NAVIGATIONAL CONTROL EFFECT ON REPRESENTING VIRTUAL ENVIRONMENTS

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This present study investigated how users' navigational devices and modes of operation affect their ability to develop an accurate mental spatial representation of a virtual environment. Three input devices varying in their degree of egocentric calibration control were used for navigation: joystick, wand and headtracker, all of which were used in relative or absolute control mode, thus yielding six navigational method conditions. Participants were tested both in a non-ego-centric manner and in an ego-centric manner, and our hypotheses were that absolute and more ego-centric control devices would generate higher quality spatial mental representations than relative and non-egocentric devices. Experiment results showed that navigation control methods produce different amounts of exploration, and indicated an advantage for absolute mode devices in comparison to relative mode, but there was no benefit for ego-centric devices.

INTRODUCTION

Having a limited size of field-of-view (FOV) increases the difficulty of spatial perception and of constructing an accurate mental representation (Arthur, 2000; McConkie & Rudmann, 1998). Normally, a human's binocular FOV spans about 200º horizontally, and 135º vertically (Werner, 1991); whereas a typical head-mounted display (HMD) virtual environment (VE) system provides only 40º to 60º horizontally and 30º to 50º vertically. This is like examining the world through a window, which we refer to as the viewport (McConkie, Zheng, & Schaeffer, 2001). Such a viewport is illustrated in Figure1, showing that only a portion of the whole environment can be seen at a particular moment. Some interaction or navigation method must be used in order to bring the different regions of the VE into the area of the viewport so that they can be seen. Forming a mental representation of the larger space requires the integration of information from different views.

Figure1. An example of a viewport relative to a larger environment.

Because many studies have shown that motor (e.g., vestibular) information is used together with sensory (e.g., visual) information to construct a mental spatial representation (e.g., Chritou & Bültoff, 1999; Simons & Wang, 1998), the manner in which people explore the virtual environment is likely to have an influence on this process. Several recent studies have employed different navigation devices or means of travel in VEs to investigate how they affect people's spatial learning and performance (Arthur, Hancock, & Chrysler, 1997; Singer, Allen, McDonald, & Gildea, 1997). The present study investigates how users' navigational devices and mode of operation, affect their ability to develop an accurate mental spatial representation of a VE.

Various input devices can be used for navigation control within VEs (MacKenzie, 1995), including the mouse, joystick, wand, head-tracking, data glove, treadmill, or body suit, many of which can also be implemented in different control modes. McConkie, Zheng & Schaeffer (2001) proposed four distinctions that are needed to examine the possible influence of navigation control methods on users' mental representations. The first distinction is between absolute and relative modes of control. In absolute control mode, there is a direct mapping between input device position and current viewport location in the VE, whereas, in relative control mode, the position of the input device simply indicates the direction and speed with which to move the viewport relative to the VE. The second distinction is between ego-centric and non-ego-centric calibration control. Our head movement is the natural example of ego-centric calibration control. With a head-tracking interaction method, the viewport goes to the position to which the head is directed. With non-egocentric control, such as a joystick, there is not a natural relationship between the control movement and the resulting location of the viewport relative to the observer. The third distinction is between space-constant versus space-consistent displays. With the space-consistent display, the VE remains fixed in its location and the viewport is moved to bring the desired region into view. For example, an absolute head-tracking method allows user to rotate their heads to look in desired directions, and to see the objects at their actual locations. With a space-constant display, the viewport itself is at a fixed position in space; navigation occurs by rotating the virtual world and bringing different regions of the space to be viewed to the location of viewport. The last distinction is between different degrees of experience that users have had with different methods and mode of navigation.

In a previous study (McConkie, Zheng, & Schaeffer, 2001), we designed virtual room environments in which users must look, via a HMD (viewport), around a large, 3D room from a single position in the center of the room, and must remember the locations of pictures located randomly on the walls. Three different input devices varying in their degree of egocentric calibration control were used for navigation: wand, joystick, head (head-tracking control); each was used in both relative and absolute control mode, thus yielding six navigation method conditions. Observers were tested both in a non-ego-centric manner (numbered picture frames replaced the pictures, and the observer had to indicate the number of the frames where specified pictures had been) and in an ego-centric manner (observers imagined themselves sitting in the middle of the room and pointed to the locations where specified pictures had been.

We had expected that both control method and mode would influence test results (which were taken as indicating the quality of the observer's mental representation). We predicted that: 1) a space-consistent control method (absolute head control) would produce a more accurate mental spatial representation than space-constant methods (absolute wand or absolute joystick control); 2) an ego-centric control method would produce more accurate representations than non-egocentric; 3) an absolute control method would produce more accurate representations than relative methods; and 4) the mode (relative vs. absolute) in which participants had the most experience in using a given device would produce more accurate mental representations.

To our surprise, we found only an advantage for absolute over relative control. There was no significant difference between absolute head, wand and joystick nor a significant interaction. One possible reason for this result could be that control device was a within-subject variable; participants used all three devices in navigation and this may cause them to fail to focus on, and make use of, the unique properties of each type of control. So in the current study, the device was designated as a between subject variable. A recent study (Werner, Saade & Lüer, 1998) showed the nature of the task can also influence people's construction of mental representations. We also made some adjustment to the tasks that were used to test the accuracy of people's spatial representations.

METHOD

Participants

Thirty-six students (21males and 15 females) from the University of Illinois at Urbana-Champaign were paid to participate in the study (mean age: 20.89; range 17-39).

Apparatus

A Virtual Research Corporation VR4 3D HMD VE system was used this study (see McConkie, Zheng & Schaeffer, 2001 for more details), which featured 247x230 pixel resolution in each lens, producing a FOV (viewport) 48º horizontally and 36º vertically. Three control devices were interfaced with the system: a joystick, a wand (a hand-held magnetically tracked pointing device), and a magnetic head-tracker. Each device could be used in absolute mode (i.e., the position of the input device maps directly to a viewport position), or relative mode (i.e., the input device position only indicates the direction of movement of the viewport).

Six virtual rooms were constructed as the testing environments for the experiment, with two rooms having four walls, two having six walls and two having eight walls. All walls in a given room were of equal width, and formed equal angels with adjacent walls. In each room, ten pictures of common objects, such as a car, hammer, etc., hung on the walls at random locations within participants' viewable range. By using a navigation control method, a person was able to move the viewport up to 90º left or right of the initial position, giving a total 180º of horizontal movement but the opportunity to view about 220º as viewed from the center of the room. The viewport could also be moved up to 45º up or down, thus giving 90º of vertical movement and the opportunity to view about 120º. The participant could only see a portion of the whole room in the viewport at a given moment.

Design

A 2 (mode) x 3 (device) randomized design was used. Six participants were randomly assigned to each of the six combinations of the mode (absolute vs. relative) and the device (joystick, wand, or head) navigation method group. Each participant was tested using the non-ego-centric method (indicate the number of the frame that contained the pictured object) after viewing each of the first four rooms; an ego-centric task (point to the location where the indicated picture hung) was used after the last two rooms. Confidence ratings on a five-point scale were also obtained.

Procedure

A paper-and-pencil test was used to measure participants' spatial memory ability. Two matrices, one 3 by 4 and the other 4 by 4, containing 12 and 16 different simple geometric shapes (e.g., square, circle, triangle) were used. Each participant was given 30 seconds to study each matrix, and then tried to reproduce it in an empty matrix, receiving a score indicating the number of correct matches.

Participants then sat on a fixed chair and explored each room for 60 seconds using their assigned input device and mode, and then were tested in the manner indicated above. The ego-centric (pointing) task used a magnetic wand as a pointing device. It is important to note that the non-ego-centric test could be carried out without relating the locations of pictures to the observers' own location, whereas the ego-centric test required the use of this type of relationship. We had anticipated that the observers would spontaneously form an ego-centric representation with the head-tracking and wand device in absolute mode, but not necessarily with the joystick or in relative mode.

Dependent variables were the number of picture locations accurately indicated in the non-ego-centric test, and the size of the deviation from the center of the indicated picture to the pointed location in the ego-centric test, as well as a confidence rating for each such test. We also examined the total distance traveled in scanning the rooms with each of the device/mode combinations.

RESUTLS

The participants were randomly assigned to one of the six navigation method groups. However, an ANOVA test showed a near-significant difference between different groups on their pretest spatial memory scores, $F(5, 30) = 2.47$, $p = .054$. In order to eliminate the influence caused by individual's spatial memory ability, the pretest scores were used as a covariate in the following data analysis.

Navigation Analysis

Figure 2 shows the mean traveling distance of the viewport under different navigation method conditions. A 2(mode) x 3(device) ANCOVA analysis showed no mode effect on the total traveling distance of viewport, $F(1, 28) = 0.27$, $p = .607$, but a significant device effect, $F(2, 28) = 9.365$, $p < .001$, and a significant interaction effect, $F(2, 28) = 4.41$, $p < .022$. A simple effect analysis of the interaction showed that with the joystick device, the viewport traveling distance was significantly longer in absolute than relative mode ($p < .02$). The head tracking device appeared to reverse this, with the traveling distance being longer in the relative mode than the absolute mode, though this was not significant ($p<.098$). There was no difference between absolute and relative wand conditions ($p >.946$).

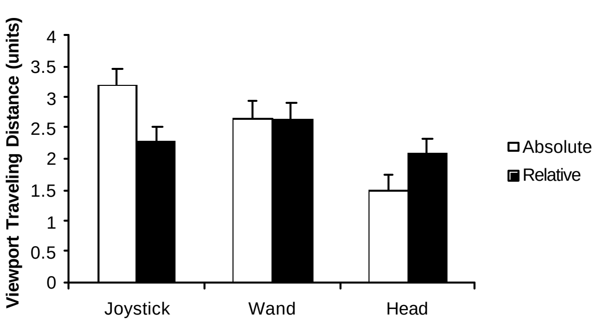

Figure 2. Mean total viewport traveling distance (+SE) of different modes and different control devices, which indicates amount of movement of the viewport relative to the viewed room. The width of a virtual room (220º) is defined as one "unit".

The Non-egocentric (Search) Task

The average searching accuracy for different navigation methods is shown in Figure 3. ANCOVA test found a significant effect for different mode conditions, $F(1, 29) = 7.777$, $p < .001$; participants were 10.7% more accurate in absolute mode than in relative mode. However, neither the device effect, $F(2, 29) = .022$, $p = .978$, nor the interaction effect, $F(2, 29) = 1.068$, $p = .357$, was significant. For the confidence rating in the search task, there was no mode ($F(1, 29) = .034$, $p = .855$), device ($F(2, 29) = .375$, $p = .691$), nor interaction effect ($F(2, 29) = .726$, $p = .493$).

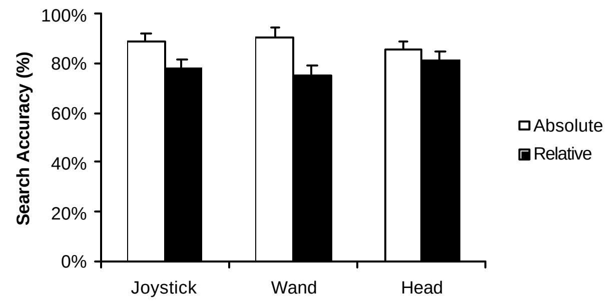

Figure 3. Mean accuracy (+SE) as a function of different modes and different control devices in the search task.

The Ego-centric (Pointing) Task

Figure 4 shows the mean pointing deviation under different navigation conditions. The statistical test showed no mode effect ($F(1, 29) = .102$, $p = .751$), no device effect ($F(2, 29) = .693$, $p = .509$), and no interaction effect ($F(2, 29) = 1.785$, $p = .187$). The analysis on the confidence rating of the pointing task showed a significant mode effect, $F(1, 29) = 9.488$, $p < .004$; participants were more confident in relative mode than absolute mode. There was no device effect, $F(2, 29) = .341$, $p = .714$, or interaction effect, $F(2, 29) = .862$, $p = .433$, for the confidence rating level.

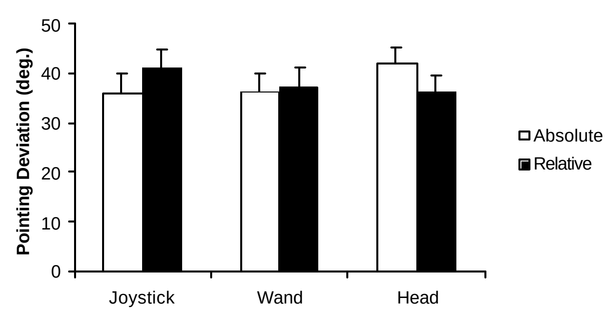

Figure 4. Mean pointing deviation (+SE) as a function of different modes and different control devices in the pointing task.

DISCUSSION

The above results indicate that navigation control devices produce different amounts of exploration (distance traveled) as observers seek to explore, perceive and represent the locations of objects in a VE. Absolute-mode devices make it easiest to make large changes in the viewport position; abrupt device movements make abrupt location changes. Given this, it might be expected that absolute mode devices would produce greater total movement than the slower-moving relative mode devices. While that difference was observed for the joystick, it was not for the other devices; in fact, the absolute mode head control produced less movement than did the relative mode.

The distance traveled, however, did not appear to produce a direct effect on the memory representations developed by people in the different groups. While viewport movement is obviously necessary in order to explore the VE space, conditions that encourage greater exploration apparently do not necessarily lead to a better representation of that space.

The most noteworthy result of navigation device and mode on test performance in this study is the general lack of effect. The perspective from which our predictions were generated seemed to be a reasonable one. We expected that a device (head tracker) that causes objects to be seen at their actual locations (absolute mode) would provide a basis for developing a more accurate mental representation of the space, than would devices in which the viewport remains at the same location with the space being passed behind it, thus requiring a mental spatial transformation. This should particularly be true, we thought, for performance on the ego-centric (pointing) test, which requires an ego-centric representation of the space. However, what we observed, both in this study and our last, is a lack of difference among conditions (with one exception). Even subjects who are exploring the VE space using a bizarre control condition in which they move their head or their wand, not to indicate what part of the VE they want to see, but to cause the VE to rotate behind a fixed viewport (relative mode) at a particular direction and speed, are able to form representations that produce test performance nearly equal to that from the more natural absolute headtracking condition. While the absolute mode did produce better performance on the non-ego-centric (search) test than did the relative mode, there was no interaction suggesting less difference for the joystick, where people have often had experience with both modes, than with head tracking, where this was undoubtedly the participants' first experience with relative mode tracking. Thus, it appears that experience with the device, and cognitive compatibility between the perceived and actual locations of objects (within the limits employed here) have little effect on people's ability to develop mental representations of VE spaces.

It was expected that participants who had used the absolute headtracking device in inspecting the first four rooms would develop a set to form ego-centric representations, which should be facilitated by this condition, and would then excel in the pointing task. However, their pointing deviations were actually somewhat larger in this than in the other conditions, though the difference was not large enough to be statistically significant.

This lack of effect is clearly not the result of people simply failing to form representations. In fact, they were able to properly locate about 80% of the pictures, and their mean pointing deviations were in the 35 deg range, indicating quite successful representations.

This pattern of results suggests that people are very effective in using restricted information of various types, whether from a viewport moving over a stable room or a room moving behind a viewport, to form a mental representation of the space, indicating the locations of objects in that space. Furthermore, this representation is either developed in an ego-centric framework, or has the properties necessary to make it possible for people to mentally place themselves within it and thereby interpret it in an ego-centric manner. People's ability to keep track of what they are seeing, and how it relates to the rest of the space, is sufficient to overcome factors that would seem to present obstacles to forming an accurate representation.

There is some advantage to devices operating in absolute mode, as compared to relative. In absolute mode, there is a direct relationship between the position of the device, together with the position of the head or hand that is directing the device, and the position of the viewport. This gives further evidence for the role of kinesthetic and vestibular information in facilitating spatial memory (Chritou & Bültoff, 1999; Simons & Wang, 1998).

It is important to note the limitation of the present study: the participants were viewing a room-sized space as viewed from a position at the center of the room. It is possible that in large VEs where people must virtually move around to explore the space, the effect of different navigation control devices could be greater. Within this limitation, the present results suggest that the choice of navigational device to use in a VE may be less important than might initially appear.

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