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Publisher's version / Version de l'éditeur:
https://doi.org/10.1016/j.chb.2011.06.014
Computers in Human Behavior, 27, 6, pp. 2186-2191, 2011-07-19


Volume 27, Issue 6, November 2011
ISSN 0747-5632
ELSEVIER
COMPUTERS IN
HUMAN BEHAVIOR
Robert D. Tennyson, Editor
Paul Kirschner, Associate Editor
Jen-Her Wu, Associate Editor

Computers in Human Behavior 27 (2011) 2186–2191

Contents lists available at ScienceDirect

Computers in Human Behavior

journal homepage: www.elsevier.com/locate/comphumbeh

A comparative study of four input devices for desktop virtual walkthroughs

J.-F. Lapointe *, P. Savard, N.G. Vinson

Institute for Information Technology, National Research Council of Canada, 1200 Montreal Road, Building, M-50, Ottawa, Ontario, Canada K1A 0R6

ARTICLE INFO

Article history:
Available online 19 July 2011

Keywords:
Virtual walkthroughs
Input devices
Desktop virtual environments
Control devices
Navigation
Travel

ABSTRACT

This paper presents the results of an experiment measuring the effect of four different input devices on overall task performance for desktop virtual walkthroughs. The input devices tested are: a keyboard, a mouse, a joystick and a gamepad. The results indicate that the participants completed the tasks in significantly less time and distance travelled with the mouse than with the three other input devices. The use of the mouse also significantly reduced the number of collisions, while the use of the gamepad resulted in significantly more collisions.

1. Introduction

Virtual walkthrough is a common travel metaphor used for viewpoint control in virtual environments (VEs) (Brooks, 1986; Usoh et al., 1999). Today, a large proportion of users perform walkthroughs on desktop VEs (i.e. displayed using a monitor) as opposed to immersive displays (e.g. HMDs, CAVEs) (Ruddle, Payne, & Jones, 1997; Santos et al., 2009). Virtual walkthroughs can be divided into a set of cognitive tasks and a set of physical tasks that a person performs to get from one location to another (Bowman, Kruijff, LaViola, & Poupyrev, 2005; Sebok, Nystad, & Helgar, 2004). While many studies have investigated the cognitive aspects (orientation and wayfinding) of walkthroughs (e.g. Ruddle, 1999; Ruddle, Payne, & Jones, 1998; Ruddle et al., 1997) we are focusing on travelling itself, which is the physical tasks that allow a navigator to move from one location to another by using the input devices (a.k.a. control devices) of the user interface (Bowman et al., 2005; Sebok et al., 2004). The input device design space for virtual walkthroughs is quite large given the possible combinations of commands that can be issued from a number of input devices. However, very little of this design space has been investigated empirically. As with other user interfaces, empirical evaluation of possible interaction techniques is important to improve our understanding and to develop theoretical models and to assist designers in building more usable systems (Fröhlich, Hochstrate, Kulik, & Huckauf, 2006; Lampton et al., 1994; Lindeman, 2006; Newell & Card, 1985).

In virtual walkthroughs, the number of Degrees Of Freedom (hereafter "DOF") of movement varies between 2 and 4, out of a potential 6. Three of the six DOFs involve translation: forward/back, left/right, and up/down (which is typically not needed in virtual walkthroughs). The other three DOFs involve rotation: rotation around the axis perpendicular to the travel plane (yaw axis), and rotation around each of the axes forming the travel plane (pitch and roll axes), though the last one is not typically needed in virtual walkthroughs. Each DOF can potentially be controlled by a different input device and a different input command from that device. Moreover, several travel techniques are possible by using one or two-hands.

To date, the research shows that, in the case of 3D interface, there is still not an input device that demonstrates its superiority for accomplishing basic 3D tasks such as navigation, manipulation and selection. This contrasts with the case of the 2D graphical interface where the computer mouse established itself as the de facto standard input device (Zhai, 1998).

In the case of maze travelling tasks, research indicates that bimanual travel control is quite feasible and even outperforms the status quo mouse-mapping interface (Zhai, Kandogan, Smith, & Selker, 1999). Also, two studies did not find significant differences in performance when travelling with a user interface using two or three DOFs, when the third DOF is a strafe movement (i.e. a side translation of the viewpoint) (Lapointe & Savard, 2009; Lapointe & Vinson, 2002). Finally, another study suggests that the use of either velocity or position control techniques for viewpoint orientation does not have a large effect on travel performance (Lapointe & Savard, 2007).

For desktop walkthroughs, commonly found control interfaces in video games use a keyboard and mouse combination for PC games and two joysticks (on a gamepad) for console games. The use of these specific combinations appears to be driven by availability of the input devices and is not backed by published scientific analysis of the performance or usability of these interfaces.

* Corresponding author.
E-mail addresses: jean-francois.lapointe@nrc-cnrc.gc.ca (J.-F. Lapointe), pascal.savard@nrc-cnrc.gc.ca (P. Savard), norm.vinson@nrc-cnrc.gc.ca (N.G. Vinson).

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doi:10.1016/j.chb.2011.06.014

To place the design and use of walkthrough interfaces on a more empirical footing, and to contribute to the exploration of the design space, we conducted an experiment in which we compared the user's performance and preference when using four different input devices, using either two or three DOF to travel in desktop virtual walkthroughs. We employed four input devices that are commonly used for desktop virtual walkthroughs: a keyboard, a mouse, a joystick and a gamepad.

Hence, this paper describes the results of an experiment that aims to characterize the usability benefits of those control devices for doing desktop virtual walkthroughs.

2. Method

To evaluate the different travel techniques, we used a maze-like virtual world made of a complex trail offering an open view, so that users could always look around and/or keep an eye on the end point of the maze while they travelled (Fig. 1). This open-view maze offered more incentives to use all the available DOF than a traditional maze environment. A traditional maze has high walls in which only views along the center line of a corridor offer interesting visual cues to spatially orient the users.

2.1. Participants

Of the 34 participants who began the experiment, eight were unable to complete it due to cybersickness, and two were outliers, exceeding all participants' average trial completion time by more than two standard deviations. This left 24 participants that corresponded to the 24 interface presentation order permutations, producing a properly counterbalanced experiment.

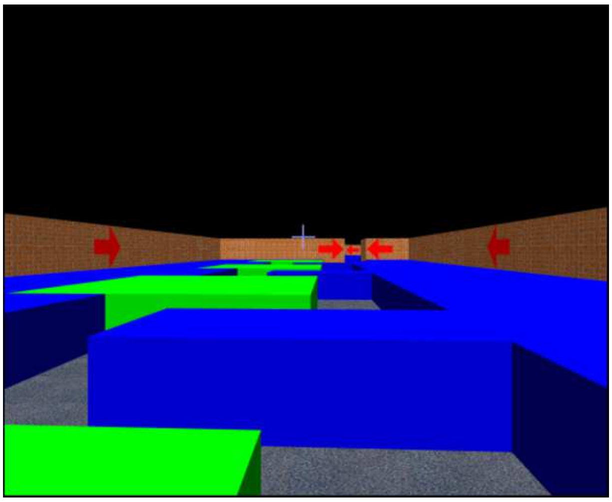

Fig. 1. The walkthrough virtual maze environment.

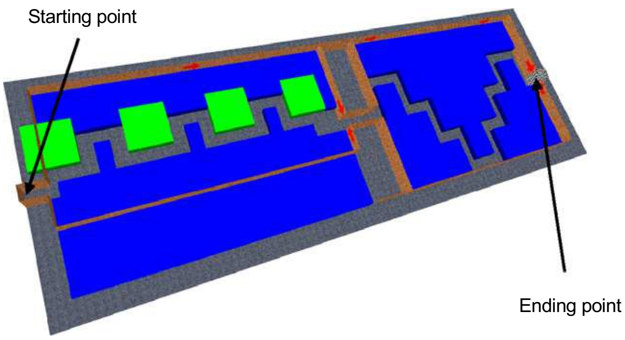

Fig. 2. Top view of the walkthrough virtual maze environment.

Fifteen of the 24 unpaid participants were male, and nine were female. Twenty of them were right handed, three were left handed and one was ambidextrous. They were all computer literate, had at least a high-school-level education, and an age distribution of 18/58/36 (min/max/average). They all had normal or corrected-to-normal vision.

2.2. Task

Participants had to complete a primed search task, where they knew in advance where the target (end point) was positioned (Bowman et al., 2005). They were instructed to travel from the start point to the end point in the shortest time possible (Fig. 2).

2.3. System

The system included a color desktop monitor with a diagonal size of 54 cm and a resolution of 1600 × 1200 pixels. The frame rate was 60 Hz, with system latency less than 120 ms. The participant's viewing distance was 70 cm. The avatar had a radius of 0.25 m, a viewing height of 1.8 m, and a Field Of View (FOV) of 75° × 60° (H × V). The virtual trail was 2 m wide with walls that were 3 m high and obstacles that were 1 m high, thus allowing the participants to see over them. The corridor was 164.5 m long (measured along the center line), with 15 turns to the right and 15 to the left (see Fig. 2).

2.4. Travel techniques

Participants used four different travel techniques for their virtual walkthroughs. By technique, we mean a particular combination of an input device, a number of hands used to control the device, a number of DOFs, and a device-to-avatar movement mapping. Each technique moved the avatar and viewpoint together, such that the avatar's viewpoint always faced in the same direction as the avatar's forward motion. For all travel techniques, collisions between the avatar and objects of the scene (obstacles or walls) were slippery, so that the avatar did not get stuck in a corner. In all cases, a rate control algorithm controlled the translations of the viewpoint in the VE. A pilot study helped us select speed control mechanisms for each travel technique to optimize user performance.

The first travel technique involved using a standard 104 key keyboard from Dell (Dell SK-8135) to control 3 DOFs (Fig. 3). The four directional arrow keys had two translation DOFs: fore/aft and left/right without any rotation (a.k.a. strafe). The 4 and 6 keys of the numerical keypad produced a rotation along the horizontal plane, around the vertical axis (a.k.a. yaw). Speed was constant at 5 m/s for translations and 180°/s for rotations.

Fig. 3. The keyboard travel technique.

Fig. 4. The mouse travel technique.

The second travel technique is based on a Microsoft Laser Mouse 6000 mouse (Fig. 4). Here, the lateral, side-to-side movement of the mouse rotated the viewpoint along the horizontal plane, around the vertical axis, (a.k.a. yaw). Rotation speed was determined by an algorithm with a linear function gain of 25°/cm (with mouse acceleration disabled). The left and right buttons controlled the fore/aft movement at a constant speed of 5 m/s. Thus, the mouse travel technique had only two DOFs: one translation and one rotation.

The third travel technique involved a 3-DOF joystick as the input device (Fig. 5). A lateral tilt of the joystick resulted in a lateral displacement of the viewpoint (strafe motion) while forward/backward joystick tilt produce a fore/aft movement of the viewpoint. Finally, a twist of the joystick's handle rotated the viewpoint on the horizontal plane, around the vertical axis (yaw). Translation speed was controlled through a linear function gain up to a maximum speed of 5 m/s. Rotational speed was a constant 180°/s.

The fourth and final travel technique employed a Logitech Dual Action gamepad with two mini joysticks to control 2 translation DOFs and one rotation DOF. As with the 3D joystick, a lateral tilt of the left joystick produced a lateral movement (strafe) of the viewpoint. A foreword/backward tilt of the left joystick produced the fore/aft movement of the viewpoint. Unlike the 3D joystick, the horizontal plane rotation, around the vertical axis, (yaw) was controlled by the second joystick. Translation speed had proportional velocity control with a linear function gain, to a maximum of 5 m/s. The rotation speed was a constant 180°/s (see Fig. 6).

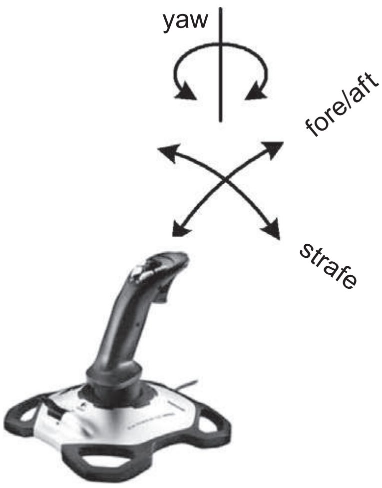

Fig. 5. The joystick travel technique.

Fig. 6. The gamepad travel technique.

2.5. Design

The independent variables were the four travel techniques described earlier and the dependent variables were the task completion time, the total traveled distance and the number of collisions. A collision is detected when a movement of the avatar towards an obstacle causes a contact. Collisions are detected at each frame, i.e. 60 times/s, thus implying a maximum of 60 collisions/s. We used a within-subject design and trials were blocked by travel technique. We counterbalanced the order in which participants used each travel technique to minimize skill transfer effects. For each travel technique (each block), the participants received brief explanations by the experimenter, followed by two practices and five trials.

2.6. Procedure

Participants read the instructions and completed a consent form along with a background questionnaire. They were then seated in front of the system and told to begin the experiment.

The instructions were displayed on-screen before each trial. A 3 s audio countdown preceded each trial. The trials ended automatically when the participants reached the end point. Once the trials completed for all travel techniques, each participant was invited to complete a post-test survey to rate each travel technique on the ease-of-use, fatigue, accuracy, speed and preference.

That survey builds on previous work in the field to measure ease-of-use and fatigue (Zhai, 1993) by using a standard five-point Likert scale to measure each item. The motivation for conducting the questionnaire survey is to acquire valuable feedback from the participants.

3. Results

3.1. Quantitative results

We first determined the effect of practice on performance. This allowed us to exclude practice effects from our analyses of the travel technique performance effects. Fig. 7 shows that practice-

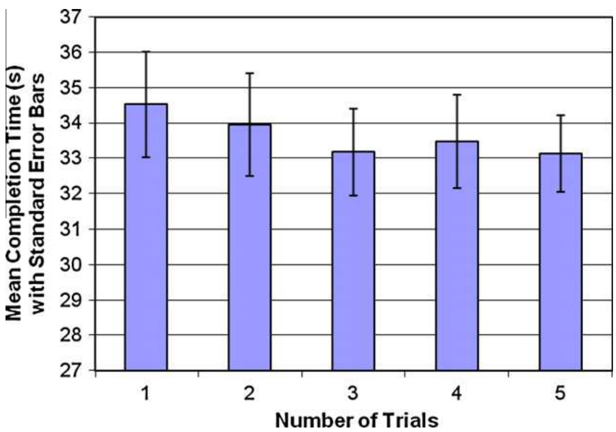

Fig. 7. Effect of practice on mean completion time.

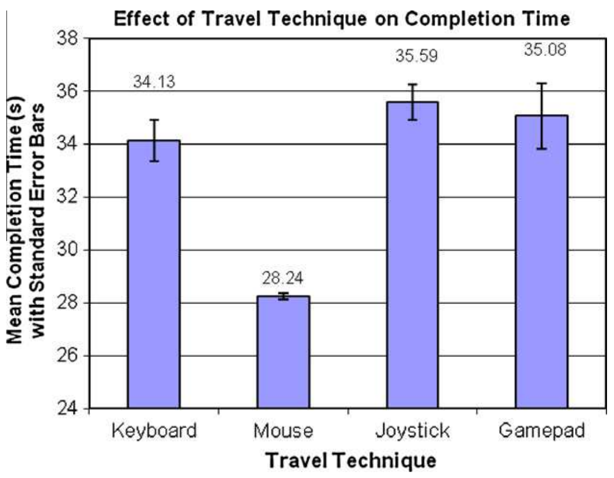

Fig. 8. Mean completion time.

related performance improvements on completion time disappeared after a few trials. Consequently, we restricted our travel technique performance analyses to the last three trials in each block.

Fig. 8 illustrates the mean task completion times for the 4 travel techniques (average of the last three trials). An analysis of variance (ANOVA) with the pseudo-F test was significant, $F(3, 69) = 10.30$, $p < 0.001$.

A Duncan's multiple range test (Duncan, 1955) reveals that the only significant difference is between the mouse travel technique and each of the three other ones.

The mean completion time was between 20% and 26% higher when using the keyboard, joystick or gamepad than when using the mouse. The effect size (using Cohen's method (Cohen, 1988) is illustrated in Table 1.

We can see that there is a large effect size (i.e. >0.8) between the mouse and each of the three other interfaces.

Table 1
Effect size for the completion time between the four interfaces.

Effect size	Mouse	Joystick	Gamepad
Keyboard	1.22	0.24	0.11
Mouse		1.84	0.92
Joystick			0.06

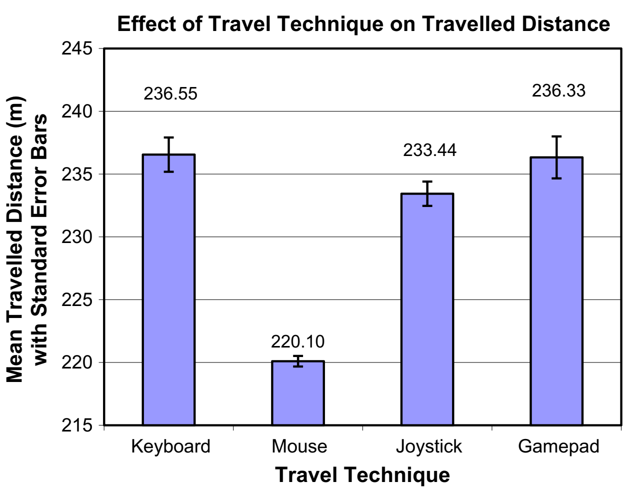

Fig. 9. Mean travelled distance.

Table 2
Effect size for the travelled distance between the four travel techniques.

Effect size	Mouse	Joystick	Gamepad
Keyboard	1.92	0.31	0.02
Mouse		2.11	1.57
Joystick			0.25

Fig. 9 illustrates the results for the three interfaces for the travelled distance (average of the last three trials). An analysis of variance (ANOVA) with the pseudo-F test was significant, $F(3, 69) = 23.12$, $p < 0.001$.

A Duncan's multiple range test reveals again that the only significant difference is between the mouse travel technique and each of the three other travel techniques.

Here, the mean travelled distance was between 6% and 8% higher when using the keyboard, joystick or gamepad than when using the mouse. The effect size is illustrated in Table 2.

Again, we see that there is a large effect size between the mouse travel technique and each of the three other travel techniques.

Fig. 10 illustrates the results for the four travel techniques for the number of collisions per travelled meter (average of the last three trials). An analysis of variance (ANOVA) with the pseudo-F test was significant, $F(3, 69) = 9.89$, $p < 0.001$.

A Duncan's multiple range test reveals a significant difference between the mouse and the joystick as well as between the gamepad and the three other travel techniques.

Using the gamepad increases from 33% to 122% the number of collisions per travelled meter as compared to the use of the keyboard, mouse or joystick. The use of the joystick increases the number of collisions per travelled meter by 67% as compared to the use of the mouse. The effect size is illustrated in Table 3, computed from the left column.

Fig. 11 illustrates the results for the four travel techniques for the number of collisions per second (average of the last three

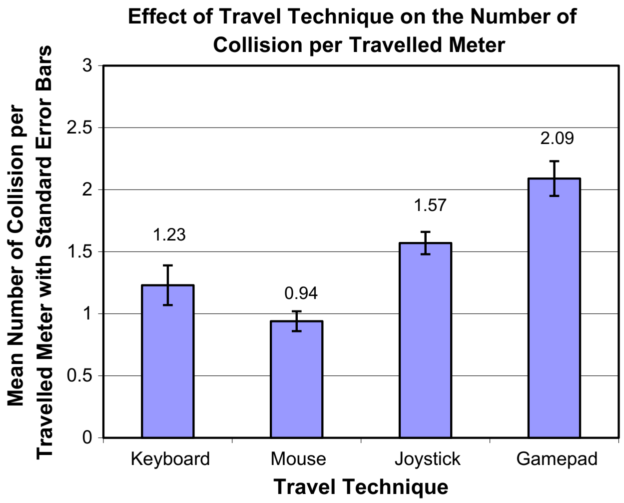

Fig. 10. Mean number of collisions per travelled meter.

Table 3
Effect size for the number of collision per travelled meter for the four travel techniques.

Effect size	Mouse	Joystick	Gamepad
Keyboard	0.27	0.31	0.68
Mouse		0.52	1.17
Joystick			0.52

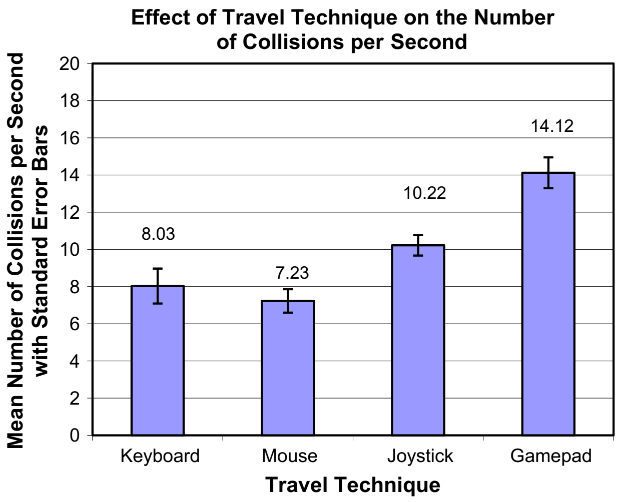

Fig. 11. Mean number of collisions per second.

trials). An analysis of variance (ANOVA) with the pseudo-F test was significant, $F(3, 69) = 9.18$, $p < 0.001$.

A Duncan' multiple range test reveals a significant difference between the mouse and the joystick as well as between the gamepad and each of the three other travel techniques.

Using the gamepad interface increases from 38% to 95% the number of collisions per second as compared to the use of the keyboard, mouse or joystick. The use of the joystick increases the number of collisions per second by 41% as compared to the use of the mouse. The effect size is illustrated in Table 4, computed from the left column.

Fig. 12 reports the subjective ratings on a scale from 1 to 5, a higher score meaning a better score. Participants had to rate each interface according to five dimensions which are ease-of-use, fatigue, accuracy, speed and preference.

Participants rated the mouse-based travel technique as their preferred method for virtual walkthroughs, overall, for ease of use, for accuracy, and for speed.

Table 4
Effect size for the number of collisions per second for the four travel techniques.

Effect size	Mouse	Joystick	Gamepad
Keyboard	0.12	0.34	0.81
Mouse		0.60	1.10
Joystick			0.66

The results also indicate that the joystick was the least appreciated of the four travel techniques. Because of non-linearity, the subjective data were not subjected to statistical analysis.

4. Discussion

The results of this experiment indicate that, for this specific virtual environment, the mouse travel technique offers better performance than the three other travel techniques tested, namely the keyboard, the joystick and the gamepad travel techniques.

Accordingly, the subjective ratings indicate that the mouse travel technique also provides a better user experience in regard to ease of use, speed, accuracy and overall preference.

It is important to note that the mouse travel technique uses its two buttons thus limiting the possibilities of further interaction with the environment (e.g. selecting an object with a click).

Given the popularity of the gamepad, these results can be surprising. There is however no contradiction as the gamepad does not require a desktop surface to operate, contrary to the three other input devices. It is therefore appropriate for users of video games who are generally located on a couch in front of a television.

It could be interesting to see whether assigning the translations to another input device while conserving the mouse to control the orientation would offer better results. Given the different nature of translation (move) and rotation (look) actions, the idea of separating those actions on different input devices could lead to better performance as indicated by previous studies (Jacob, Sibert, McFarlance, & Mullen, 1994). In fact, results of a previous experiment conducted with the same virtual environment (Lapointe & Savard, 2009) indicates that using a bimanual travel technique made of a joystick and a mouse results in a much better performance than using a joystick only but slightly worse than using the single-handed mouse travel technique used here. This would hold true even if a third degree-of-freedom (strafe) is added as found in that previous experiment. In order to maximize performance, and given the results obtained here, it would be interesting to test a two-handed travel technique made of a keyboard (for move control) and a mouse (for look control). This travel technique is used extensively in first-person (egocentric) 3D computer games although no formal experiment demonstrated that this configuration offers the best usability for desktop virtual walkthroughs.

Overall it seems that the mouse has an advantage in terms of performance, but can quickly become overloaded if additional input channels are needed, for example to select objects in the virtual environment.

The results reported here are limited to one example of virtual environment and one particular set of users. Indeed, fully half of

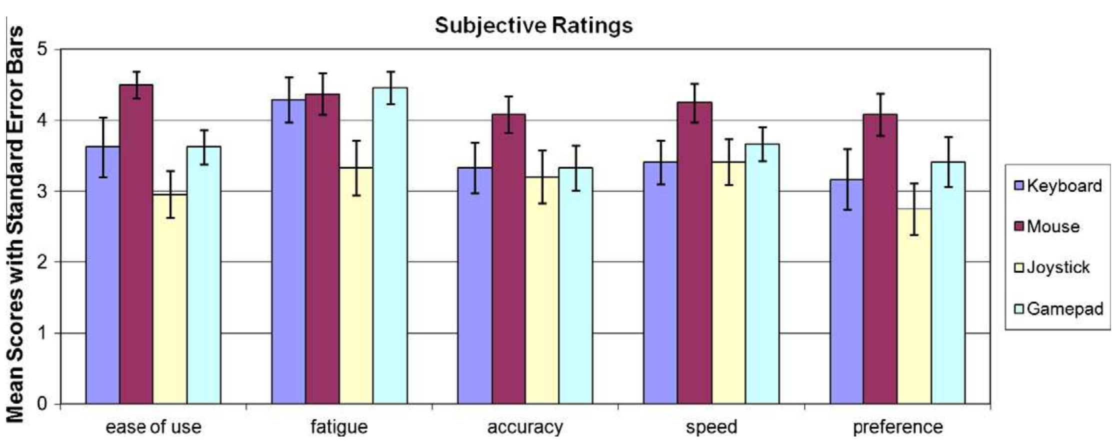

Fig. 12. Subjective ratings.

our participants almost never played computer/video games. Only 2 of the 24 participants played almost daily. In contrast, all participants used a mouse on a daily basis. Consequently, we can state that our participants, as a whole, had much more experience with the mouse than with the joystick or gamepad. This is not surprising, given that he mouse is a standard input device for desktop computers, and consequently, it is used for many other tasks besides game playing and virtual walkthroughs. This experience could have played a role in the mouse's outperformance, but seem to reflect the experience of computers users in general.

For more comprehensive results, additional experiments should be conducted, by using tasks and virtual environments of different complexities with different sets of users. For example, tasks involving walkthroughs in several different environments such as a straight line (1D), a plane (2D), or space (3D) could help show which DOF of the control interfaces are well suited to specific types of movement.

One important contribution of this paper is to report not only the results of this particular experiment, but also the evaluation method that was used and that could be reused for further experiments, including replications.

5. Conclusion

In conclusion, the mouse input device seems well suited as a single-handed device for simple walkthrough tasks in a desktop virtual environment.

Moreover, further experimentation is required to confirm the superiority of the mouse in other virtual environments and for other users.

6. Future work

Given the superiority of the mouse and previous findings showing high performance levels for bimanual techniques, travel could potentially be further improved by combining the mouse with a keyboard as is often the case in first-person (egocentric) 3D computer games. Of course, this hypothesis awaits empirical confirmation.

Another future research direction could look at other input devices and interaction techniques such as those provided by sensor-based input techniques such as the Wii and Kinect.

Also, since standard testing methods do not exist in the field, more work in that direction would be needed in order to make systematic progress in improving interaction techniques.

Acknowledgements

The authors thank all the volunteers who participated in this study. This experiment has been approved by the research ethics board from the National Research Council of Canada. This research has been funded by the Institute for Information Technology of the National Research Council of Canada.

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