Point & Teleport Locomotion Technique for Virtual Reality

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ABSTRACT

With the increasing popularity of virtual reality (VR) and new devices getting available with relatively lower costs, more and more video games have been developed recently. Most of these games use first person interaction techniques since it is more natural for Head Mounted Displays (HMDs). One of the most widely used interaction technique in VR video games is locomotion that is used to move user's viewpoint in virtual environments. Locomotion is an important component of video games since it can have a strong influence on user experience. In this study, a new locomotion technique we called *"Point & Teleport"* is described and compared with two commonly used VR locomotion techniques of walk-in-place and joystick. In this technique, users simply point where they want to be in virtual world and they are teleported to that position. As a major advantage, it is not expected to introduce motion sickness since it does not involve any visible translational motion. In this study, two VR experiments were designed and performed to analyze the *Point & Teleport* technique. In the first experiment, *Point & Teleport* was compared with walk-in-place and joystick locomotion techniques. In the second experiment, a direction component was added to the *Point & Teleport* technique so that the users could specify their desired orientation as well. 16 users took part in both experiments. Results indicated that *Point & Teleport* is a fun and user friendly locomotion method whereas the additional direction component degraded the user experience.

Author Keywords

Virtual reality; locomotion; teleportation.

ACM Classification Keywords

H.5.1. Information interfaces and presentation (e.g., HCI): Multimedia Information Systems: Artificial, augmented, and virtual realities.

INTRODUCTION

Since the development of virtual worlds, researchers have been working on different locomotion techniques. Locomotion can be defined as self-propelled movement in virtual worlds [9]. Locomotion is considered as one of the most important interaction components of virtual reality (VR) experiences, since it is a very common and crucial task for moving in 3D virtual environments [2]. Although usually locomotion is not the main goal of VR applications and games, in almost every case some kind of locomotion is required to move the user's viewpoint in the virtual world.

In immersive VR applications, HMDs make it possible for users to control the position and the orientation of the viewpoint by moving their heads. These applications are usually suitable to be explored on foot. But due to the limited physical tracked area, large virtual environments cannot be examined simply by normal walking. In those cases, applications need different locomotion techniques. A poorly designed locomotion technique may distract the user and reduce immersion. It may also introduce motion sickness since locomotion triggers movement which is directly related to motion sickness. In the last few years, with the introduction of new HMDs such as Oculus Rift [20] and HTC Vive [10], and VR goggles that can work with mobile phones like Samsung Gear VR [23] and Google Cardboard [8]; VR games and applications gained a lot of attention and popularity. The developed games and applications use interaction techniques that are specifically designed considering the capabilities of these new devices. Previous generation headsets were capable of tracing the rotation of the head. The games were mainly using video game controllers such as Xbox hand held controllers or keyboards and mice for locomotion [4], [31]. With the recent improvements in HMDs, new generation devices now can track position of the head as well. They also supply hand controllers with real time position and rotation tracking. With these new capabilities, video games started to use real walking as an alternative to the controller based locomotion. But since the tracked area is still limited, games need to use different alternatives for locomotion beyond the physical limitations. One alternative is to limit the virtual space to be similar to the real space. The game focuses on a limited area and game objects and agents come to the user instead of the user moving around [11]. While this is a good approach to keep the user in a restricted area, environmental variety and the user's freedom of locomotion is restrained which would degrade enjoyment until a fully immersive game design is achieved. Another alternative approach is to move the user passively in the virtual world.

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In most of the cases, this is done via a vehicle such as a car and a plane. The game may give the control of the vehicle to the user or the vehicle may be controlled automatically. While the vehicle does the transportation, the user focuses on different game objects [27]. Although this is also a clever solution, it limits game design alternatives and is likely to induce motion sickness since the user remains passive while the virtual world moves.

In this study, a new VR locomotion technique we call *"Point & Teleport"* is described and compared with two commonly used VR locomotion techniques: walk-in-place and joystick controller. In *Point & Teleport*, users simply point where they want to be in the virtual world and they are teleported to that position. Locomotion techniques that are similar to *Point & Teleport* are starting to be used in today's new VR games but there are only very few related studies in the literature. Since our technique enables locomotion without real walking, it is suitable for limited tracking areas. Pointing can be done either with hand tracking or with a tracked hand held controller. Main expected advantage of this technique is the reduced motion sickness since there is no visible translation of the virtual world. As a proposed improvement, we designed a variation of the *Point & Teleport* with the additional feature of the direction specification. Both techniques were implemented as simple VR video game like interactive experiments and a user study was performed with 16 participants. This paper presents the design and the implementation of the *Point & Teleport* VR locomotion technique and the user study with the motivation of providing insight to future VR studies and video games.

RELATED WORK

Various locomotion techniques with different characteristics have been evaluated by researchers so far. Some techniques use special devices to sense the locomotion and keep the user in a secure place, while some other techniques use general purpose tracking devices with some possible gestures to control the locomotion along with algorithms to keep the user inside the tracking area. There are also some applications that use general controllers such as joysticks. Each technique has their advantages and disadvantages which may also depend on the aimed application.

U.S. Army's Dismounted Infantry Training Program developed and compared different devices for locomotion in virtual environments [5]. After a group of studies, researchers developed an *"Omni-Directional Treadmill"* to enable walking in any direction freely in virtual worlds. The system is a combination of moving belts that can move together perpendicular to their moving direction. Different studies later developed different Omni-directional treadmills with the same underlying idea [12], [25]. Another approach was to create low friction surfaces so that the users can walk without any actual displacement. This has usually been done by using ball bearings, with the users secured at the center of the locomotion device [15], [29]. With the increasing popularity of HMDs and VR games, similar locomotion devices started to get more attention. Some commercial devices recently announced to be commercially available soon [3], [30]. There are also some unusual locomotion devices that were developed for experimental research studies such as a large sphere that the user gets in and moves in any direction by turning the sphere according to the walking speed and direction [6], [18]; powered shoes [14]; and moving tiles [13]. Although these devices are inventive alternatives for locomotion and proved to offer an immersive and intuitive user experience, they are costly, require learning and good balancing skills, and the users are restrained in an unnatural way.

Another main trend in locomotion is to use general purpose tracking devices to sense user's movements while the user walks freely inside a tracked area. In this method, user's position and direction data is utilized to render the virtual environment from the user's point of view. Since the tracked area is limited, these algorithms must also keep users inside the tracking area, to make continuous interaction possible and to ensure safety of the user. One of the most popular among these techniques is called *redirected walking* [22]. In this technique, user's walking and turning speeds are manipulated to keep the user inside the tracking area. Furthermore, the virtual world is rotated in small amounts so that the user walks in circles although they think that they are walking straight. The unnoticeable limits of these manipulations were studied by Steinicke et al. [26]. Although this algorithm tries to keep the user inside the tracking area, it is possible that the user may occasionally come to the edge of the tracked area. For those cases, different approaches were suggested such as intercepting the application and asking the user to do some movements to go to the center of the tracked area [34] or using distracters to direct the towards the center [21]. Some researchers worked on different algorithms which were designed to change the virtual environment to keep the users inside the tracked area. One example was to change the direction of the doors inside the virtual world while the user was looking elsewhere [28]. Although it seems like a major change at first glance, only 1 out of 77 users could notice this change. Another example was to change the environment layout dynamically [33]. These clever solutions have the limitation of being applicable to only indoor virtual environments.

Furthermore, there are some gesture based locomotion techniques. One of the most popular techniques is called *walk-in-place* [24]. The user marches without actually walking forward and this gesture triggers the locomotion in the virtual world. Usually the virtual walking direction is specified by the user's head direction. Some researchers examined alternative gestures for the walk-in-place technique such as tapping and wiping [19]. Another gesture used for locomotion is leaning [32]. The user leans forward to go forward and leans sides to turn in the virtual word.

Although teleportation is a simple yet powerful possible alternative to the previous locomotion techniques, it has not been quite explored yet. There are a few studies that explored methods related to our proposed *Point & Teleport* locomotion technique. One example developed for CAVE-like environments used teleportation in the virtual world thorough portals [7]. This technique utilized redirected walking and when a user created a portal by using a controller, a conjugate portal gate appeared in the center of the tracked area, so that the user is kept inside the tracked area. Another study used the teleportation approach to help the users walk long distances in the virtual environments [1]. The locomotion was done by real walking, and when the user made a jumping gesture, teleportation was triggered in the head direction. No other studies we are aware of studied teleportation for locomotion in VR.

POINT & TELEPORT TECHNIQUE

To use the *Point & Teleport* technique, users should point to wherever they want to be in the virtual world and the virtual viewpoint will be teleported to that position. In our design, to trigger the teleportation, users should point to the same place or a close vicinity for two seconds. After that, the teleportation is triggered and the virtual avatar is instantaneously moved to that position. An illustration of the *Point & Teleport* technique can be seen in Figure 1 (a).

Implementation

In our implementation, the hand and the shoulder of the user's dominant side are tracked with the optical motion tracking system. The pointing direction is determined as the vector from the virtual shoulder position data to the virtual hand position data. In this approach, the wrist is assumed to be straight. Another alternative approach to determine the pointing direction could be using only the hand position and the orientation data. According to our in-house testing, with the latter approach it is harder to track the user's pointing direction accurately. Small unintentional hand movements or errors in the motion tracking of the hand orientation may cause large displacements at the pointed position. This makes the technique harder to control, which may introduce frustration. When both hand and the shoulder are tracked as in the first approach, the aiming is more accurate and easier to control. Furthermore, the virtual viewpoint is usually close to the vector formed from the shoulder to the hand, which makes aiming easier for the user.

The pointed position in the virtual world is calculated by ray casting. The ray origin is the virtual hand position and the ray direction is the pointing direction calculated by subtracting the virtual position of the shoulder from the virtual position of the hand of the user. The collision detection is performed between the ray and the possible teleportation surfaces. In our case, the only possible surface was the ground of the virtual environment. Once a collision is detected, the position of the collision point is stored. In the next frames, if the distance between the new collision position and the stored position is smaller than a threshold, it is assumed that the user is pointing to the same point constantly, and the timer is increased by the frame length. If the distance is larger than the threshold, the stored collision position is updated with the new collision position and the timer is reset. If no collision is detected, the stored collision position is cleared until another collision is detected. Balancing the threshold value is important since the larger the threshold is, the larger the tolerance is to the unintentional hand movements. But this comes with the cost of lowered precision when the vicinity of the target is pointed. After in-house testing, we found out that a threshold value similar to the virtual character's bounding capsule diameter worked well, since it will occupy the same virtual space after the teleportation.

In our design, to exclude interfering effects of any additional components, we did not include any controllers to trigger the teleportation. Users needed to point to the same place or a close vicinity for two seconds. Two seconds was decided by in-house testing to be just long enough to eliminate unintentional teleportation instances yet to be short enough not to cause tiredness to the users. Although turned out to be suitable for evaluation, this triggering method may not be suitable for fast paced games. Different designs can use different triggering methods such as hand held controllers.

Activation

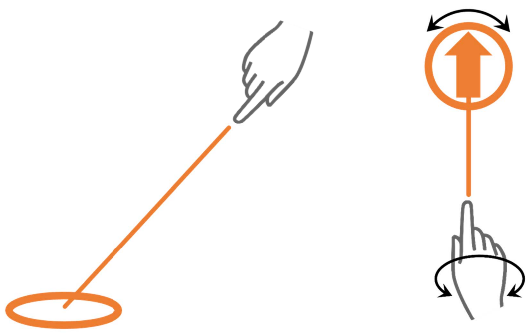
Point & Teleport is always active unless the tracked arm is lowered by the user's sides. Since we do not use any handheld controller in our implementation to activate or deactivate the teleportation, we utilized the lowered arm posture to make the teleportation inactive. With this implementation, the users can wait at a constant position in a relaxed posture with their arms lowered. However, this design may not work well for applications in which the user is supposed to do some activities with their hands while waiting. In that case, another gesture or a controller may be utilized to control the activeness of teleportation. Before checking for collision, the angle between the pointing vector and the down vector for the environment is calculated and if the angle is smaller than a threshold, the teleportation is deactivated. This is important for the users to be able to stay in the same position without getting constantly teleported unintentionally. The disadvantage of this approach is that it does not let the users move in very short distances, which was not required in our experiments. If that is required in game design, controller based triggers may work better.

Visual Cues

To make the locomotion more user-friendly, in our implementation, an orange ring overlay is placed on the pointed position in the virtual world if the pointed position is on a possible teleportation surface. This way, the users can easily see where they are pointing at and where they are going to be teleported. The color of this ring is gradually turned into green as long as the user points at the vicinity of the initial position. The color feedback is helpful for users in understanding if they are pointing the same position and how much longer they need to point. Furthermore, a virtual laser beam was displayed that originated from the user's virtual hand and extended towards the ring, parallel to the pointing direction. In our in-house testing, this laser beam helped with the sense of being in control and distance estimation. Without the laser beam, it was difficult to see the ring if the user pointed to a position that was far away from their viewpoint. The color of the laser beam is kept the same with the ring color if the ring is active; otherwise the laser beam's color is kept red, indicating that no possible teleportation surface is pointed currently.

Teleportation

Once the teleportation is triggered by the user, the virtual character and the virtual viewpoint is moved to the pointed position in the virtual world instantaneously. The orientation of the user is kept the same during the teleportation. In our implementation, the user rotates in the virtual world by rotating their bodies in the real world. So the user is able to adjust their orientation after the teleportation. Different approaches were tested in-house before designing the experiment. One approach was to move the virtual character in the virtual world until it reached to the destination point. The speed could be adjusted as an average walking speed or a faster speed. In both these conditions, the approach has introduced motion sickness to the testers. Motion sickness with this approach was not unexpected since the users saw themselves moving in the virtual world while they were standing still in the real world. Another approach was to make the teleportation with a fade-out and fade-in effect in order to help the users cope with the instantly changing virtual world. This approach was found to break immersion and unnecessary since the users did not get overwhelmed by the changing virtual world. In addition, fading introduced wasted time for each teleportation which caused impatience in the testers. The users could expect what to see once they were teleported because they already saw where they were going to be teleported. Hence we suggest that the fading effect may only be resorted to for very crowded virtual worlds in which the teleportation would result in significant change in the environmental visuals.



(a) (b)

Figure 1: Illustration of the (a) Point & Teleport and (b) Point & Teleport with direction specification techniques.

Teleportation with Direction Specification

In the explained implementation of the *Point & Teleport* so far, the teleportation was performed without any change in the orientation before and after the teleportation. To be able to turn in the virtual world, the users were required to make a real turn after the teleportation. We wondered if we could improve the *Point & Teleport* by adding a direction feature. Hence, a variation of this technique was implemented with a direction specification. With this modified technique, while the users point to a position in the virtual world, they can also specify which direction they want to be facing after the teleportation. For this purpose, in our implementation, a 3D arrow is placed above the ring. The arrow is restricted to x-z plane and the rotation in the y-axis is determined by the rolling axis of the pointing hand (see Figure 1(b)). This way, users can both point to the destination position and specify the direction they will be facing when they are teleported by only using their one arm. After our initial in-house testing, the rolling axis was found to be the easiest for the rotation of the hand to specify the direction among other alternatives in terms of understanding and operating the gesture.

Testing System

An optical tracking system with 12 OptiTrack V100R2 FLEX cameras (640x480 resolution, 100FPS, sub-millimeter accuracy) and passive reflective markers for real time head, hands and feet tracking was used. The tracking area was 2m by 2m. A high resolution HMD (Virtual Realities LLC. VR2200) was used for viewing the virtual world. Our server computer had AMD FX-8150 3.61Ghz Eight-Core CPU, AMD FirePro W600 GPU and 16GB RAM. Implementation was done using the Unity game engine.

EXPERIMENT ONE

In our first experiment, we compared the *Point & Teleport* technique with walk-in-place and joystick controlled locomotion techniques that are commonly used in VR systems. In the walk-in-place technique, locomotion is performed with a marching gesture performed in a constant position. The locomotion direction is controlled by the head orientation. In the joystick control, locomotion is simply controlled by continuously pushing the joystick. For the locomotion direction, the users can either turn their heads or push the joystick sideways.

Objective

The objective of the experiment is to go to the destination points in the virtual environment. The destination points are pointed out using three objects in the virtual world. A circle having 0.6m radius on the ground, a semi-transparent animated textured cylinder of an equal diameter placed on the circle, and an oscillating arrow pointing the destination to emphasize the position (see Figure 2, top). These three objects help the user to see the destination point not only from a large distance but also when they are inside it. The color of these three objects is orange in default. Once the user gets inside the circle, the color of all objects immediately turns into green. This is an important feedback for the users to understand that they are inside the destination point. Once they get into the destination point, a timer for that destination point starts. The user is supposed to stay inside the circle for three seconds. During this interval, the color of all three objects gradually turns into cyan. As the user stays inside the circle for three seconds, the destination point disappears and then appears at another position in the virtual environment. The reason for this forced waiting inside the destination point for three seconds was to incorporate the user's control over starting and stopping the locomotion technique and eliminate unintentional destination point triggering while passing by. The users are required to go to ten destination points with each locomotion technique. After completing the sixth one, some obstacles in the form of pillars are placed in the virtual world. The users are asked not to collide with these static obstacles while going to the destination points. If the users get teleported very close to the obstacles, collision occurred. We did not give any feedback to the users when a collision occurred not to discourage them, but we stored the collision data in the background.

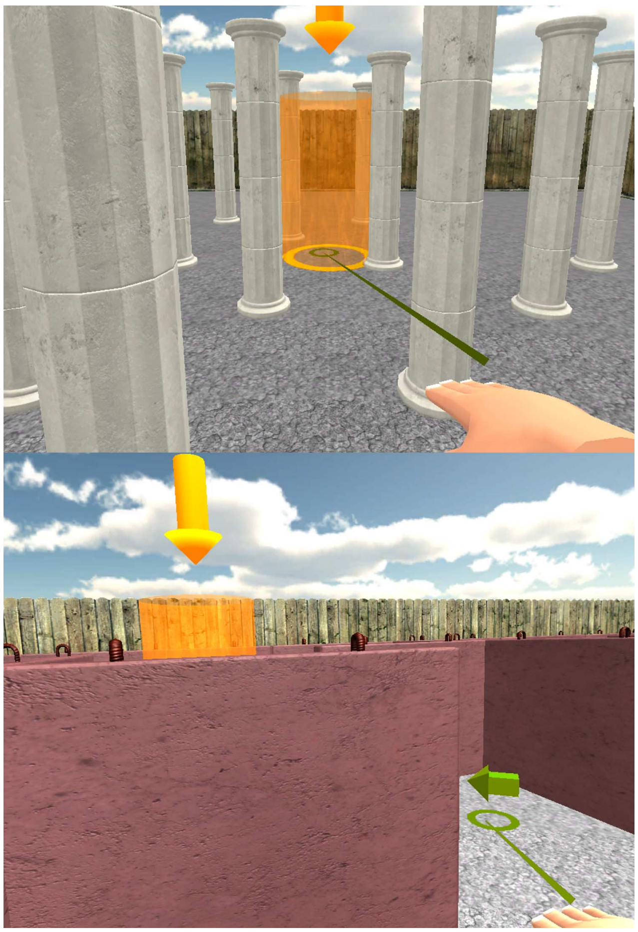


Figure 2: (Top) Experiment one. User points to the destination point. Laser beam and the circle color is close to green, meaning that the user is about to get teleported inside the destination point. (Bottom) Experiment two. User points to the destination point using the direction specification feature. When teleported, the user will be facing the green arrow's

Environment

For the virtual world, a simple 16m by 16m outdoor environment is used. The environment is limited by fence walls of 2.2m height at all sides. After the sixth destination point, 21 cylindrical static obstacles with 0.5m diameter and 2.4m height are placed in the environment. The obstacles are modelled as roman pillars and the distance between each neighbor pillars is 1.77m (Figure 2, top). The environment is designed as simple as possible yet realistic looking for immersion purposes. No distractors or unexpected objects are used to keep the user's attention only on the locomotion.

Experiment Design

The experiment was designed as within subjects with the independent variable of locomotion technique having three levels (*Point & Teleport*, walk-in-place, joystick). Each user was asked to try all three locomotion techniques with a random order. With each locomotion technique, the users needed to go to ten destination points. The first two destination points for each locomotion technique was considered as training, determined by in-house testing, and not taken into account for the results and data analysis. The next four destination points were tested without obstacles and the last four destination points had static obstacles. The user started the testing at the center of the virtual environment. The first destination point appeared 2m away from the user, since it was the first training destination. The rest of the destination points appeared 4m away from the previous destination point and they required 160 to 210 degrees turns between each destination point. There were predefined destination point sets for each locomotion technique to ensure that no learning effect of the destination points interfered with the collected data. During the testing, data was collected for the time passed for each destination point, collision counts and positions as well as the user's real and virtual positions. After each locomotion technique, the users were asked to fill a survey about usability, presence and motion sickness. At the end of all locomotion techniques, the users were asked to rank their preferences. We built the following four hypotheses for experiment one: **Hypothesis 1:** Point & Teleport will be the best technique in terms of enjoyment. **Hypothesis 2:** Point & Teleport will be less effortful than the walk-in-place technique. **Hypothesis 3:** Point & Teleport will result in the lowest motion sickness results. **Hypothesis 4:** Point & Teleport will result in lower number of collisions with obstacles.

User Study

16 participants (11 male, 5 female) aged between 21 and 35 (μ = 26.38, σ = 3.74) participated in the experiment. All participants' dominant side was right. All participants had none to minimal previous VR experience. Due to a hardware malfunction in the testing session of one user, their data was discarded and 15 users' data was used in the analysis.

Procedure

The participants entered the testing laboratory, read and signed the consent form and filled out the demographics questionnaire. Then, we explained the users the system and their objective in the experiment. They were told about the destination points, color changing dynamics of the objects and the obstacles after the sixth destination point and trying not to hit them. After that, we helped the participants wear

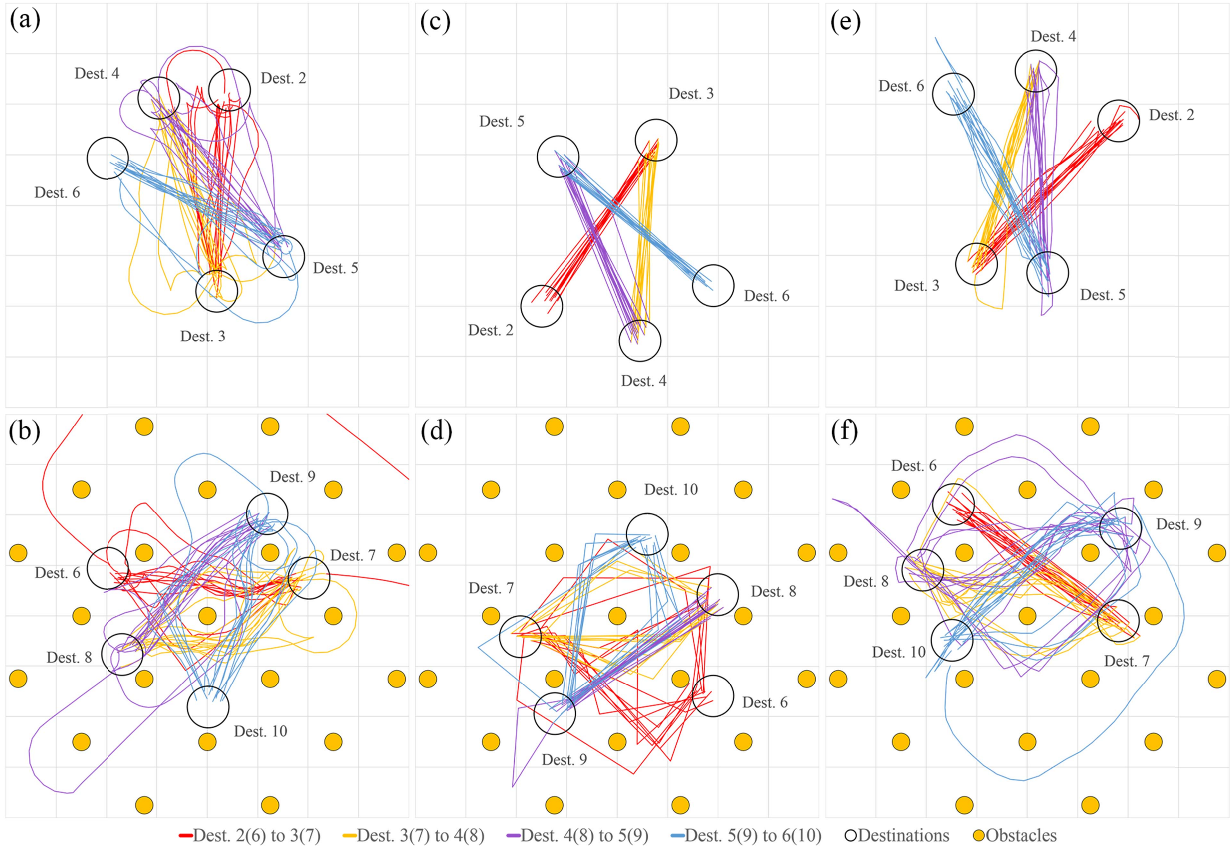


Figure 3: Trajectories of the users' virtual world movements. Joystick (a) without, (b) with obstacles. Point & Teleport (c) without (d) with obstacles. Walk-in-place (e) without (f) with obstacles.

the HMD and the markers for motion tracking and the experiment started. Locomotion methods were assigned to the users randomly but counterbalancing was also done to ensure an even distribution. When the user completed all 10 destination points with a technique, they were given a survey about their experience with that technique. After all techniques were tried, an overall survey was given to the users for the ranking of the methods.

Results

The first two destination points were treated as training and discarded from all data analysis. Trajectories of the virtual world movement of the users are presented in Figure 3. Error bars in all charts are standard error of the mean.

Time to Reach the Destination Points

To analyze the average time it took to reach the destination points with different methods, we divided the data into two groups according to the presence of the obstacles, since the obstacles may have caused longer times (Figure 4). We conducted one way ANOVA analysis and found significant difference between the techniques for both *'without obstacles'* case ($F(2, 12) = 7.707$, $p = 0.001$, F crit. = 3.047) and *'with obstacles'* case ($F(2, 12) = 8.352$, $p = 0.0003$, F crit. = 3.047). When we applied t-tests to pairs of techniques, there was significant difference between *joystick* and *walk-in-place* ($t(14) = -3.455$, $p = 0.001$, Cohen's d = 0.631), and between *Point & Teleport* and *walk-in-place* ($t(14) = -3.256$, $p = 0.001$, Cohen's d = 0.595) for *'without obstacles'* case. As we examined the techniques for *'with obstacles'* case, t-tests resulted in significant difference between *joystick* and *Point & Teleport* ($t(14) = -4.028$, $p = 0.000$, Cohen's d = 0.735), and between *joystick* and *walk-in-place* ($t(14) = -3.544$, $p = 0.001$, Cohen's d = 0.647).

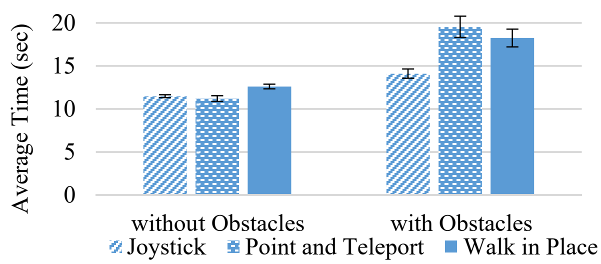


Figure 4: Average time to reach the destination points.

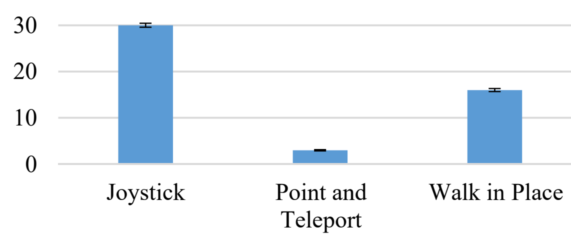


Figure 5: Total number of collisions in the presence obstacles for different locomotion techniques.

Collisions

We looked at how many times the users collided with the obstacle pillars as a measure of their control over the locomotion (Figure 5). One way ANOVA analysis resulted in significant difference between the three techniques ($F(2, 12) = 7.814$, $p = 0.001$, F crit. = 3.22). As we conducted two sample t-tests, there was significant difference between *joystick* and *Point & Teleport* ($t(14) = -4.006$, $p = 0.0004$, Cohen's d = 1.463), and between *Point & Teleport* and *walk-in-place* ($t(14) = 2.402$, $p = 0.023$, Cohen's d = 0.877).

Survey Results on Usability

To analyze the usability of different locomotion techniques, we used a modified version of Loewenthal's core elements of the gaming experience questionnaire [17] with eight different sub categories that are relevant to our evaluation: difficulty of understanding the method, difficulty of operating the method, feeling of being in control while using the method, required effort to use that method, feeling of tiredness the method gave to the user, feeling of enjoyment while using the method, feeling of being overwhelmed while using the method and feeling of frustration the method gave to the user. Each question had answers on a 5 point Likert scale (1: not at all, 5: very much). Results of these eight categories can be seen in Figure 6.

Difficulty of Understanding and Operating the Method

One way ANOVA analysis resulted in significant difference between three techniques ($F(2, 12) = 3.775$, $p = 0.031$, F crit. = 3.22) for difficulty of understanding the locomotion method. Two sample t-tests revealed that the only difference was between *joystick* and w*alk-in-place* ($t(14) = -3.024$, $p = 0.005$, Cohen's d = 1.104). No significant difference was found in one way ANOVA analysis between the three techniques ($F(2, 12) = 2.67$, $p = 0.081$, F crit. = 3.22) in terms of difficulty of operating the locomotion technique.

Feeling in Control

As we conducted one way ANOVA analysis, there was no significant difference between the three locomotion techniques ($F(2, 12) = 2.634$, $p = 0.084$, F crit. = 3.22) in terms of the feeling of being in control they provided.

Effort and Tiredness

One way ANOVA analysis resulted in significant difference ($F(2, 12) = 5.630$, $p = 0.007$, F crit. = 3.22) between the three locomotion techniques in terms of the effort it took to use them. Two sample t-tests resulted in significant difference between *joystick* and *walk-in-place* ($t(14) = -3.286$, $p = 0.003$, Cohen's d = 1.2), and between *Point & Teleport* and *walk-in-place* ($t(14) = -2.055$, $p = 0.049$, Cohen's d = 0.751). As we conducted one way ANOVA analysis to the tiredness data, there was significant difference ($F(2, 12) = 5.851$, $p = 0.006$, F crit. = 3.22). We then conducted two sample t-tests and found significant difference between *joystick* and *walk-in-place* ($t(14) = -3.313$, $p = 0.003$, Cohen's d = 1.21), and between *Point & Teleport* and *walk-in-place* ($t(14) = -2.157$, $p = 0.04$, Cohen's d = 0.788).

Enjoyment, Overwhelmedness and Frustration

One way ANOVA analysis resulted in no significant difference for level of enjoyment ($F(2, 12) = 0.442$, $p = 0.646$, F crit. = 3.22), feeling of being overwhelmed ($F(2, 12) = 0.062$, $p = 0.94$, F crit. = 3.22), and level of frustration ($F(2, 12) = 0.269$, $p = 0.765$, F crit. = 3.22).

Motion Sickness and Presence

To measure motion sickness, a modified version of the Pensacola Diagnostic Criteria survey [16] was used with four levels (0: none, 3: major). The questions measured nauseousness, cold sweating, drowsiness, headache, flushing/warmth and dizziness. One way ANOVA analysis resulted in no significant difference for the motion sickness data ($F(2, 12) = 0.691$, $p = 0.507$, F crit. = 3.22). To measure presence, a modified version of Witmer and Singer's questionnaire [35] was used with four levels (1: not at all, 4: completely). There was no significant difference for level of presence ($F(2, 12) = 0.499$, $p = 0.611$, F crit. = 3.22). Results for motion sickness and presence are presented in Table 1.

	Joystick		Point&Tel.		Walk-in-Place	
	M	**SD**	**M**	**SD**	**M**	**SD**
Motion Sickness	0.067	0.258	0.333	1.047	0.333	0.617
Presence	2.71	0.58	2.87	0.71	2.93	0.58

Table 1. Motion sickness and presence scores.

User Preference

Weighted averages of the user preference ranking scores are presented in Figure 7. *Point & Teleport* got the highest preference score while *walk-in-place* got the lowest. However, as we conducted the Friedman test, no significant difference was found between the ranking scores of the three techniques (χ^2 (2, N = 15) = 2.80, $p = 0.247$).

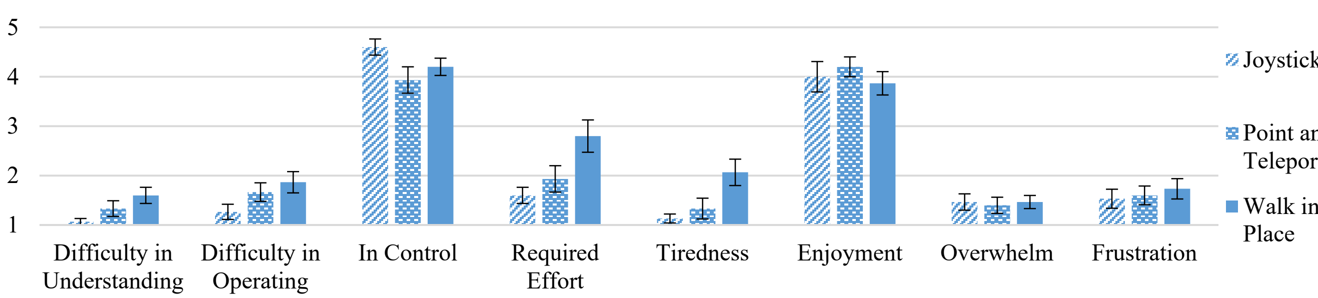


Figure 6: Survey Results for Joystick, Point & Teleport and Walk-in-Place locomotion techniques.

Learning Effect Analysis

In our experiment, the first two destination points were considered as training and the remaining 8 destination points were used to evaluate the techniques. The training number was determined by in-house testing to give the users enough time for comfortable use of the techniques. Simple design of our experiment and the techniques contributed to the low number of training instances required. As we analyzed the data for any correlation to find out if there was any learning effect in the evaluation, no significant correlation was found between the completion time and the destination order (r(Joystick) = 0.113, r(Point & Teleport) = 0.030, r(Walk-in-Place) = -0.109). This can be considered as an evidence for no learning effect being present in our experiment.

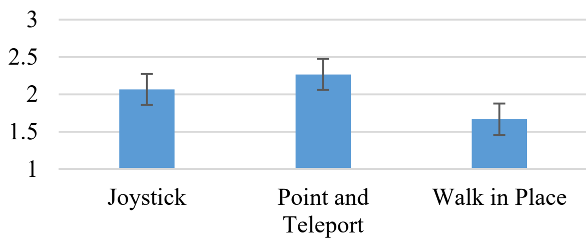


Figure 7: Weighted averages of the user preference ranking.

User Comments

We asked the participants to describe anything they liked, disliked or would like to suggest about each locomotion method. Participants gave many positive comments about the simplicity and usability of *Point & Teleport* "Pointing is very easy and interesting." "Easy to move and avoid obstacles." "This felt more like a video game because I wasn't actually walking to move in VR." "Really cool method. Would be fun for video games." "This method was very easy to use." "I liked the magic wand in my hand." A few users stated that it was a bit challenging using *Point & Teleport* with the obstacle pillars "It was fun and accurate. It got challenging with the columns." "Getting around obstacles was a lot of time. But good for longer, unobstructed distances." For the joystick method, a few users gave positive comments such as "Love this method. No thinking, no effort. Know for sure." There were some negative feedbacks for the joystick as well "It was easier to control the walking but completely conscious that I was controlling from outside." For the walk-in-place method, some users made positive statements "I think it is simple and also have real walk." "Feels more natural when walking and turning at the same time." "While not as easy as joystick, it did feel more immersive." Some users made negative comments about the effort the marching gesture needed in walk-in-place "Needs more effort." "Actually it is intuitive but I cannot walk sideways."

Discussion

When there were no obstacles in the scene, it took similar times to reach the destination points for all three techniques. However, when there were obstacles, it took longer with *Point & Teleport*. We interpret that our triggering method of pointing the same place for two seconds for teleportation may have contributed to this. When the users needed to walk around the obstacles with multiple teleportations, these activation times accumulated. Although we didn't receive any negative comments from the users about the two seconds pointing for teleportation nor observed any impatience in the users while activating the teleportation; we recommend using an instantaneous triggering method such as a controller button in video games that involve many objects to walk around. *Point & Teleport* resulted in significantly lower number of collisions with obstacles than joystick and walk-in-place, which supports Hypothesis 4. This was expected since *Point & Teleport* isn't a process oriented technique. It is rather result oriented. The user only points to where they want to go and does not need to care about the rest. With the other two techniques however, the user needs to control the walking aspect continuously. Walk-in-place was found to be more difficult to understand than the joystick, whereas no difference was found between the *Point & Teleport* and the other two techniques. We interpret this as *Point & Teleport* not exerting significant cognitive load for learning how to use it. All three techniques got high scores for feeling in control and no significant difference was found between them. We interpret this as *Point & Teleport* giving the users a feeling of control as strong as the other two commonly used locomotion techniques. Although joystick got the highest score for the feeling of being in control, we observed that there was a drifting effect in turning with the joystick (see the arcs in Figure 3 (a) and (b)). Although the users could have stopped, turned and then moved forward, they preferred to move forward and turn at the same time, which resulted in unnecessary distances travelled. We did not observe this effect with the other two techniques. Walk-in-place required the users to exert more effort than the other two techniques, which supported Hypothesis 2. Walk-in-place also caused more tiredness in the users than the other two techniques. This can be interpreted as *Point & Teleport* not causing significant effort or tiredness in users, which makes it a favorable candidate for video games in terms of usability. We think that our gesture design may have contributed to this. Lowering the arms while waiting was appreciated by the participants. We think that it is important to keep the users in a relaxed position unless they need to trigger something, to avoid tiredness. *Point & Teleport* enables the users to move very large or small distances with the same minimal effort. It removes the time component from moving inside the virtual world. All techniques got similar scores for enjoyment. While *Point & Teleport* got slightly higher scores, there wasn't evidence to support Hypothesis 1. However, we received very positive comments about the *Point & Teleport* resembling a superpower, being fun and being like a magical experience. The idea of teleportation made the participants excited. Many participants made positive statements about how fun it was like to have a magical power or how cool to emit a laser beam; although what we provided was actually just a simple line. This makes us believe that an embraced theme can contribute greatly to the user experience. Most of the participants made verbal statements such as "Wow" and "Cool" just as we told them the name of the technique. None of the techniques caused feeling of being overwhelmed or frustrated, which makes us think that *Point & Teleport* is a user friendly locomotion technique. All three techniques resulted in low motion sickness results. We couldn't find evidence to support Hypothesis 3. We believe that since the objective of the experiment was designed to be simple to enable the users to concentrate on the locomotion techniques and the environment was also designed to be simple with no moving objects or distractions, not to inject any artificial contributions; the results for the motion sickness turned out to be similar for all techniques. This at least shows that, *Point & Teleport* does not introduce more motion sickness than the two commonly used techniques in static and roomy virtual worlds. We think that *Point & Teleport* may result in lower motion sickness results in more dynamic virtual environments as well since this technique does not present the user locomotion movement of their own, however experiments are needed for scientific and reliable results. We didn't observe any significant effect of the three locomotion techniques on the level of presence. To sum up, experiment results and reactions from the participants make us think that *Point & Teleport* is an intuitive, fun and user friendly way of locomotion with a high potential to be a popular technique in VR video games. We suggest that *Point & Teleport* can be used for low paced adventure or exploration games in which immediate actions such as dodging or moving in small increments aren't necessary. For FPSs, MMORPGs or highly realistic serious games, this technique may not work well.

EXPERIMENT TWO

In our second experiment, *Point & Teleport (P&T)* was compared with a modified version of itself: *Point & Teleport with Direction Specification (P&T w/DS)*. In this modified version, users could specify the direction they would be facing when teleported by rotating their hands in the rolling axis before the teleportation. The same participants who attended experiment one attended the second experiment.

Objective

Experiment two's objective is similar to experiment one. The participants were asked to go to the destination points and wait inside until another destination point appeared somewhere else. Same destination point objects with experiment one were used to designate the target positions. Users completed two trials, each with 6 destination points. One trial was played with *P&T* and the other was played with *P&T w/DS*. Order of the trials was decided randomly with counterbalancing. Destination points of the two trials were different to eliminate any learning effect. The users started the testing at the center of the virtual maze. Each destination point was 8m away from the previous destination point.

Environment

In this experiment, the virtual world was designed as a simple maze (see Figure 2, bottom) to measure effects of the additional direction specification component more effectively. The maze was designed not to be challenging, with 14m length and 14m width. No gaps were placed on the exterior walls so the user could not go outside the virtual maze. The corridors had 2m length for easy navigation. The longest dead-end corridor was 2m long, so the users did not waste too much time if they made wrong path choices. The height of the maze walls was 1.5m, which made it possible for the users to see the destination point from anywhere in the maze. Since the environment was designed as a maze and the maze walls inherently were obstacles, no additional obstacles in the form of pillars were used in this experiment. That's why this experiment had 6 destination points in total.

Experiment Design

Experiment two was also designed as within subjects. Each participant tried both *P&T* and *P&T w/DS* techniques with a random order. Similar to experiment one, first two destination points for each technique were considered as training and discarded, and the remaining four destination points were taken into consideration for evaluation. After each technique, the participants filled out a survey about the technique they tried. After completing both trials, the participants were asked to state their preference between the two techniques on an additional survey question. We built the following hypotheses: **Hypothesis 5:** *P&T w/DS* will give lower average time to reach the destination points. **Hypothesis 6:** *P&T w/DS* will require more effort.

Results

Time to Reach the Destination Points

The average time to reach the destination points are presented in Figure 8. Two sample t-tests resulted in no significant difference ($t(14) = -1.289$, $p = 0.200$, Cohen's $d = 0.235$) in the time it took to reach the destination points.

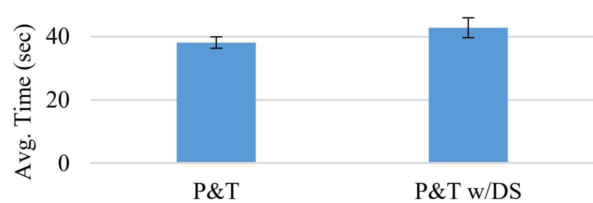


Figure 8: Average time to reach the destination points.

Collisions

In terms of the number of collisions made by the users, two sample t-tests resulted in no significant difference between the two techniques ($t(14) = -1.339$, $p = 0.191$, Cohen's $d = 0.489$). Data can be seen in Figure 9.

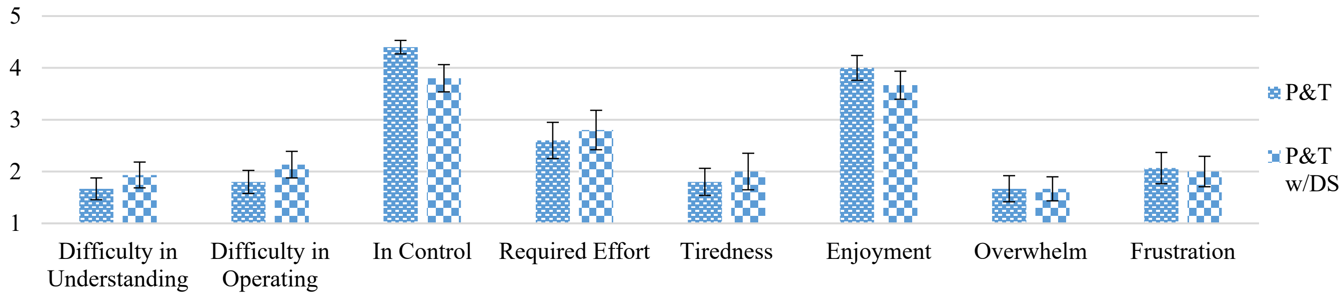


Figure 10: Survey Results for Point & Teleport and Point & Teleport with Direction Specification locomotion techniques.

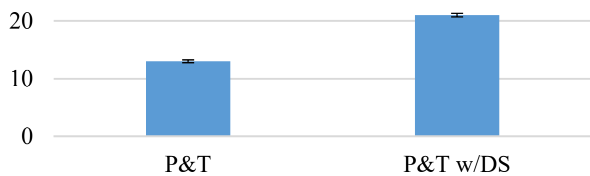


Figure 9: Total number of collisions with maze walls.

Survey Results on Usability

To analyze the usability aspects of the two versions of the *Point & Teleport*, we used the same eight sub categories with experiment one: difficulty in understanding, difficulty in operating, feeling of being in control, required effort to move, feeling of tiredness, enjoyment, being overwhelmed and frustration. Each question had answers on a 5 point Likert scale (1: not at all, 5: very much). Results of these eight categories are presented in Figure 10. As two sample t-tests were conducted, the only significant difference between the two locomotion techniques was in the feeling of being in control (see Table 2). No significant difference was found in terms of motion sickness although P&T w/DS got higher scores (M = 0.47, SD = 1.06) than P&T (M = 0.27, SD = 0.59). Presence results weren't significantly different as well although P&T got slightly higher scores (M = 3.04, SD = 0.52) than P&T w/DS (M = 2.89, SD = 0.50).

User Preference

To analyze the user preference data (Figure 11), we conducted the Friedman test and found no significant difference (χ^2 (1, N = 15) = 0.067, p = 0.796).

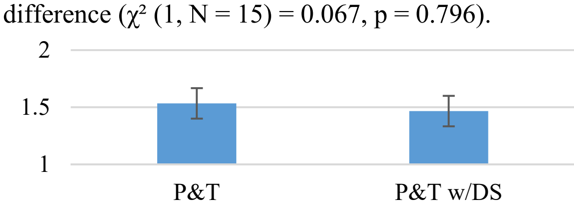


Figure 11: Weighted average user preference ranking.

User Comments

Many users stated preference for P&T over P&T w/DS in their comments "I liked this method [P&T]. It made navigating the maze relatively easy." "I think it is [P&T] better than the first one [P&T w/DS]. I am not very dizzy." "I like pointing and then I look for directions. I think I do it faster this way."

	t	df	p	Cohen's d
Diff. Understand	-0.819	14	0.420	0.299
Diff. Operate	-0.983	14	0.334	0.359
In Control	2.049	14	0.050	0.748
Required Effort	-0.387	14	0.701	0.141
Tiredness	-0.456	14	0.652	0.167
Enjoyment	0.924	14	0.363	0.337
Overwhelm	0.000	14	1.000	0.000
Frustration	0.159	14	0.875	0.058
Motion Sickness	-0.638	14	0.529	0.233
Presence	0.838	14	0.409	0.306

Table 2. T-test results for the survey data of experiment two.

"It was easier overall to reach my destination in this method [P&T]." Only a few users made comments stating preference over *P&T w/DS* such as "I liked the added control of choosing the direction. It made the method feel more efficient." A lot of users complained about feeling dizzy or disoriented with *P&T w/DS* "Might be [P&T w/DS] more confusing than before [P&T]. Difficult to fully realize own orientation after teleporting." "A little bit dizziness for me [with P&T w/DS]." "While I really liked this method [P&T w/DS] over regular teleporting [P&T], the directional controls were a bit touchy. Accordingly, I sometimes felt a little disoriented."

Discussion

Average time to reach the destination points was similar for the two techniques, not supporting Hypothesis 5. In fact, it took more time to reach the destination points with *P&T w/DS* as opposed to what we expected. No difference was observed in the required effort to use the two techniques, not supporting Hypothesis 6, although *P&T w/DS* required slightly more effort. *P&T w/DS* resulted in slightly higher motion sickness results. User preference results were similar between the two techniques. *P&T w/DS* was more difficult to operate and understand. We interpret this as the effect caused from merging two components of moving and rotating into one in this modified version. In the original *P&T,* users controlled the locomotion sequentially; first they moved to the desired location, then they turned to face wherever they wanted. *P&T w/DS* merged these components and induced more cognitive load in users. We received a lot of complaints about the feeling of disoriented and dizziness *P&T w/DS* caused whereas none for the *P&T*. Since *P&T w/DS* changed the environment's orientation instantly, this may have caused disorientation in the users. Hence, we do not recommend using the additional direction specification feature and we recommend keeping *P&T* in its simple form. As possible solutions to disorientation, we recommend using in game mini maps or making the user's previous position marked for a while after they teleport to somewhere else to help them maintain their sense of orientation. To wrap up, although we expected the additional direction specification feature to enhance the *P&T* locomotion technique, experiment results indicated the opposite.

CONCLUSION

In this study, *Point & Teleport* locomotion technique is described and evaluated. Two VR experiments were designed and performed with 16 participants. In experiment one, *Point & Teleport* was compared with walk-in-place and joystick locomotion techniques. In experiment two, a direction component was added to the *P&T* so that the users could specify their post teleportation orientation beforehand. Results indicated that *Point & Teleport* is an intuitive, easy to use and fun locomotion technique. However, the additional direction specification component degraded the user experience. Future work may consist of evaluating the *P&T* in more dynamic, challenging and high paced virtual environments, especially regarding motion sickness and disorientation, exploring the controller triggered version and studying the usability of *P&T* for multiplayer games.

REFERENCES

1. Benjamin Bolte, Gerd Bruder, and Frank Steinicke. 2011. The Jumper Metaphor: An Effective Navigation Technique for Immersive Display Setups. In *Proceedings of the Virtual Reality International Conference* (VRIC) (2011), 1-7.
2. Doug A. Bowman, Ernst Kruijff, Joseph J. Laviola, and Ivan Poupyrev. 2004. *3D User Interfaces: Theory and Practice*. Addison Wesley Longman Publishing Co., Inc.
3. Tuncay Cakmak and Holger Hager. 2014. Cyberith virtualizer: a locomotion device for virtual reality. In *Proceedings of the ACM SIGGRAPH 2014 Emerging Technologies* (Vancouver, Canada2014), ACM, 2614105, 1-1. http://dx.doi.org/10.1145/2614066.2614105.
4. Creative Assembly. 2014. *Alien: Isolation*. Game [Oculus]. (7 October 2014). Sega, Tokyo, Japan.
5. Rudolph P. Darken, William R. Cockayne, and David Carmein. 1997. The omni-directional treadmill: a locomotion device for virtual worlds. In *Proceedings of the Proceedings of the 10th annual ACM symposium on User interface software and technology* (Banff, Alberta, Canada1997), ACM, 263550, 213-221. http://dx.doi.org/10.1145/263407.263550.
6. Kiran J. Fernandes, Vinesh Raja, and Julian Eyre. 2003. Cybersphere: the fully immersive spherical projection system. *Commun*. ACM 46, 9, 141-146. http://dx.doi.org/10.1145/903893.903929.
7. Sebastian Freitag, Dominik Rausch, and Torsten Kuhlen. 2014. Reorientation in virtual environments using interactive portals. In *3D User Interfaces (3DUI), 2014 IEEE Symposium on*, 119-122. http://dx.doi.org/10.1109/3DUI.2014.6798852.
8. Cardboard Google. Retrieved April 15, 2016 from https://www.google.com/get/cardboard/
9. Kelly S Hale and Kay M Stanney, 2014. *Handbook of virtual environments: Design, implementation, and applications*. CRC Press.
10. Htc Vive. Retrieved April 15, 2016 from https://www.htcvive.com/
11. I-Illusions. 2016. *Space Pirate Trainer*. Game [HTC Vive]. (April 5, 2016). I-Illusions, Brussels, Belgium.
12. Hiroo Iwata. 1999. The Torus Treadmill: realizing locomotion in VEs. *Computer Graphics and Applications, IEEE* 19, 6, 30-35. http://dx.doi.org/10.1109/38.799737.
13. Hiroo Iwata, Hiroaki Yano, Hiroyuki Fukushima, and Hirokazu Noma. 2005. CirculaFloor [locomotion interface]. *Computer Graphics and Applications, IEEE* 25, 1, 64-67. http://dx.doi.org/10.1109/MCG.2005.5.
14. Hiroo Iwata, Hiroaki Yano, and Hiroshi Tomioka. 2006. Powered shoes. In *Proceedings of the ACM SIGGRAPH 2006 Emerging technologies* (Boston, Massachusetts2006), ACM, 1179162, 28. http://dx.doi.org/10.1145/1179133.1179162.
15. Huang Jiung-Yao. 2003. An omnidirectional stroll-based virtual reality interface and its application on overhead crane training. *Multimedia, IEEE Transactions on* 5, 1, 39-51. http://dx.doi.org/10.1109/TMM.2003.808822.
16. Ben D Lawson, David A Graeber, Andrew M Mead, and Er Muth. 2002. Signs and symptoms of human syndromes associated with synthetic experiences. In *Handbook of virtual environments: Design, implementation, and applications*, 589-618.
17. Kate Miriam Loewenthal. 2001. *An introduction to psychological tests and scales*. Psychology Press.
18. Eliana Medina, Ruth Fruland, and Suzanne Weghorst. 2008. Virtusphere: Walking in a Human Size VR "Hamster Ball". In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 52, 27 (September 1, 2008), 2102-2106. http://dx.doi.org/10.1177/154193120805202704.
19. Niels Nilsson, Stefania Serafin, Morten Laursen, Kasper Pedersen, Erik Sikstrom, and Rolf Nordahl. 2013. Tapping-In-Place: Increasing the naturalness of immersive walking-in-place locomotion through novel gestural input. In *3D User Interfaces (3DUI), 2013*

IEEE Symposium on, 31-38. http://dx.doi.org/10.1109/3DUI.2013.6550193.

20. Oculus Rift. Retrieved April 15, 2016 from https://www.oculus.com/
21. Tabitha Peck, Henry Fuchs, and Mary Whitton. 2010. Improved Redirection with Distractors: A large-scale-real-walking locomotion interface and its effect on navigation in virtual environments. In *Virtual Reality Conference (VR)*, 2010 IEEE, 35-38. http://dx.doi.org/10.1109/VR.2010.5444816.
22. Sharif Razzaque, Zachariah Kohn, and Mary C Whitton. 2001. *Redirected Walking*. Technical Report. University of North Carolina at Chapel Hill.
23. Samsung - Gear Vr. Retrieved April 15, 2016 from http://www.samsung.com/us/explore/gear-vr/
24. Mel Slater, Anthony Steed, and Martin Usoh. 1995. The virtual treadmill: a naturalistic metaphor for navigation in immersive virtual environments. In *Proceedings of the Selected papers of the Eurographics workshops on Virtual environments '95* (Barcelona, Spain1995), Springer-Verlag, 237143, 135-148.
25. Jan Souman, Paolo Robuffo Giordano, Martin Schwaiger, Ilja Frissen, Thomas Thummel, Heinz Ulbrich, Alessandro De Luca, Heinrich Bulthoff, and Marc Ernst. 2008. CyberWalk: Enabling unconstrained omnidirectional walking through virtual environments. *ACM Trans. Appl. Percept*. 8, 4, 1-22. http://dx.doi.org/10.1145/2043603.2043607.
26. Frank Steinicke, Gerd Bruder, Jason Jerald, Harald Frenz, and Markus Lappe. 2010. Estimation of Detection Thresholds for Redirected Walking Techniques. *IEEE Transactions on Visualization and Computer Graphics* 16, 1, 17-27. http://dx.doi.org/10.1109/tvcg.2009.62.
27. StressLevelZero. 2016. *Hover Junkers*. Game [HTC Vive]. (April 5, 2016). StressLevelZero, Los Angeles, CA, USA.
28. Evan. A. Suma, Seth Clark, David Krum, Samantha Finkelstein, Mark Bolas, and Zachary Warte. 2011. Leveraging change blindness for redirection in virtual environments. In *Virtual Reality Conference (VR),* 2011 IEEE, 159-166. http://dx.doi.org/10.1109/VR.2011.5759455.
29. Minghadi Suryajaya, Tim Lambert, and Chris Fowler. 2009. Camera-based OBDP locomotion system. In *Proceedings of the Proceedings of the 16th ACM Symposium on Virtual Reality Software and Technology* (Kyoto, Japan2009), ACM, 1643938, 31-34. http://dx.doi.org/10.1145/1643928.1643938.
30. David Swapp, Julian Williams, and Anthony Steed. 2010. The implementation of a novel walking interface within an immersive display. In *3D User Interfaces (3DUI), 2010 IEEE Symposium on*, 71-74. http://dx.doi.org/10.1109/3DUI.2010.5444717.
31. Tammeka Games. 2016. *Radial-G : Racing Revolved*. Game [Oculus]. (28 March 2016). Tammeka Games, Brighton, UK.
32. Dimitar Valkov, Frank Steinicke, Gerd Bruder, and Klaus Hinrichs. 2010. A multi-touch enabled human-transporter metaphor for virtual 3D traveling. In *3D User Interfaces (3DUI)*, *2010 IEEE Symposium on*, 79-82. http://dx.doi.org/10.1109/3DUI.2010.5444715.
33. Khrystyna Vasylevska, Hannes Kaufmann, Mark Bolas, and Evan Suma. 2013. Flexible spaces: Dynamic layout generation for infinite walking in virtual environments. In *3D User Interfaces (3DUI), 2013 IEEE Symposium on*, 39-42. http://dx.doi.org/10.1109/3DUI.2013.6550194.
34. Betsy Williams, Gayathri Narasimham, Bjoern Rump, Timothy P. Mcnamara, Thomas H. Carr, John Rieser, and Bobby Bodenheimer. 2007. Exploring large virtual environments with an HMD when physical space is limited. In *Proceedings of the Proceedings of the 4th symposium on Applied perception in graphics and visualization* (Tubingen, Germany2007), ACM, 1272590, 41-48. http://dx.doi.org/10.1145/1272582.1272590.
35. Bob G. Witmer and Michael J. Singer. 1998. Measuring Presence in Virtual Environments: A Presence Questionnaire. *Presence: Teleoper. Virtual Environ*. 7, 3, 225-240. http://dx.doi.org/10.1162/105474698565686.