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Navigating Virtual Environments: Re-Directed Driving in a Motorized Wheelchair

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Abstract

Virtual realities are computer-simulated 3D environments that provide visual and auditory information, often used in conjunction with motion tracking to give feedback for physical motion. Virtual reality often requires exploration of virtual environments much larger than the physical space available. This problem could be solved with re-direction: a tool used to make one motion feel like another–for example, subtly rotating a virtual world to make a person walk in circles when they think they are walking straight. One might think that the less accurate the motion feels, the harder it is to naturally update position while navigating an environment; however, previous research has proven that the illusion of motion is more important than actually moving. The present experiments use a motorized wheelchair to isolate rotational movement and measure navigational efficiency. Our study is broken up into two experiments; the first is a box search task where participants explore a circular room with sixteen randomly oriented boxes, eight of which are hidden targets. They explore the room in four states: complete physical movement, half physical movement, rotational only movement, and no movement. Our second experiment places the participant in the center of the room, and tests their ability to point to learned objects in the room while rotating, sometimes physically and sometimes only in their imagination. Initial results suggest that inaccurate motion (physical motion that does not align with the visual display) is better than no motion at all.

1. Introduction

One of the biggest problems faced in the development of virtual reality is that when in a virtual environment (VE), people become noticeably worse at *automatic spatial updating*, the ability to update position while moving through space. This phenomenon has been researched heavily: see [8, 11, 13]. Ruddle and Lessels [12] suggested that real walking is necessary for automatic spatial updating within an environment, but it was later proven that full movement is not obligatory if there are at least physical rotations [7]. There has been research on other methods of locomotion besides walking [15, 16], and it has been shown that controlling a wheelchair, although not as natural as walking, is a satisfactory alternative when completing a box search task [5]. Bruder *et al.* suggested that by putting participants in a wheelchair instead of allowing them to walk freely, it becomes easier to redirect them without participants feeling it [2]. This can most likely be attributed to the less familiar vestibular and proprioceptive cues in locomotion methods other than walking, as well as lessened sensitivity.

Redirection is essential when the finite physical space is smaller than the potentially infinite virtual space, and a wheelchair allows not only effective distraction methods, but direct intervention through the joystick, as well [3]. Redirection techniques involving walking have been studied [4, 6, 14], but there is room for redirection development with other locomotive methods, such as the wheelchair. Using a wheelchair is also more cost efficient than a 360 degree treadmill or similar setups, therefore making it a more appropriate instrument for urban planning, gaming, training, or entertainment companies. Since previous research has proven that wheelchairs are a comparable locomotion method to walking, and that full movement is not completely necessary [7, 9], the present experiments aim to show roughly how much movement is needed in a motorized wheelchair to efficiently complete tasks and continuously and automatically spatial update.

The remainder of this paper is structured as follows. In Section 2 we describe the experiments that we created to study partial motion efficiency and re-directed driving in a wheelchair. Section 3 we display the initial results from our pilot testing. Section 4 concludes our paper and explains the significance of the results and what future research must be done.

2. Experiments

Two experiments have been set up to test re-directed driving in a motorized wheelchair. The first experiment has been pilot tested, but the second experiment has not.

2.1. Experiment One

The first experiment is a box search task, the same as was used in Nybakke *et al.* [5]. There were eight hidden boxes in a room of sixteen, and participants had to search until they found them all or revisited too many boxes in a row.

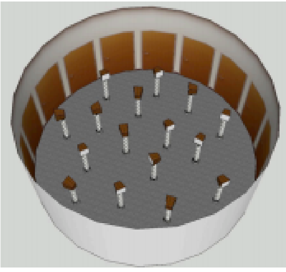

Figure 1: *The room from a birdseye view.*

2.1.1. Participants

This experiment was designed to run with sixteen participants using the Latin Square method to ensure that all important permutations of the conditions were investigated thoroughly. (Not all sixteen participants completed the experiment, due to a technical problem that caused increased cybersickness. The experiment will be rerun when the problem is fixed.) So far there have been eight males and five females. The ages ranged from 18 to 56 and the average was ~26.

2.1.2. Materials

The VE was rendered on a custom built PC with a dual-core 2.83GHz Intel Xeon processor and nVidia Quadro FX 5800 card. The head mounted display was connected by a 18' cord to a wheeled video control unit, which was in turn connected to a desktop computer by another set of cables spanning 16'. There was an audio track which played non-spatialized sounds through the HMD headphones in order to obscure external auditory cues that might contribute to spatial updating (as Riecke *et al.* has shown spatialized sound can affect spatial updating [10].) The VE was shown through a nVisor SX on two 1280x1024 images that had complete stereo overlap and a 60 degree diagonal field of view. Black cloth was placed over the HMD to prevent any unwanted peripheral distraction. Tracking was done through the HiBall 3100 system, which had three sensors, attached to the head mounted display, the hand-held wand, and the wheelchair.

The wheelchair used in all trials of this experiment was a Hoveround MVP5; it has a maximum speed of 5 miles/hour (restricted to 2 miles/hour using wheelchair arm controls) and a 22.7 inch turning radius (pivoting about the left or right wheel). The VE was modeled by previous researchers in SketchUp and rendered using OpenGL and G3D. The room was circular, with a diameter of 24' and 10' height, with walls that were textured with one of the actual lab doors repeating all around the room. The design was engineered to make participants comfortable with the environment by using familiar images, as well as to encourage 'presence' and, hopefully, natural search methods. The model contained 16 identical columns in a random orientation (determined by our program at the start of a trial) at least 1m apart from other pillars and within a 2.5m radius from the center of the room to discourage movement near walls. Each pillar had a box with five brown sides and one white side that was larger than the others. A virtual hand was modeled and appeared in the scene on top of the wand tracker. When this virtual hand intersected the white side of the box, the white would flash red (for target boxes) or blue (for decoy or previously visited target boxes).

For our experiments we also used a device created by Fiore *et al.*[3] to control the joystick to the wheelchair from the computer when needed. It permits us to both read and write to the wheelchair, most importantly allowing us to manipulate the wheelchair to move, for example, exactly half as fast. It uses an Arduino board.

Figure 2: *The joystick on the wheelchair in use.*

2.1.3. Methods

Each participant started the experiment by signing a consent form and completing a test to ensure they had stereo vision. They were then were given a sheet of instructions, an entrance survey, and had a researcher explain how to use each piece of equipment. Before they began the first condition, they filled out a baseline cybersickness questionnaire.

The experiment had four different types of trials.

1. Full Translation and Rotation (T): The participant uses a wheelchair to navigate a virtual environment, and the movement has a 1:1 correlation between visual and physical movement.

2. Rotation Only (R): The participant has full control of their rotation, but the wheelchair is restricted from moving in a translational manner. Visual rotation matches the physical rotation and translational movement occurs only in the virtual world, but is controlled by the wheelchair joystick.

3. Visual Only (V): The participant controls their visual movement with the wheelchair joystick, but there is no corresponding physical movement.

4. Partial Translation/Rotation (P): The participant uses the wheelchair to navigate the virtual environment and the movement has a 2:1 correlation from visual to physical movement.

The participants were told that the conditions involved one where they would be only physically rotating, a condition where there was no physical movement, and two that involved movement in both a translational and rotational direction. They were also given the order that the conditions would occur during the experiment.

The participants were asked to complete a box search task in each trial while seated in a wheelchair and holding a wand sensor. They were placed in a circular room filled with sixteen boxes; eight boxes were decoys and eight boxes were targets. They were instructed to use the wand in their hand to touch the white face of a box, which would then flash a color–red for targets and blue for decoys. After a target was found, it would become a decoy. The trial ended when the participant found all eight targets, or had revisited seven previously touched boxes in a row.

Figure 3: *A participant completing the experiment.*

Each participant completed three trials in each of the four conditions. In between each condition, there was a mandatory five minute break during which the participant had to complete a cybersickness questionnaire and was offered water and food. Participants were encouraged to remove the HMD if at any point they felt nausea or eyestrain. There was an emergency stop function that was used to halt a trial in the case of severe nausea or technical difficulties (the system used was prone to losing connection between the sensor and the tracking device). After the twelve trials were completed, the participant filled out an exit survey and cybersickness questionnaire, and were compensated for their time with a gift card.

Our goal for this experiment was to expand on the box search task from previous studies in an experiment that kept the manner of controlling movement (a joystick) consistent throughout all conditions in order to study how partial movement affects search efficiency. Our hypothesis was that since wheelchair movement is accepted as a mode of transportation, yet is not familiar to most people, that a reduction in physical movement in comparison to visual movement would not greatly affect search strategies, and could be a viable option for the practice of redirection.

Figure 4: *The room as seen by the participants. In the left of this image, they have found a 'hidden' red box. The number in the upper right hand corner indicates how many boxes are left to be found.*

2.2. Experiment Two

This experiment involves a participant sitting in a wheelchair centered in the room, surrounded by a ring of pillars. Each pillar has an object on it, and the participant is instructed to point at objects as they are rotated around the room.

2.2.1. Materials

The wheelchair and Arduino are the same as in experiment one. Instead of the HiBall tracking system, we use the Vicon Blade. The participants head and hand are tracked. The pillars are made of foam board, plywood squares, and hot glue. The objects placed on the pillar are an alarm clock, a soap dispenser, a rubik's cube, an empty milk carton, a framed photograph, a pikachu stuffed animal, a bowling pin, a beer bottle, and a stack of books.

2.2.2. Methods

The second experiment is a variation on a spatial updating study by Riecke *et al.* [9]. The participants are seated in a wheelchair and surrounded by nine pillars, each with a readily identifiable object. The participant is taught the order and orientation by being asked to point at the objects in rapid succession. When their accuracy reaches a certain level, the trials can begin.

There are five different cases: Control, Update, Ignore, Ignore Backmotion, and Imagine

1. Control: In this case, the participants are rotated to a new orientation, then back to the original one and asked to point to objects.

2. Update: In this condition, the participants are rotated and then asked to point from their new location.

3. Ignore: In the Ignore case, the participants are rotated

to a new orientation, and instructed to point as though they had not rotated.

4. Ignore Backmotion: Here the participants are rotated back from the Ignore position to the original and asked to point to a series of objects in order to reorient them for future conditions.

5. Imagine: Here the participants are asked to imagine that they have moved to a new location and asked to point to various objects from that point, despite no physical movement.

For each trial there are three phases. In the first phase the participant is told the type of case (Ignore, Ignore Backmotion, Update/Control, Imagine). In the second, they are moved to a new location. In the third, they are asked to point to a series of objects; this is done through an auditory instruction of the object to point to, followed by the pointing motion, and concluding with the pointing instrument (a Wiimote) being returned to a neutral location.

Our goal is to analyze spatial updating with partial motion, instead of full. It's been shown that it's difficult in the imagine case for a person to pretend they've moved when they haven't. Our hypothesis is that if we move the person even slightly it will help them to spatially update to the new location with much more ease, even if the movement is innacurate. Our study might also look at what happens if participants are given certain cues that are associated with movement, such as an audible mechanical noise from the motor engaging, that could encourage them to spatially update with significantly more ease than with no cue.

3. Results

Figures 5-8 are graphs of data averages from our initial tests over all participants. Participants had the greatest number of revisits with rotation only (~6.73) and visual only (~6.26), fewer with partial translation and rotation (~5.78) and fewest with full translation and rotation (4).

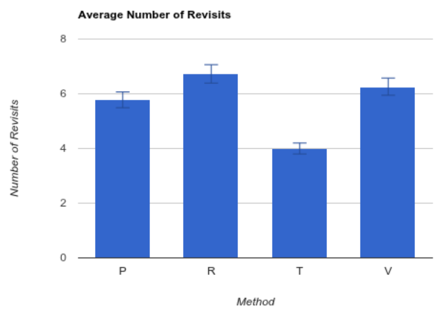

Figure 5: *The average number of revisits per trial from each of the four conditions.*

Partial translation and rotation had the quickest average completion time (143.98 seconds), while full translation and rotation had the slowest (194.03 seconds). However, both partial rotation and full translation had the highest percentage of successes versus failures, at 77.78% and 81.82% respectively, with visual only and rotation only scoring 73.91% and 59.09% respectively.

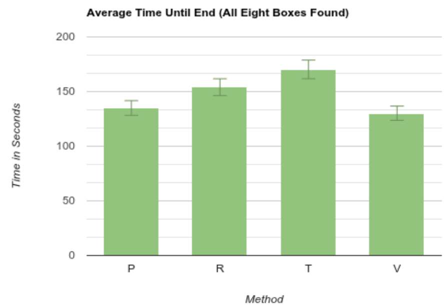

Figure 6: *The average time to complete a trial from each of the four conditions.*

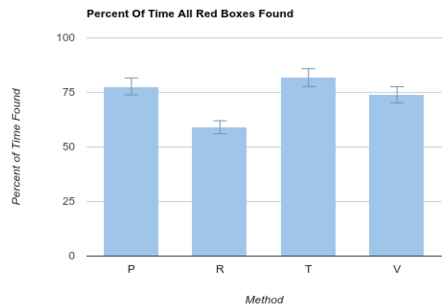

Figure 7: *The percent of time all 8 red boxes were found for each of the four conditions.*

Although there was a relatively large difference in performing for full translation and rotation from visual only, they scored equally well on the participant preference form (Fig 13). In the comments, some mentioned that they liked visual only because it felt similar to a video game. The fact that for some it feels more natural for a joystick to move the world around them but not their bodies could also explain the relatively quick speed of movement in visual only (Fig. 8).

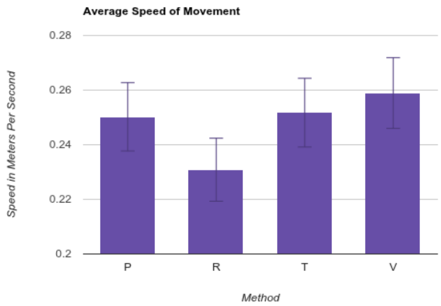

Figure 8: *The average speed of movement from each of the four conditions.*

Figures 9-12 show the participants' traversed paths for the best and worst cases for each method. These plots help to show inherent differences in search strategies from method to method. Figure 10 suggests that although visual only was a relatively popular method, that it was one of the least efficient. The visual only condition shows the only best case where a traversal path crossed itself, as well as the only best case situation where the participant passed through a box, which implies less of an understanding of the spatial layout; this was expected as visual only involved no vestibular motion cues. The other three cases each have similar search patterns, which reinforces the belief that vestibular motion cues contribute to spatial updating. However, it is interesting to note that when looking at the best and worst case data in context with the averages, partial rotation and translation scores second only to full translation and rotation, and it has quicker average completion times.

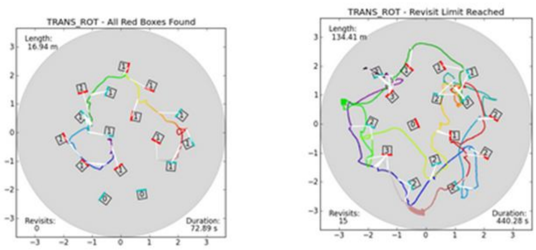

Figure 9: *Left: best case full translation and rotation {Length: 16.94m, Time: 72.89s, Revisits: 0}; Right: worst case full translation and rotation {Length: 134.41m, Time: 440.28s, Revisits: 15}*

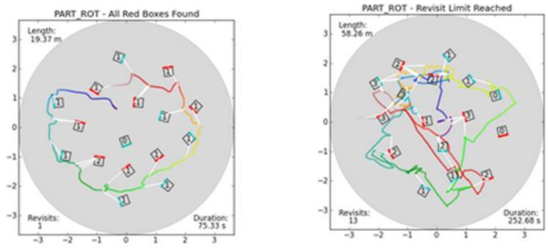

Figure 10: *Left: best case partial translation and rotation {Length: 19.37m, Time: 75.33s, Revisits: 1}; Right: worst case partial translation and rotation {Length: 58.26m, Time: 252.68s, Revisits: 13}*

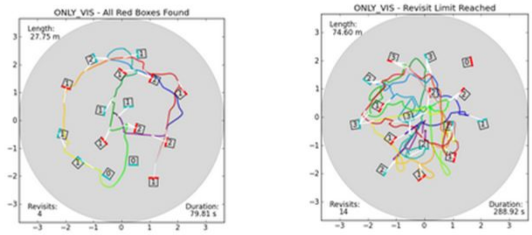

Figure 11: *Left: best case visual only {Length: 27.75m, Time: 79.81s, Revisits: 4}; Right: worst case visual only {Length: 74.60m, Time: 288.92s, Revisits: 14}*

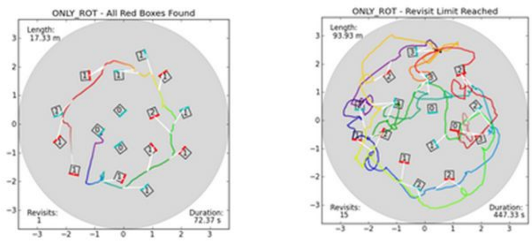

Figure 12: *Left: best case rotation only {Length: 17.33m, Time: 72.37s, Revisits: 1}; Right: worst case rotation only {Length: 134.41m, Time: 440.28s, Revisits: 15}*

Although this was intended to run as a full study, we were forced to stop after the first fourteen participants (not all of whom had full data collected) due to cybersickness reoccurrences from an inherent latency in our motion tracking equipment. If a participant ended a trial early or admitted they gave up because of cybersickness, we disregarded the data. We noted that the two cases we had of participants getting physically sick were during partial rotation and translation, and that this condition happened to be those participants final condition.

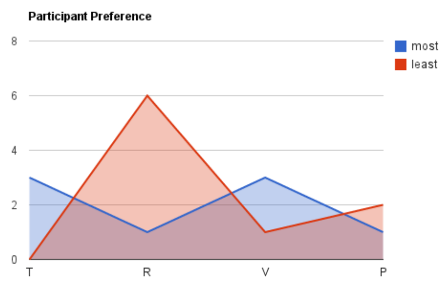

Figure 13: *The results of the participant preference form. Each participant chose a favorite and a least favorite method. R was the least favorite, and V and T were tied for best.*

So far, no results have been collected for experiment two.

4. Conclusion

The results of our intial testing provide tentative reassurance that innacurate or partial motion is better than no motion at all, but further testing must be done. It is impossible to know how much cybersickness affected our results, and the trends we see in the results are difficult to measure with such a small body of participants. Further testing will be important in order to determine whether the case, the order, and/or the latency was to blame for the cybersickness. If our conclusions hold, then there could be more experiments to measure exact thresholds of partial motion and find applications for the development.

Acknowledgments

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