Can people learn about elevation following navigation through a virtual building?

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Abstract

This study examined people's spatial knowledge of elevation following exploration of a multistorey virtual environment. Fifty-four University students explored a virtual house consisting of three floors that were connected by a lift and two staircases. Each floor contained two distinctive objects, which served as targets in a subsequent pointing task. When pointing to the targets (which were hidden from view), the accuracy of the tilt (up/down) responses was significantly better than chance level. Estimates towards targets above and below were made with equal accuracy.

Keywords

Virtual Reality, spatial memory, elevation

INTRODUCTION

Virtual environments (VEs) provide an inexpensive and safe training medium (Bliss, Tidwell, & Guest, 1997). A number of studies have demonstrated the usefulness of virtual simulations. For example, Waller (2000) found that measures of spatial knowledge in a VE were predictive of subsequent performance in a similar real environment. Good transfer of knowledge from virtual to real space has been observed with people benefiting from virtual learning experiences prior to encountering the equivalent real-world environment (Foreman, Stirk, Pohl, Mandelkow, Lehnung, Herzog, & Leplow, 2000).

There are important questions to be answered as to our ability to acquire spatial knowledge from VEs. The present study examines whether people can learn about elevation following exploration of a VE. This is a critical question because an understanding of elevation is relevant in many contexts (e.g. aviation, submarine operation, mountaineering). Few empirical studies have investigated this issue. For example, Wilson, Foreman, and Tlauka (1997) asked people to explore either a (multistorey) real building or a to-scale computer-simulation of the same building. Participants' spatial knowledge of the building was then tested in two types of pointing task. One task tested horizontal (left/right) estimates while the other tested vertical (tilt) judgements. The main finding of interest in the present context was that the horizontal estimates were significantly better than chance (when compared with a control group that had not explored the building), while the tilt (up/down) did not differ significantly from chance. In a study by Witmer, Bailey, Knerr, and Parsons (1996), participants learned a complex route through a building consisting of three floors. Like the Wilson et al. (1997) study, there was no evidence of configurational knowledge when participants took part in direction and distance estimation tasks (see also Richardson, Montello, & Hegarty, 1999).

Few theories of spatial cognition have considered the vertical aspect of space. Research into the mental representation of narratives (verbal descriptions of spaces) has revealed an asymmetry of judgements involving the three body axes (Bryant, Tversky, & Franklin, 1992). For the upright observer, it has been shown that head/feet estimates (when the target is above or below the observer) are faster than front/back estimates which, in turn, are faster than left/right estimates. The head/feet axis is the most physically salient because it is associated with gravity. The front/back axis is salient (but to a lesser degree) in that the perceptual system is tuned to perceive objects in front of rather than behind the observer. The left/right axis does not possess such asymmetries and is the least salient axis. Note that one of the primary differences between navigation in virtual and real spaces is that the former lack gravity. It is possible that the absence of gravity in VEs affects learning.

The picture that emerges from earlier studies indicates that virtual navigation leads to good horizontal judgments. However, people's ability to make vertical (tilt) estimates appears to be less developed. In the present investigation, University students explored a virtual house consisting of three floors that were connected by a lift and two flights of stairs (see Figure 1). As the students explored the simulated house, they encountered several objects. The objects served as targets in subsequent pointing tasks, which assessed their ability to make vertical judgements. By comparing their estimates with chance performance, we were able to examine whether the students were capable of learning about elevation following virtual navigation through the simulation.

METHOD

Participants. Fifty-four University students (27 females and 27 males) took part in the study. Their mean age was 22 years (range: 18 to 44 years).

Apparatus. The VE was created using the Sense8 WorldUp virtual reality toolkit. The simulation was displayed on a 19-inch monitor, which was run by a Pentium PC. Two VEs were created. First, a practice environment (consisting of a simple space that contained a platform, a lift, a staircase, and several objects) allowed participants to learn how to effect movements through a virtual space (see procedure). Second, the virtual house consisted of three floors (floors 1 to 3). Each floor contained two distinctive objects (e.g. a dartboard, a cup) that were located on stands halfway between floor and ceiling). The floors were connected via a lift, which could be activated by pressing keyboard buttons. For example, pressing '1' on a standard keyboard moved the lift to floor 1. Two flights of stairs (floors 1 and 2) allowed participants to 'walk' up/down the stairs in order to move between the floors. A flight of stairs was also included on floor 3 in order to make floor 3 similar in appearance to floors 1 and 2. However, participants were unable to use this staircase.

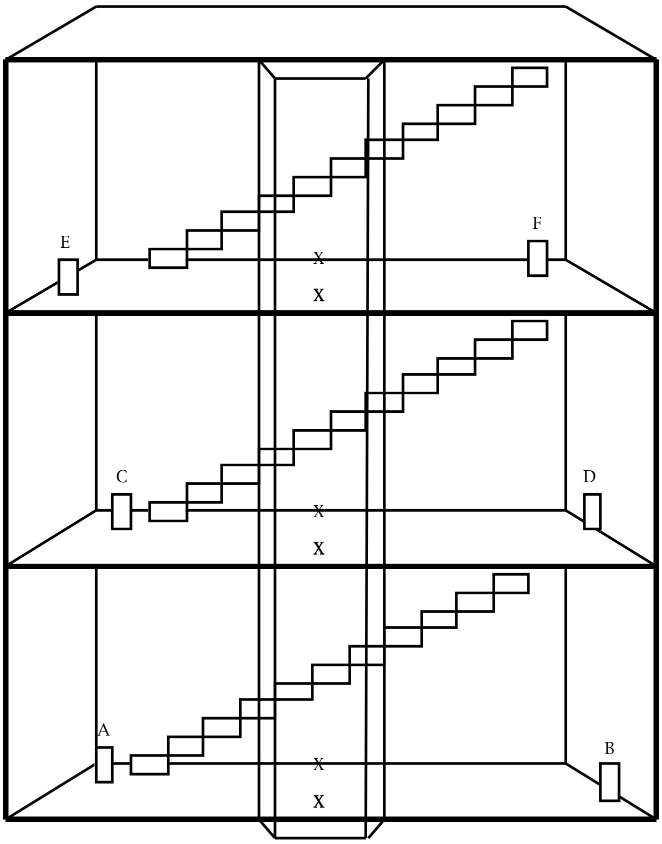

Figure 1: Illustration of the multistorey virtual house, showing example positions of the six target objects (A-F), the test locations used in the pointing task (marked with crosses), the staircases and the lift shaft.

Procedure. Navigation through the VE was effected by the arrow keys on the keyboard. The 'up' arrow moved the viewpoint forward, the 'down' arrow moved the viewpoint backward, and the left and right arrows resulted in left and right rotations, respectively. The 'A" and 'Z' keys allowed the viewpoint to be tilted upwards and downwards, respectively. Participants practised using the keys in the practice environment for approximately 2 minutes.

In the exploration phase of the experiment, the students navigated through the virtual house. Exploration began on the middle floor (floor 2). The participants were encouraged to visit each floor at least twice. Particular emphasis was placed upon the six target objects. It was stressed that participants needed to familiarize themselves with the exact position of each target.

Following exploration (which, on average, lasted 7 minutes), the test phase began. Participants completed a pointing task in which they indicated the direction of the six target objects from two locations on each floor (Figure 1). The order of pointing estimates to the targets from the different floors was counterbalanced across participants. For the purpose of the pointing task, the target objects were made invisible. Pointing was effected by moving a crosshair in the centre of the computer screen in the appropriate direction by pressing the ‘A’, ‘Z’, left/right arrow keys (see apparatus section). Pointing judgements were made to objects that were one floor up (e.g. a judgement made from floor 1 to a target object located on floor 2), two floors up (from floor 1 to floor 3), one floor down (e.g. from floor 3 to floor 2), two floors down (from floor 3 to floor 1), and judgements on the same floor.

RESULTS

The accuracy of participants’ directional tilt estimates to the targets was computed by subtracting estimated angles from actual angles. The mean absolute error scores derived from the estimates were used as data in the analyses. In order to compare the estimates against chance, one sample t-tests were employed. Note that as the range of possible tilt scores was 90 degrees (the range of possible scores resulting from pointing straight down towards the observer’s feet to pointing straight up towards the observer’s head), chance performance of absolute errors was half this range, i.e. 45 degrees. Accordingly, a test value of 45 degrees was used in the one-sample t-tests.

As shown in Figure 2, the mean absolute pointing errors ranged between 3 and 15 degrees. These scores were found to be significantly lower than the chance value of 45 degrees (p's $< .001$) providing evidence of significant learning of the vertical dimension of the VE. A comparison of up versus down estimates revealed no significant differences (ps $> .05$).

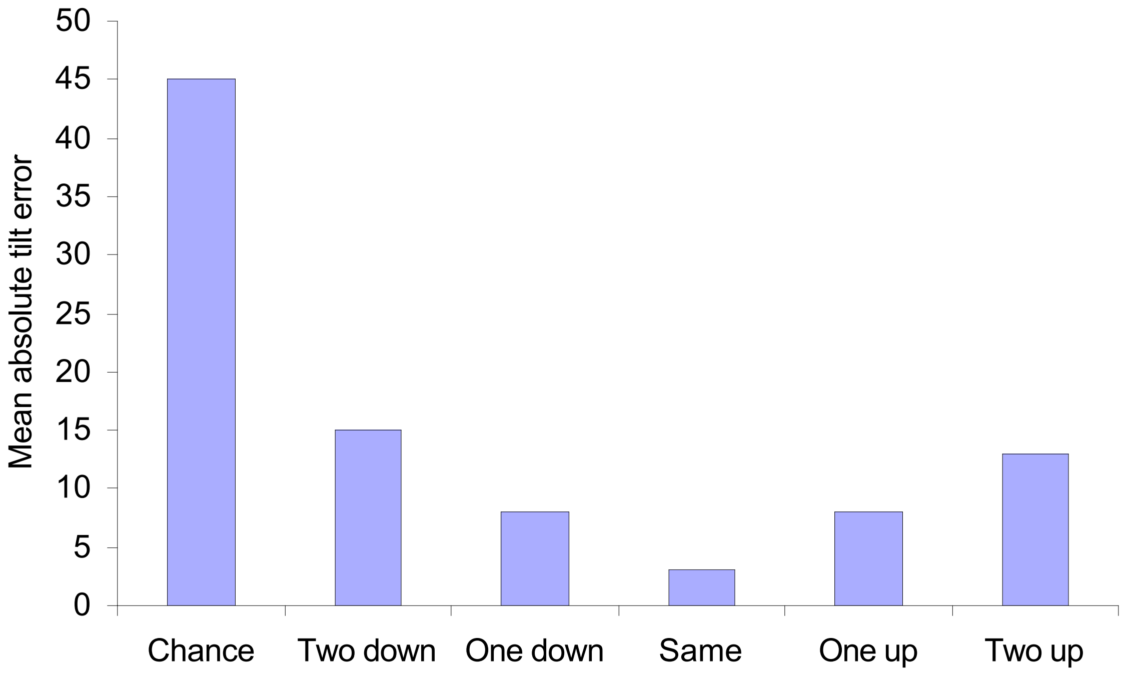

Figure 2: The mean absolute tilt errors for judgments two floors down, one floor down, same floor, one floor up, and two floors up. Chance performance is also shown.

DISCUSSION

The present results indicate that participants were able to learn about elevation following virtual navigation through a computer-simulated environment. This is an important finding for two reasons. First, VEs provide an inexpensive and safe training medium. The world we live in is three-dimensional, and our ability to acquire spatial knowledge of elevation through simulated navigation is relevant for those researchers that employ VEs as a simulation tool. Second, previous investigations of virtual navigation (e.g. Wilson et al., 1997) found evidence of learning of the horizontal dimension of space (left/right judgements), but failed to find evidence of significant learning of elevation.

Wilson et al. (1997) argue that one possibility for the absence of vertical learning in their study was the construction of the stairs connecting the different levels of their computer-simulated building. Some of the staircases were bland resulting in a lack of available visual cues. This may have contributed to poor orientation performance. In the present study, the stairs and the walls were texture-mapped providing sufficient detail thereby avoiding disorientation. Further, the participants also used a lift, which enabled them to move between the three floors of the virtual house. As all participants used both the stairs and the lift, this may have aided the integration of spatial information from the three floors. At present, it is unclear which types of stimuli and types of movement between floors enhance the encoding of elevation in VEs. Additional experimental work is required to determine the relevant factors.

Figure 2 shows that up and down judgements were equally accurate (see also Results section). There are some suggestions in the literature that down estimates are better than up estimates when learning is based on virtual navigation (Wilson et al., 2004). Bryant et al. (1992, Experiment 1) found that after reading a description of a three-dimensional array of objects, participants were faster when they responded to objects that were located below rather than above a referent object. Our results are inconsistent with these earlier findings suggesting that either potential differences between up and down judgements are unreliable or mediated by factors that as yet are not fully understood.

In conclusion, when navigating through a virtual house consisting of three floors, University students were able to learn about elevation in the simulated building. In a pointing task in which they made pointing judgements to target objects that were located on different floors, the students' performance was significantly better than expected on the basis of chance alone. It appears that although gravity is absent in virtual simulations, participants can learn about the important vertical aspect of space. The results further indicate the usefulness of VEs as a training medium.

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