Comparing four interaction techniques on a simple structured navigation task using a Head-Mounted Display

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Abstract

Virtual Reality (VR) is a scientific and technical domain that can provide mediums to dive users into an interactive 3D computer-generated world. Several processes of immersion bring to user the feeling of having quit the real world and of being present in the virtual environment, physically as well as psychologically (1,2). VR must provide a coherent experience in terms of sensory, cognitive and functional information (2). Fidelity, as the objective degree of exactness with which a system reproduces real-world, is hence a key point to design immersive VR-based systems. Since the 2010's, low-cost cave automatic virtual environment (3) and many Head-Mounted Display (HMD) are available for immersive VR. However, navigate through 3D environments displayed in HMD is still challenging because it can cause sickness and disorientation. Since techniques based on haptic devices like keyboard and joystick have been extensively explored in the past, the present study aimed to investigate the impact of the navigation technique on performance on a simple traveling-centered task and the user experience with the HMD HTC Vive. Since techniques based on haptic devices like keyboard and joystick have been extensively explored in the past, the present study aimed to investigate the impact of the navigation technique on performance on a simple traveling-centered task and the user experience with the HMD HTC Vive. We compared four continuous navigation techniques: Arms Swinging, Walking-In-Place, Pointing and Touchpad. Results on the learning effect indicated that the repetition was especially beneficial for Directional Touchpad. On the user experience, the results revealed a general discomfort of attendees with the presented systems, but they found themselves competent at the end of the experiment in the accomplishment of the proposed task. Joysticks or directional was associated to a failure in using the gaze to orientate the camera view in virtual reality.

1 Introduction

Several studies have tried to understand how the design of more naturalistic techniques affects user task performance. According some results, increasing fidelity seems to increase spatial performance (4,5). Thus, Feasel et al. (4) have found that the techniques based on Real Walking outperformed a Low Latency version of the Walking-In-Place and a joystick based-technique. Nonetheless, authors have recognized that devices used for Walking-In-Place (introduced by 6) lacked accuracy and responsiveness compared to the joystick. Wilson et al. (5) have compared Real Walking, Walking-In-Place and Arm Swinging on spatial awareness. Participants were asked to turn to look at a virtual target previously learned from different positions in virtual environment. Latencies and turning errors (difference between the user's actual direction and direction needed to face the target) were measured. Results have shown the superiority of Real Walking compared to Walking-In-Place and Arm Swinging, and the superiority of Walking-In-Place compared to Arm Swinging on turning. However, a similar study has previously shown that Arm Swinging provided similar performance as Real Walking in terms of spatial awareness. In both studies (5,7), Arm Swinging was based on a wearable EMG (7). Wilson et al. (5) have hence hypothesized that subjects might need more training with this condition and were more likely to make produce outliers in the Arm Swinging condition. In addition, according Pai et al. (8), Arm Swinging was perceived as particularly natural compared to Walking-In-Place and allowed more prolonged usages.

Other studies have suggested that both high-fidelity techniques and well-designed low-fidelity techniques could conduct to higher performances compared to moderate fidelity techniques (9,10). For instance, Marsh et al. (9) have compared Real Walking, a pseudo-natural technique (Position-to-Velocity), and a Gamepad-based technique on performance to navigate and to remember a items sequence. They have found that navigation performances were higher with the Real Walking and the Gamepad, compared to the pseudo-natural technique. In addition, higher memory performance was found with the Real Walking compared to the pseudo-natural technique and the Gamepad, suggesting that non-natural techniques add a cognitive load. Together, these results have suggested that simultaneous spatial navigation and memory tasks may both compete for the same cognitive resources. In the same vein, Nabiyouni at al. (10) have compared the Real Walking, a technique based on a low-cost omnidirectional treadmill and a Gamepad-based technique. In a virtual museum, participants were asked to follow a blue line on the floor to reach a target. Derivation from the blue line and time to complete the task were used as navigation performance measures. Results were similar to those obtained by Marsh et al. (9): navigation performances were higher with the Real Walking and the Gamepad, compared to the pseudo-natural technique. Finally, the improvements of interaction algorithms and better adequation with the implemented task may conduct to a priori suppressing results. For example, Ferracani et al (11) have compared Walking-In-Place, Arms Swinging, and Index-Finger-Pointing and Push (i.e., closing and opening the hand while translating the hand itself forward with respect to the user's elbow) using several mini tasks. They have used a HMD, but external tracking devices were to interact (Kinect and Leapmotion). Results have shown that all techniques were highly perceived as naturalness. Walking-In-Place and Index-Finger-Pointing have shown the best performance results: the shortest completion times with less collisions best obstacle collision avoidance. However, about half of participants have indicated to prefer Index-Finger-Pointing, a third have chosen Push, and only a few participants preferred Walking-In-Place (3 out of 19). These outcomes suggest that novel gestures such as Index-Finger-Pointing could be adopted with comparable results in terms of effectiveness and user experience.

2 Materials and Method

2.1 Participants

Twenty healthy volunteers were recruited via poster in a French engineering school.

The mean age was 25 years (range 18 to 56 years). According to a preliminary questionnaire, most of the participants was familiar with interactive new technologies. Indeed, 75% reported to play video games at least once a day. Moreover, 15% reported to play several times each week. Only 10% reported to not play video games or play for less than one a month.

2.2 Procedure

To measure the learning effect, the practical part was divided into two identical consecutive sessions, separated by a five-minutes break (or 10-minutes if needed). At each session, participants completed four trials, one trial per navigation technique. In other words, each participant repeated overall eight times the task (2 sessions x 4 conditions). Each trial consisted to perform a simple goals-oriented navigation task. The first navigation technique was randomly selected and was the same for the two sessions. For each new condition, participants were explained the use of device and were given two minutes of familiarization in a dedicated virtual environment. The software collected performance-based data automatically. In case of symptoms of cybersickness, participants could stop the experience. Finally, participants were asked to fill out three post-questionnaires to document their subjective experience.

2.3 Materials

2.3.1 Navigation conditions

The implemented techniques are described in the Table 1**Erreur ! Source du renvoi introuvable.**.

Table 1. Description of the implemented navigation techniques.

Aspect	Walking-In-Place	Arms Swinging	Pointing	Directional Touchpad
Input body movements to move forward	Step in place	Swing arms at the sides	Outstretch an arm and press the HTC Vive controller to begin walking	Move thumb to translate on the touchpad
Input control for virtual walking speed	Step frequency, obtained from the roll's frequency of HTC Vive headset*	Swing frequency, obtained from the controllers' frequency	Pitch angle of arm, obtained from the controller orientation during walking	Distance from the center of the touchpad
Input body movements to turn	Shake the head	Head direction	Controller direction during walking	Move thumb to translate on the touchpad
Input control for virtual direction	Head shaking direction	Head direction	Controller direction during walking	Touch from the left to the right axis on the touchpad

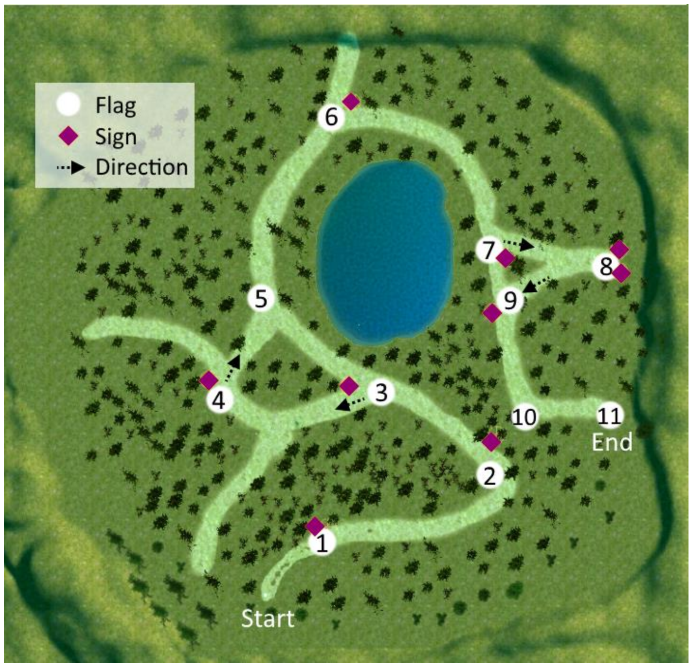
* According to Ferracani et al [11] the method named Shake Your Head (SYH) causes severe cyber sickness. Examine the rhythm of the legs is impossible with only the HTC Vive headset. Participants were invited to use the Walking In Place (WIP) which induces SYH through body movements.

2.3.2 Virtual environments

The same environment was used for all the conditions (see Figure 1).

Figure 1. Map used to prime participants as to the start location ("Start"), the directional panels (lozenge) and the flags (circle).

The trajectory was materialized by a path bordered with trees and orientations were materialized by directional signs. Trajectory, position of signs and the distance between them were customized to propose a smooth navigation experience (31). Eight directional signs were placed at each intersection so that the chevron-shaped side pointed to the direction to follow. The trees did not mask the next objective. Two signs were also added at the beginning of the path and in the first curve.



2.3.3 Task

A single task was used for each of the eight trials. Participants were instructed to follow a forest path in the direction indicated by the signs and to collect eleven flags, until they reached the indicated end. A first flag was placed at the beginning and the second in the first curve. Then, eight flags were placed next to the intersection's directional signs. The eleventh flag was place at the end. To collect a flag, user had to pass her hand through it walk on it. An audio signal indicated that the flag was picked up. The virtual walk ended once all the flags had been collected.

2.3.4 Training

The training environment was a small forest clearing with a flag that participants were asked to collect.

2.3.5 Outcomes

Objective performance was collected by the designed software, which recorded task completion duration and travelled distance. After the sessions, participant completed the Simulator Sickness Questionnaire (SSQ; 12,French translation by 13).

3 Results

All 20 participants performed the first session. However, two participants stopped the experiment after the first session.

3.1 Results by technique

Results by technique are summarized in the Table 2.

126 **Table 2.** Results obtained for each navigation technique.

Table 2A. Main performance outcomes at the Session 1 and Sessions 2 for the studied navigation techniques.

Technique Performance	Session 1 Mean [Range]	Session 2 Mean [Range]	Evolution (%)
Walking-In-Place			
Completion time (s)	117.1 [95.3–210.3]	110.5 [92.1–169.3]	-5.6
Distance traveled (m)	653.9 [559.8–1182.0]	617.5 [548.1–855.4]	-5.6
Speed (m/s)	5.6	5.6	0.4
Arm-Swinging			
Completion time (s)	118.3 [98.4–128.0]	107.9 [99.2–115.3]	-8.8
Distance traveled (m)	635.8 [559.8–696.8]	601.7 [555.3–627.6]	-5.4
Speed (m/s)	5.4	5.6	3.2
Pointing			
Completion time (s)	117.6 [94.3–181.4]	105.2 [95.3–117.9]	-10.6
Distance traveled (m)	574.2 [545.7–629.2]	566.1 [554.7–583.2]	-1.4
Speed (m/s)	4.9	5.4	10.2
Directional Touchpad			
Completion time (s)	149.8 [108.3–240.8]	126.4 [102.3–153.1]	-15.6
Distance traveled (m)	603.1 [552.2–749.4]	581.6 [543.3–641.6]	-3.6
Speed (m/s)	4.0	4.6	14.1

Table 2A presents completion time, distance traveled and speed, for each studied navigation techniques. The main value for each variable represents the average value across the participants, obtained separately at Session 1 and Session 2. Minimum and maximum values are also indicated (Range). The column evolution represents the change at Session 2 compared to Session 1.

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Table 2B. Distance traveled from a flag to the next flag in the sensitive area of the path (from flag 7 to flag 11).

Technique	Local results from flag 7 to flag 11
Walking-In-Place	We found higher mean values at the Session 2 compared to the Session 1. The only flag showing a lower travelled distance at Session 2 compared to the Session 1 is the flag number 9, which leaves no doubt when deciding (Evolution Session 1 to Session 2: -16.6%). It may imply that the user succeeds to better control his movement but not necessarily to better observe his environment.
Arm-Swinging	Arrival at the seventh flag is highlighted by a higher distance at the Session 2 (+11.7% compared to the Session 1), but the passage soliciting observation (flag 8) is highlighted a reduced distance at the Session 2 (-19.7% compared to the Session 1). Similar distances traveled at the two sessions are found otherwise, suggesting that the user can not improve with this technique.
Pointing	Arrival at the seventh flag and the passage soliciting observation (flag 8) are highlighted by a higher distance at Session 2 compared

	to Session 1 (+9.8% and +14.3% respectively), but reduced distances were found at the flags 10 (-23.3%) and 11 (-6.9%).
Touchpad	The traveled distance from flag to flag in the sensitive area suggested that participants could mainly optimize their trajectory on the passage soliciting observation (flag 8: -10.59%), and at flags 9 and 10 (+4.76% and +3.66% respectively).

3.2 Comparison of techniques

Comparison of techniques are summarized in the Table 3.

3.3 SSQ

As a reminder, 2 of the 20 participants wanted to stop after the first session because of cybersickness. According the SSQ, more than half of the participants felt general discomfort, tiredness and eyes fatigue due to the headset. Transpiration, nausea, difficulty to focus, headaches and vertigo occurred for more than a quarter of the participants.

4 Conclusion

This paper aims to extend previous findings concerning navigation techniques for immersive virtual environments. We proposed and evaluated four technique in a simple navigation task. We observed that participants varied a few in their ability to complete the task and that the navigation techniques appeared to have little influence on the task completion time. However, the directional touchpad-based technique led to a difference revealed by a lower execution speed. It suggests that this technique requires a cognitive effort. Despite a medium distance travelled and an improvement by navigation speed, the lower speed linked to this technique led to an overall lower performance. The walking-in-place, arms-swinging and pointing techniques shown similar performance in terms of completion time. However, the last one was found to be the most efficient showing a lower completion time as well as a low travelled distance.

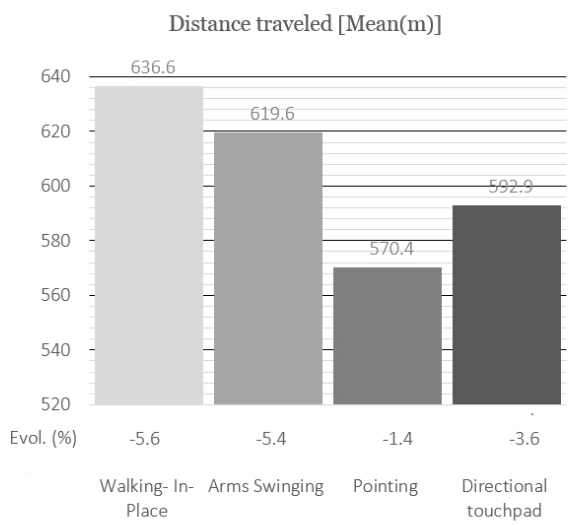
The pointing technique showed a similar learning pattern than the touchpad one between Session 1 and Session 2, suggesting that such a technique is not so intuitive. The results regarding the learning process indicate that users can optimize their trajectory through a more accurate control of the technique and waste hence less time in exploration. The execution speed is better in those cases, but the distance travelled is clearly bigger. Regarding the learning process, the walking-in-place and arms-swinging techniques shown similar patterns, with a lower completion time due to a lower distance travelled, while the navigation speeds remained stable at a good level.

The results from Session 1 and Session 2 suggest that the perception of the environment may be lower when using those techniques as the user has to dynamically control their movements, forcing the user to explore more the environment by navigating. The results also indicate that users may have difficulties to optimize their trajectory. However, they can manage to improve their movements speed.

This study suffers from some limitations, such as small sample (N=20). Repetition of the task may let participants to spend less time to collect the flag because they learn the prescribed path though all conditions and sessions. The walking-in-place as we implemented it could be improved to obtain better performance and comfort to use.

Table 2. Performance across the different navigation technique conditions.

Erreur ! Source du renvoi introuvable. presents the aggregate performance across the different navigation technique conditions in terms of completion time, distance traveled and speed. In addition, is shows the evolution of the data from Session 1 to Session 2.



Across all the techniques, the sample took about 2 minutes to travel the path. On average, there was a negligible difference between the two sessions (session 1: 2.1 min; session 2: 1.8 min). Comparing the techniques on this completion time variable, similar results were found for Arm-Swinging, Walking-In-Place and Pointing. Only the most artificial technique, based on the Touchpad, shown distinct results. Indeed, the sample took longer to travel the path with the Touchpad compared to the other techniques. This is measured at the first session, but also at the second session, despite a decrease (16%) in the mean completion time (session 1:2.5 min; session2: 2.1min).

Across all the techniques, the distance traveled was about 600 m. On average, there was a negligible difference between the two sessions (session 1: 617 m; session 2: 592 m). The four techniques shown similar distances traveled. Noticeably, Pointing was the more efficient technique (i.e., shown the minimal travelled distance), followed by the technique based on Touchpad, followed by Arm-Swinging, followed by Walking-In-Place which shown the longest travel. This same pattern was found for the first as well as for second session.

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7 Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.