provide sufficient accuracy. A WIM is typically a handheld representation of the entire world. The larger the area represented by the WIM, the larger the ratio between "real" space and WIM space. With a large ratio small motions in the WIM will result in large motions in the "real" world, making accurate placement difficult.

The Voodoo Dolls technique overcomes this problem by allowing users to create *contexts* on the fly. A context is a handheld representation of a small section of the world centered on a particular object. The user specifies the center of the context, the focus, by image plane selecting [9] an object with his non-dominant hand. In response, the system creates a handheld, miniature copy (a doll) of the selected object and arranges copies of nearby objects to provide the context. The size of the context depends on the size of the selected object. The user manipulates a distant object by creating a doll of that object with his dominant hand and placing the doll in the context around his non-dominant hand; this positions the object represented by the doll in his dominant hand relative to the object represented by the doll

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in his non-dominant hand. The Voodoo Dolls technique works for a broad range of object sizes, allows users to manipulate both nearby and distant objects, and allows users to accurately position objects when the target position is nearby or far away.

IMPROVING VOODOO DOLLS

We made one improvement to the Voodoo Dolls technique for this study. In order to place an object in a particular location the original implementation of the Voodoo Dolls technique requires that users select a nearby object to provide the focus of the context. This requirement causes problems when there is no object near the target location.

To overcome this drawback we modified the technique to allow a user to simultaneously create a temporary object and its doll by selecting a point on the ground (or room, if the user is indoors) where he wants the object to appear (Figure 1). The temporary object appears as a colored cube half a meter long on each side, and disappears as soon as the user drops the doll representing it. We provide a context for the doll whose volume depends on the distance from the user to the temporary object; the farther the object, the larger the context. In practice we found creating a context with a radius equal to 3/5 of the distance to the created object effective.

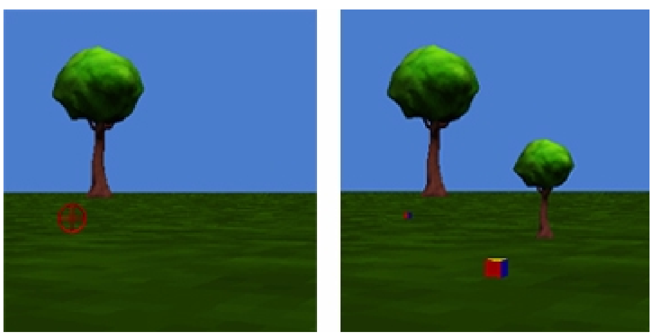

Figure 1: A user can image plane select the ground (left) to create a temporary reference object, doll, and context (right).

CHOOSING AN ARM-EXTENSION TECHNIQUE

We wanted to compare the Voodoo Dolls technique with an equally versatile arm-extension technique. We chose HOMER, specifically Indirect HOMER, as the technique for comparison. With HOMER a user ray-casts to select the object to manipulate, and the user's virtual arm essentially lengthens instantaneously so that his virtual hand touches the object. The user can then rotate the object as if holding it in his hand. The vector from the user's torso through his physical hand determines the orientation of his virtual arm. With the Indirect HOMER variant the user moves his physical hand closer to or further from his torso to move the object an equal distance closer or further at the end of his virtual arm. The user can also change the length of his virtual arm by pushing buttons to shrink or grow it at a constant rate. This variant thus allows users to select any visible object and place it at an arbitrary distance.

We decided against the Go-Go technique because, even with the non-linear mapping between physical and virtual hand positions, the range at which users can manipulate objects is restricted by how far users can extend their arms. We similarly decided against the World-scaling technique because the scaled world also restricts placement: the system sets the scale factor when the user selects an object, and users cannot place the selected object any farther than they can reach in the scaled world.

RELATED WORK

Researchers have developed a number of testbeds for evaluating VR interaction techniques (VEPAB [7], VRMAT [12], and VR-SUITE [2]). These testbeds consist of an abstract task to allow researchers to vary a single factor (e.g. size, selection distance, placement distance) at a time. This approach allows researchers to determine with some confidence the effect of a particular factor on task performance. However, stripping a task of extraneous variables can reduce the generality of the results. In testbed tasks users typically only manipulate a single type of object, rather than a variety of objects with different shapes. Furthermore, the object type is usually a simple geometric shape (e.g. a cube) to prevent users from drawing on their knowledge of the sizes and shapes of objects, but users can do exactly that during real work.

We preferred to make the opposite trade-off [3], accepting less certainty about the effects of individual factors on task performance in exchange for more confidence about the generality of the results. Toward this end we chose to have users manipulate objects with a variety of different sizes and shapes. We chose the objects by considering two sample manipulation tasks: arranging the furniture in a room and arranging an outdoor scene. We designed the experiment tasks to emulate these sample tasks.

TASKS

We created a practice world and two experimental worlds, one indoors and one outdoors. We grouped the tasks based on the world and the size of the manipulated objects in order to allow us to draw loose conclusions about the effects of size and distance. In the indoor world users manipulated small and medium objects (3 tasks each), while in the outdoor world users manipulated small, medium, and large objects (3 tasks each), for a total of 15 tasks. Table 1 contains the dimensions of the manipulated objects and the placement distances, and Figure 2 shows the objects. We designed some of these tasks so that there was no nearby object to serve as the focus of a context for the Voodoo Dolls technique.

TABLE 1: Dimensions and Placement Distance (meters)

Model	Width	Height	Depth	Distance
Cat Bookend	0.20	0.30	0.30	7.8
Alice Bookend	0.19	0.30	0.53	8.1
Tome	0.28	0.30	0.08	7.9
Comfy Chair	1.14	1.75	1.28	5.5
Desk	2.00	0.94	1.07	6.1
End Table	0.98	1.09	0.67	5.3
Octopus	37.91	14.05	40.00	162.9
Coaster	132.83	50.01	92.95	200.1
Ferris Wheel	15.71	19.77	11.25	118.8
Ring Toss Booth	4.18	3.25	4.18	113.8
Hot Dog Cart	1.87	2.17	1.80	11.0
Popcorn Cart	1.16	1.75	0.63	73.7
Taz	0.59	0.69	0.37	66.9
Tweety Bird	0.40	0.95	0.44	67.4
Marvin Martian	0.56	0.91	0.39	66.6

Figure 2: The manipulated objects (not to scale).

Practice

The practice world initially contained only a ground plane. Within this world users completed five practice tasks. When the user started a practice task the system displayed the object to move, the target position (indicated by a translucent copy of the object), and any reference objects for that task. The practice tasks consisted of moving a chair in front of a desk, placing a television set on a desk, repositioning a toy on a table, moving a distant truck, and moving a distant biplane. All users completed the practice tasks in the same order.

Indoor World

The indoor world consisted of a living room. Users stood in the middle of the room, surrounded on all sides by the room's furnishings.

Furniture (medium: 1 - 2 meters in size)

For these tasks users manipulated medium-size objects where both the initial and final distances to the target object were within 10 meters. Users had to move three different pieces of furniture: a desk, a chair, and an end table.

Bookshelf (small: 0.2 - 0.5 meters in size)

For these tasks users manipulated small objects where the distance between the initial and final position was small. Users had to rearrange a book and two bookends on a nearby bookshelf.

Figure 3: A top-down view of the living room.

Outdoor World

The outdoor world consisted of an amusement park. Users stood in the middle of the park, surrounded on all sides by rides, food carts, and game booths. For all tasks the target position for an object was far away from its initial position.

Rides (large: 15 - 140 meters in size)

For these tasks users manipulated large, distant objects. Users had to move three rides: a roller coaster, a ferris wheel, and an octopus ride.

Booths & Carts (medium: 1.5 - 5 meters in size)

For these tasks users manipulated medium-size, distant objects. Users had to move a game booth and two food carts.

Prizes (small: 0.5 - 1 meters in size)

For these tasks users manipulated small, distant objects. Users had to move three prizes (stuffed animals) from one game booth to another.

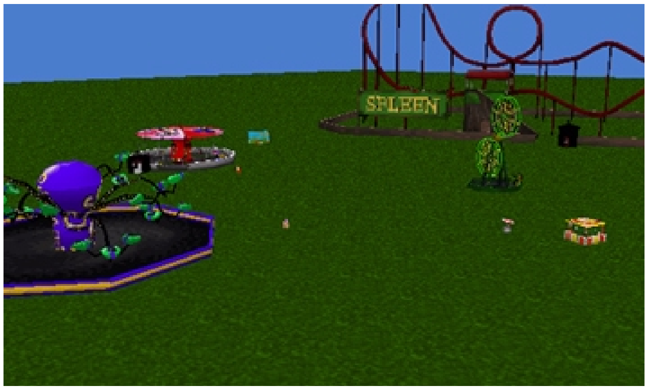

Figure 4: A bird's-eye-view of the amusement park.

Task Composition

Before the start of each task we presented the target object and target position, indicated by a translucent copy of the target object, to users. We verbally directed users until they visually located both the target object and the translucent copy in the world. Guiding users until they located both the target object and the copy allowed us to locate the object and copy so that they were not necessarily simultaneously visible. Once users had located both the target object and the copy for a task we told them to begin.

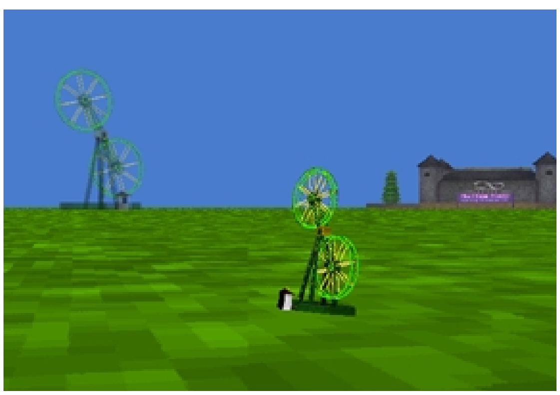

Figure 5: A Voodoo Dolls user holds a doll for the Ferris Wheel in his dominant hand, while in the background the translucent copy of the Ferris Wheel indicates the target position.

For each task users had to manipulate the target object to match the translucent copy's position and orientation as closely as possible. To avoid discriminating against the HOMER technique we did not allow users to *directly* create a doll for the translucent copy with the Voodoo Dolls technique. Users could create a doll for the target copy indirectly by creating a reference doll that contained the translucent copy in its context. Users completed each task by letting go of the manipulated object (or their dolls) and announcing "Done" when they were satisfied with the placement of the target object.

METHOD

Twelve undergraduate and graduate students, ten male and two female, participated in this experiment. All of the users had some experience with virtual reality. Half of the users used the Voodoo Dolls technique, while the other half used the HOMER technique. We chose a between-subjects design rather than a within-subjects design primarily to reduce the amount of time users had to spend in the head-mounted display (HMD). We balanced the world order (indoors and outdoors) and the task group order within a world between users, and randomized the task order within a task group for each user.

We demonstrated the relevant interaction technique for each user by performing two example placement tasks in the practice world. For the HOMER technique we demonstrated how to use ray-casting to select an object, how to position the object around its initial position, and how to reel an object in or out. For the Voodoo Dolls technique we demonstrated how to create a doll, how to grab a doll from the reference doll's context, and how to create a reference doll if there was no useful reference object near the target position.

Each user then completed all five practice tasks. We instructed users to focus on placing the objects as accurately as possible, and after each practice task we provided users with both numerical and visual feedback on their accuracy for that task. While we read off the distance error (in centimeters) and orientation error (in degrees), the system shrank the target object and the translucent copy, moved them in front of the user (maintaining their position and orientation relative to each other), and slowly rotated them over three seconds. The system then moved the target object to the copy over one second, rotated the target object to match the correct orientation over another second, and then scaled the target object and copy back up and returned them to their initial positions.

Before each experimental task group we explained in general terms what the tasks entailed and reminded the user to concentrate on accuracy. We did not provide any feedback during the experiment tasks. Between each task we reset the objects back to their original positions.

In order to protect users from prolonged exposure to the virtual environments, we allowed users to remove the HMD and take a short break between the practice and actual tasks, and between the indoor and outdoor worlds. These breaks meant that users were exposed to a virtual world for at most twenty minutes at a time. We also allowed users to take a break at any time if they started to feel dizzy or nauseous. One user did briefly feel dizzy, but recovered after a short break.

After completing all the task groups users completed a short questionnaire to determine what was easy and what was hard with the interaction technique they used, and whether they had experienced any discernible arm fatigue, dizziness, or nausea.

Apparatus

We implemented the virtual worlds in Alice 99 [4]. For the experiment we ran the worlds on a Pentium III PC. Users viewed the world in a Virtuality Visette Pro HMD (640 x 480 resolution, 60 degrees x 46.8 degrees field of view). Users did not view the world in stereo; this decision allowed us to double the frame rate, and should have handicapped Voodoo Dolls users more than HOMER users (because stereo predominantly affects the view of nearby objects). The input device users employed depended on the interaction technique: for the Voodoo Dolls technique users wore FakeSpace PinchGloves, while for the HOMER technique users held a three button joystick. The system tracked the HMD and input devices using an Ascension SpacePad. All of the worlds ran at a minimum of 30 frames per second.

Performance measures

For each interaction technique we measured the position error and the orientation error for each placement task. We defined the position error as the distance between the target object's insertion point and its copy's insertion point. To measure the orientation error we calculated the axis of rotation and the amount of rotation between the target and copy orientations, and used the amount of rotation as the orientation error. While this approach did not allow us to draw any conclusions about the direction of orientation error, it did allow us to compare the magnitude of the orientation error between tasks using a single value.

RESULTS

We conducted a multivariate repeated measures analysis of variance on the results with the interaction technique as the between-subjects variable and the five task groups as the within-subject variables. Overall Voodoo Dolls users manipulated objects more accurately than HOMER users for both distance ($F_{1, 10} = 17.953$, $p < 0.0025$) and orientation ($F_{1, 10} = 35.260$, $p < 0.001$). On average, across all the study tasks, Voodoo Dolls users positioned objects 88.28% more accurately (0.207 m off vs. 1.767 m off) and oriented objects 72.86% more accurately (5.149 degrees off vs. 18.968 degrees off).

For the task groups, the difference in accuracy for Voodoo Dolls and HOMER users was not statistically significant for either distance or orientation for the indoor, medium group. For the indoor, small group Voodoo Dolls users were significantly more accurate for both distance ($F_{1, 10} = 21.347$, $p < 0.001$) and orientation ($F_{1, 10} = 6.236$, $p < 0.05$). Voodoo Dolls users were also significantly more accurate at the small, outdoor tasks for both distance ($F_{1, 10} = 7.689$, $p < 0.025$) and orientation ($F_{1, 10} = 62.874$, $p < 0.001$). Similarly, for the large, outdoor tasks Voodoo Dolls users were significantly more accurate for both distance ($F_{1, 10} = 38.235$, $p < 0.001$) and orientation ($F_{1, 10} = 20.183$, $p < 0.001$). However, while Voodoo Dolls users were significantly more accurate at the medium, outdoor tasks for distance ($F_{1, 10} = 8.912$, $p < 0.025$), the difference in orientation accuracy was not statistically significant ($F_{1, 10} = 3.693$, $p = 0.084$). A likely explanation for this fact is that one of the tasks in this group involved placing a medium-sized object nearby, reducing the disparity in task performance between the techniques.

DISCUSSION

Our results demonstrate that Voodoo Dolls, a best-practice representation-based technique, allowed users to place objects more accurately than HOMER, a best-practice arm-extension technique. We believe that the primary explanation for the difference in performance is the additional feedback provided by the Voodoo Dolls technique, which allows users to view manipulated objects both up close and at a distance.

Overall the measurements of position and orientation error support this hypothesis. There was no significant difference in task performance when users manipulated large, nearby objects, but as the manipulated objects got smaller and the placement distances increased the disparity in task performance between the two techniques generally increased.

An exception to this trend, the fact that HOMER users were more accurate when positioning the small, outdoor objects than the medium, outdoor objects, might appear to contradict the importance of feedback, but in fact HOMER users had better feedback when positioning the small, outdoor objects than when positioning the medium, outdoor objects. Most HOMER users adopted a "silk cursor" [15] strategy when placing objects: they would move the object away until the translucent copy appeared in front of it, and would then pull the object closer until it once again appeared in front. When placing the small, outdoor objects users could use the booth they were placing the objects on for additional feedback: if the object disappeared behind the booth, it was too far away.

We did consider alternate explanations for the overall performance disparity. One alternate explanation is that the input device affected task performance. Because Voodoo Dolls users wore PinchGloves, while HOMER users held a joystick, the difference in performance could be due to differences with the input devices. However, if the input device caused the disparity then task performance should

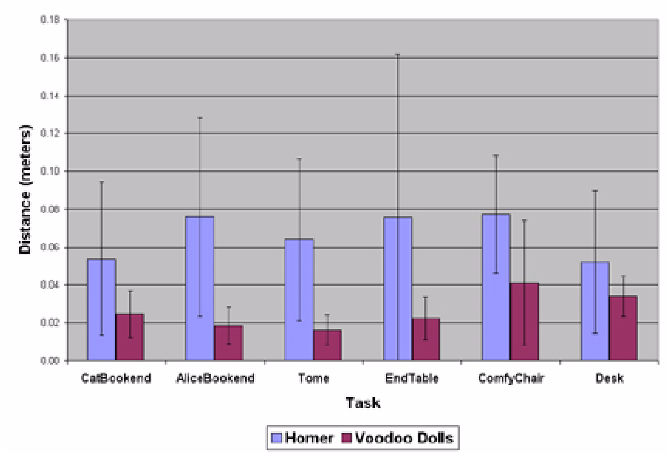

Figure 6: Mean distance error for the indoor placement tasks for the HOMER and Voodoo Dolls techniques.

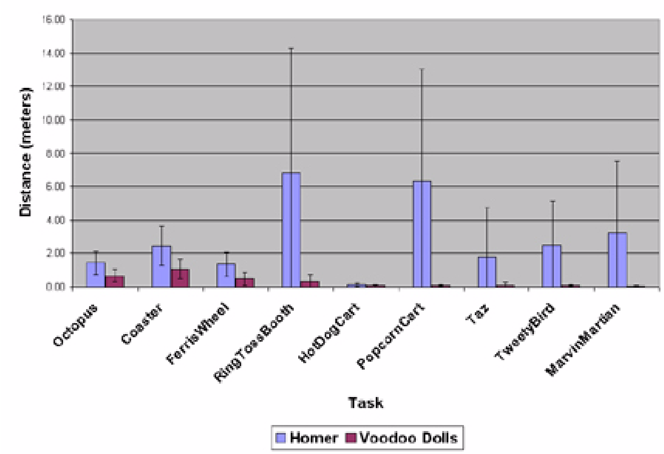

Figure 7: Mean distance error for the outdoor placement tasks for the HOMER and Voodoo Dolls techniques.

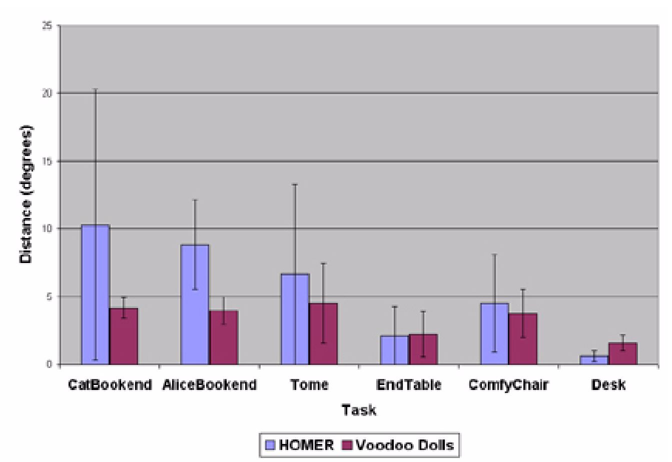

Figure 8: Mean orientation error for the indoor placement tasks for the HOMER and Voodoo Dolls techniques.

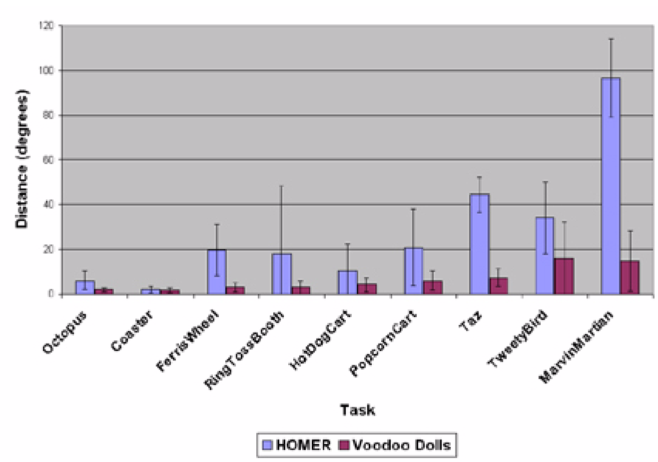

Figure 9: Mean orientation error for the outdoor placement tasks for the HOMER and Voodoo Dolls techniques.

have been significantly different for all tasks, including the indoor, medium tasks.

Another possible explanation is that HOMER users could never manipulate distant objects as accurately as Voodoo Dolls users, even with equivalent feedback. However, this explanation is unable to account for the disparity in orientation accuracy. The Voodoo Dolls and HOMER techniques theoretically allow users to orient objects with equal accuracy: both techniques allow users to rotate objects as if holding them. The disparity in orientation accuracy in practice, particularly the fact that the disparity increases as the manipulated objects shrink and the placement distances increase, suggests that the difference in available feedback is a more likely explanation.

User comments about the techniques also supported the importance of feedback. Five out of six HOMER users mentioned the lack of feedback as one of the "hardest three things" about using the technique. By contrast, four out of six Voodoo Dolls users mentioned feedback as one of the "easiest three things" about using the technique.

The other most frequently mentioned "hardest three things" about the HOMER technique were the difficulty selecting distant objects (five of six users) and the time required to reel objects in or out (five of six users). The most frequently mentioned "easiest three things" were selecting large, nearby objects (five of six users) and moving objects at a constant distance (three of six users).

TABLE 2: Mean Error and Standard Deviation for Each Task by Technique.

Task	Voodoo Dolls Distance Mean	Voodoo Dolls Distance Std. Dev.	Voodoo Dolls Angle Mean	Voodoo Dolls Angle Std. Dev.	HOMER Distance Mean	HOMER Distance Std. Dev.	HOMER Angle Mean	HOMER Angle Std. Dev.
Cat Bookend	0.0246	0.0120	4.1604	0.7744	0.0538	0.0403	10.3055	9.9930
Alice Bookend	0.0186	0.0098	3.9694	0.9863	0.0760	0.0522	8.8422	3.3211
Tome	0.0163	0.0081	4.5104	2.9429	0.0640	0.0427	6.6668	6.6630
Comfy Chair	0.0411	0.0330	3.7396	1.7566	0.0774	0.0308	4.4827	3.6254
Desk	0.0340	0.0107	1.5856	0.5599	0.0523	0.0379	0.5996	0.4042
End Table	0.0225	0.0113	2.2202	1.6703	0.0759	0.0859	2.1347	2.1404
Octopus	0.6754	0.3648	1.8159	.9702	1.4330	0.6801	6.0103	4.0924
Coaster	1.0651	0.5812	1.6411	0.8962	2.4680	1.1819	2.0171	1.2915
Ferris Wheel	0.5007	0.3929	2.9061	1.8558	1.3487	0.7232	19.6860	11.5075
Ring Toss Booth	0.3068	0.4397	2.8911	3.0885	6.8251	7.4705	17.8797	30.4267
Hot Dog Cart	0.0708	0.0594	4.1792	3.1740	0.1325	0.0856	10.1041	12.3076
Popcorn Cart	0.0883	0.0508	5.8473	4.3239	6.3132	6.6859	20.6822	17.1950
Taz	0.1031	0.1411	7.3054	4.1164	1.8094	2.9216	44.4524	7.6998
Tweety Bird	0.0818	0.0329	15.6626	16.5114	2.5188	2.6234	34.1950	16.0194
Marvin Martian	0.0562	0.0489	14.7943	13.5597	3.2571	4.2826	96.4613	17.4800

The most frequently mentioned "hardest three things" about the Voodoo Dolls technique were selecting the correct context for distant objects (four of six users) and rotating the context in the non-dominant hand (three of six users). The other most frequently mentioned "easiest three things" were fast, rough placement (four of six users), selecting objects in general (three of six users), and selecting small objects by retrieving them from the context (three of six users).

We also made a number of qualitative observations during the user study. While we had been concerned about the learnability of Voodoo Dolls, no users had any trouble learning either the HOMER or Voodoo Dolls techniques. Indeed, we had initially provided 15 practice tasks, but during an initial pilot study discovered that users learned the assigned technique after performing one or two placements. As a result, in the study reported here we reduced the number of practice tasks to 5.

The primary difficulty we observed with the Voodoo Dolls technique was that some users seemed to expect that looking very closely at one corner or side of a doll and manipulating it would make the opposite corner or side act as the doll's pivot. In other words, they wanted to make a minor adjustment to the visible corner or side without changing the doll's position at the other end. In practice this did not work; the point where the user grasps the doll acts as the pivot, so the user often completed a small adjustment only to discover that they had altered the placement on the other side. While these users were still able to make accurate placements, this observation does suggest a possible improvement to the Voodoo Dolls technique. If the user moves his head so that he can only see one corner or side of an object, the system could actually make the opposite side or corner act as the pivot. This would allow users to make incremental adjustments to a doll's position (alternating between sides) that could slowly converge to an exact placement.

Another difficulty we observed with the Voodoo Dolls technique is that on two occasions users temporarily got confused as to which of the objects in their view were the dolls, and which were the original objects. Simply waving their hands did not necessarily help, because the original manipulated object would usually move as well. Both times users were able to quickly overcome the problem by rotating their body so that only the hand-held dolls were in view and then rotating back. Presenting the worlds in stereo might eliminate this problem, or the system could make dolls visually distinct from the original objects (e.g. black and white, or less saturated colors).

We saw no evidence that the Voodoo Dolls technique caused more fatigue than the HOMER technique. While the Voodoo Dolls technique requires users to raise their arms when creating dolls, it also allows them to move their arms to a comfortable working area after creating dolls. The HOMER technique, by contrast, does allow users to select objects from a more comfortable position (assuming users do not need to sight down the ray to select an object), but may require that users work with their arms extended in front of them in order to correctly position an object. In the post-survey questionnaires, user self-reports of fatigue on a scale from 1 (no fatigue) to 4 (extreme fatigue) were actually slightly higher for the HOMER technique than for the Voodoo Dolls technique (means of 2.5 and 2.0 respectively). This result does not contradict Bowman's work [2], which suggests that image plane selection may cause more arm fatigue than ray-casting. Image plane selection may indeed cause more arm fatigue than ray-casting, but because users spent more time manipulating objects than selecting them the overall reports of arm fatigue were not affected.

TABLE 3: Responses to the Question "Did your arms get tired during the study?" by Technique

Choice	HOMER	Voodoo Dolls
Not at all	0	1
A little bit	3	4
Moderately	3	1
Extremely	0	0

CONCLUSION

In this paper we experimentally compared two techniques for manipulating objects at distance in immersive virtual environments. Our goal was to demonstrate the value of a best-practice representation-based technique, Voodoo Dolls, relative to a best-practice arm-extension technique, HOMER. The results of our experiment show that the Voodoo Dolls technique allows users to both position and orient objects more accurately than the HOMER technique. The results from our experiment also suggest that improving the feedback for 3D manipulation techniques may be a valuable direction for future research.

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