Effects of Controller-based Locomotion on Player Experience in a Virtual Reality Exploration Game

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ABSTRACT

Entertainment and in particular gaming is currently considered one of the main application scenarios for virtual reality (VR). The majority of current games rely on any form of locomotion through the virtual environment while some techniques can lead to simulator sickness. Game developers are currently implementing a wide variety of locomotion techniques to cope with simulator sickness (e.g. teleportation). In this work we implemented and evaluated four different controller-based locomotion methods that are popular in current VR games (free teleport, fixpoint teleport, touchpad-based, automatic). We conducted a user study ($n = 24$) in which participants explored a virtual zoo with these four different controller-based locomotion methods and assessed their effects on discomfort, presence, enjoyment, and affective state. The results of our study show that free teleport locomotion elicited least discomfort and provided the highest scores for enjoyment, presence, and affective state. With these results we gained valuable insights for developers and researchers implementing first person locomotion in VR experiences.

CCS CONCEPTS

• **Human-centered computing → Virtual reality;** • **Applied computing → Computer games;** • **Software and its engineering → Interactive games;**

KEYWORDS

virtual reality, game, locomotion, player experience

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1 INTRODUCTION

With the recent release of several consumer grade VR HMDs, there has been growing interest in the design and development of VR games. As a result, player experience research has been increasingly concerned with interaction in VR gaming. Games in general as well as VR games frequently require that the player can move from one position to another. While providing such an interaction is easy in non-VR games it can be quite challenging for VR games. Although locomotion is possible for roomscale VR systems like the HTC Vive [12] the available space is too limited for the requirements of a lot of games. Therefore, game developers employ many different approaches to provide locomotion for players. Commonly however, techniques suffer from problems such as discomfort (cybersickness) [8] what might be an effect of the visual and vestibular system being stimulated with conflicting information.

There are many technical approaches providing interesting solutions to the problem of locomotion in VR (cf. Section 2). However, due to hardware constraints many VR game developers employ techniques that involve the controllers that are used by a specific VR HMD. Controllers such as the HTC Vive controllers [12], Oculus Touch [25], or the Move controllers for Playstation VR [29] provide 6DOF tracking as well as several hardware buttons that are similar to game pad buttons. Input on these controllers can still be realized in very different ways. Research has shown that the game interface can affect player experience variables such as enjoyment, motivation, and perceived realism [1, 20, 27]. Further, there are guidelines that aim to give guidance for developers implementing locomotion, e.g. how to avoid discomfort [24]. However, there has been little empirical evidence regarding the effects of locomotion methods, which are commonly implemented in VR games, on player experience.

In this paper, we present a study examining the effects of four frequently used first person controller-based locomotion techniques on player experience in a VR game. Results show that free teleport locomotion provides the best player experience while simultaneously eliciting the lowest discomfort of the compared techniques.

2 RELATED WORK

There is a variety of research on the influence of the game interface on the player. In general, research has shown that the form of interaction with a game can affect enjoyment, motivation, and perceived realism [1, 20, 27] and as a result player experience. Further, effects of game interaction have

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been examined in the light of physicality [10, 11, 18, 23] and social interaction [5, 9, 15, 32].
Due to the disconnection of real and virtual world, designing input for VR experiences seems especially challenging. Approaches like omni-directional treadmills [7], redirected walking [26], or gesture-based locomotion [28] provide creative and promising solutions to the challenge of delivering realistic, comfortable locomotion in VR experiences. As these approaches require dedicated hardware [7], large tracking spaces [26], or appear to be tiring in longer VR sessions [28], current VR games mostly use regular controller-based locomotion techniques (e.g. [2, 6, 21, 31]).

Recently, Bozgeyikli et al. presented *Point & Teleport* [3], a locomotion technique in that players are teleported to a specific position to that they point with their finger. In their user study, the authors compared *Point & Teleport* to joystick locomotion and a gesture-based *walk-in-place* locomotion method. Even though there was a slight trend of preference for the *Point & Teleport* locomotion method and differences in levels of tiredness were found, the results did not indicate significant differences of the locomotion method on enjoyment, discomfort, and presence.
While several approaches to locomotion seem promising, they have not yet reached the mainstream VR game market. The effects of locomotion techniques that are used in commercial games, however, have not been examined thoroughly.

3 CONTROLLER-BASED LOCOMOTION

In general, there are many ways first person locomotion can be realized using controllers such as the HTC Vive controllers or Oculus Touch. In this work, we focused on four methods that are prevalent in contemporary VR games. In particular, we were interested in locomotion methods that can be used for first person locomotion that is independent of a specific game. For example, we did not consider any locomotion methods that use vehicles as a surrogate.

3.1 Free Teleport Locomotion

Free teleport (see Figure 1) is a locomotion that allows players to use their controller to point to a specific position in their vicinity in order to move their avatar there. Usually, players press a button to start a teleportation mode that enables a virtual ray or arc that is used to specify the desired destination. After releasing the button or pressing another button the player avatar is teleported to the specified destination. Free teleport is a locomotion method that is used in several successful VR games (e.g. *Arizona Sunshine* [31]) and the HTC Vive home application [13].

3.2 Fixpoint Teleport Locomotion

Fixpoint teleport locomotion (see Figure 2) is a technique with that players use a pointer that is based on their controller's direction in order to teleport to a specific destination. This technique provides less freedom with regard to the options the player can move to, but allows fast locomotion. Several VR wave defense shooter use such a locomotion technique in order to allow players to change their position (e.g. *QuiVR* [2]). Many of these games feature several dedicated positions from that players can defend against the waves of enemies. In some games people can move in a limited space around the defensive position, e.g. on part of a wall on that they stand. However, changing positions usually denotes teleporting to a specific fixed position.

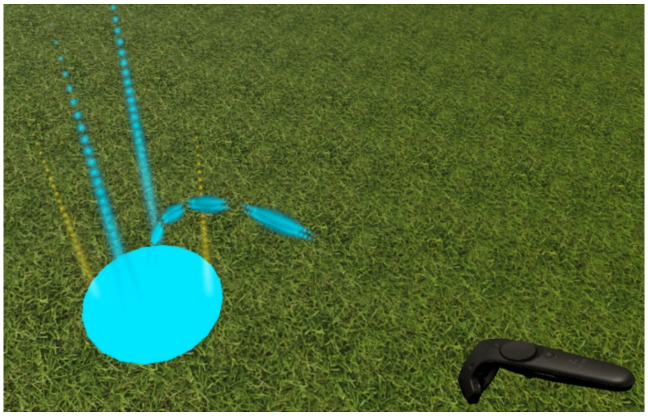

Figure 1: Free teleport locomotion allows players to teleport freely to any reachable position in the world. Here the target location is marked by a beacon that is on the end of an arc based on the controllers rotation.

Figure 2: Fixpoint teleport locomotion allows players to teleport to specific positions in the world. Here these positions are marked by glowing beacons.

3.3 Indirect Locomotion

In games that don't provide a teleport-based locomotion method, players are sometimes provided with a locomotion technique that is based on game pad input (e.g. *Onward* [14] and *Resident Evil 7 VR* [6]). Similar to input on classic game controllers, players can move their character forward by pressing forward on a joystick (cf. Oculus Touch) or on a touchpad (cf. HTC Vive).

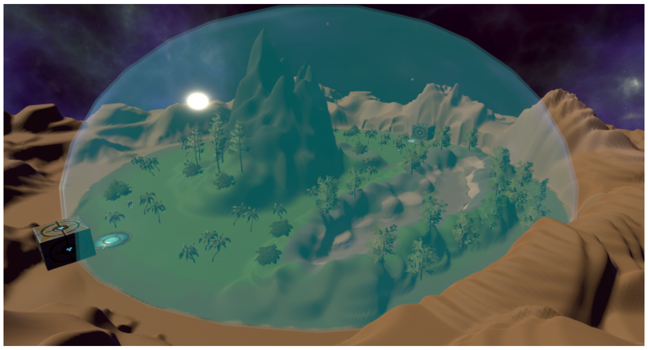

Figure 3: Compounds in *VRZoo* are contained areas that provide enough space for exploring.

3.4 Automatic Locomotion

While players can look around freely, the locomotion of the character is automated in some games. Different implementations are possible for automated locomotion. The player avatar automatically walks in the direction the player is looking (e.g. *Deadly Labyrinth VR* [30]) or the players' position moves, but is uncoupled from the players' viewing direction (e.g. rail shooters like such as *Driftwatch VR* [21]).

4 VRZOO

We implemented *VRZoo*, a virtual environment featuring a futuristic zoo that players could explore with the four described locomotion methods. It contains five areas: four compounds and a main hub area from that the compounds can be entered. Each compound contains a specific type of living (i.e. bear, horse, humpback whale) or extinct animal (i.e. allosaurus). The compounds are designed as free spaces under glass domes (see Figure 3). Thus, the compounds provide a large area that players can explore in order to observe animals. *VRZoo* further contains an adaptive information system that provides information about the animals of the compound the player currently resides in. There is no goal or victory condition in *VRZoo* and players can freely explore the virtual world in order to learn about animals or just to experience the atmosphere. Thus, *VRZoo* can be classified as an exploratory virtual reality experience and as a serious game.

5 EXPERIMENT

The goal of this user study was to explore the effects of several controller-based locomotion methods on player experience. We implemented *VRZoo* with four locomotion methods (cf. Section 3) for the HTC Vive: free teleport locomotion (FT), fixpoint teleport locomotion (FPT), touchpad locomotion (TPM) as an implementation of indirect locomotion, and guided locomotion (GM), an implementation of automatic movement with uncoupled viewing direction. For FPT there were several points distributed in *VRZoo*. Similarly, a fixed path was designed through the compounds for GM on that players automatically moved. They could look around freely and adjust movement speed to their liking. The movement speed for GM and TPM was capped 1.4 km/h, which is deemed a comfortable speed [24]. There are several instruments measuring the complex construct of player experience (cf. [22]). Frequently, these instruments are used to assess experience related to a specific activity (e.g.[19]). However, in this study we wanted to examine experience on a more abstract level and dependent on the locomotion alone. Thus, we employed questionnaires measuring several variables that are related to the players' experience. We considered discomfort, general affective state, enjoyment, and presence important variables for locomotion input techniques in VR.

5.1 Participants

We recruited 24 participants (female = 7, male = 17) with an average age of 27.04 years ($SD = 4.02$). On average they reported playing video games for 6.29 hours per week ($SD = 7.77$), but only one participant reported regularly using VR games and apps. On average they reported a total experience with VR games and apps of 2.67 hours ($SD = 8.27$).

5.2 Procedure

The user study took place in a university computer lab on a PC featuring an HTC Vive with its hand tracked controllers and a play space of approximately 2x3 meters. Participants were introduced to the main goal of the user study and were informed that they could stop the study at any point. Then, they answered an introductory demographic questionnaire and were introduced to *VRZoo* as well as the HTC Vive and its controllers in general. Subsequently, they were introduced to one locomotion method and then explored one area of *VRZoo* for 5 minutes before answering a questionnaire about their experience and switching to the next method. The participants initially were placed at the center of the main hub area of *VRZoo* and could choose to explore the compound they wanted. Initial viewing direction was randomized in order to avoid a bias to a specific compound and as a result influence of the design of the compound on the ratings of the locomotion methods. The participants reported their current level of simulator sickness via the SSQ [16], their affective state with the SAM [4], and their presence and enjoyment with an adapted version of the E^2I [17] questionnaire. The order of the locomotion methods was counter-balanced using a Latin square. After completing all sessions with the different locomotion methods they completed a final questionnaire in that they had the chance to give final qualitative feedback. Participants were compensated with 5 euros.

6 RESULTS

6.1 Simulator Sickness

SSQ nausea, oculomotor, disorientation, and total score were calculated and were analyzed with Friedman tests due to non-normality. Significance levels for the pairwise comparisons were adjusted for number of tests (adjusted significances are reported). A Friedman test revealed that SSQ nausea scores were significantly influenced by the locomotion method $\chi^2(3) = 14.643$, $p = .002$. The pairwise comparisons showed

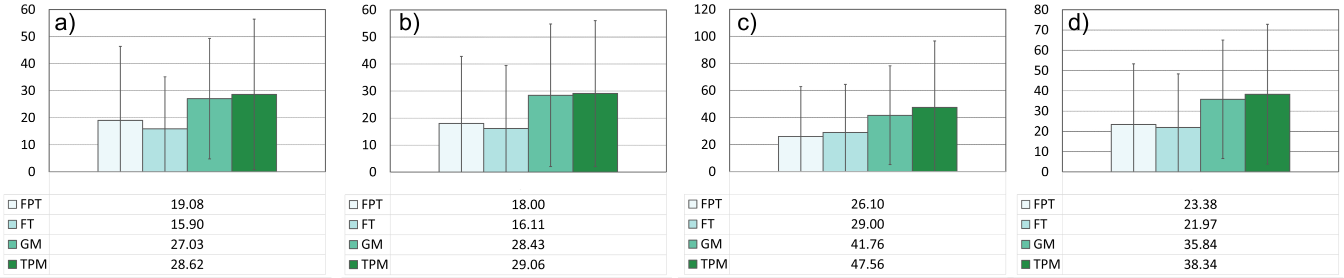

Figure 4: Overview of the (a) SSQ nausea, (b) SSQ oculomotor, (c) SSQ disorientation, and (d) SSQ total scores for fixpoint teleport locomotion (FPT), free teleport locomotion (FT), guided locomotion (GM), and touchpad locomotion (TPM). Displayed values are means while error bars indicate ± standard deviations. Lower scores indicate less discomfort.

that FT elicited significantly lower nausea scores than GM, $p = .022$. SSQ oculomotor scores were influenced by the locomotion method as well, $\chi^2(3) = 15.453$, $p = .001$. Post hoc tests revealed significantly lower scores for FT compared to TPM, $p = .031$. The locomotion method did not significantly influence SSQ disorientation scores, $\chi^2(3) = 6.911$, $p = .075$. SSQ total scores were significantly affected by the locomotion method, $\chi^2(3) = 13.859$, $p = .003$. The follow up tests showed that FT led to significantly lower scores than TPM, $p = .037$. For an overview of the SSQ scores see Figure 4.

6.2 Presence & Enjoyment

Presence scores were normally distributed while enjoyment and E^2I total score were not. Mauchly's test indicated that the assumption of sphericity had not been violated for the presence scores, $\chi^2(5) = 3.743$. A repeated measures ANOVA revealed a significant effect of the locomotion method on presence scores, $F(3,69) = 8.474$, $p < .001$. Bonferroni post hoc tests revealed higher presence scores for FT compared to FPT, $p = .001$, $r = .42$, and compared to GM, $p < .001$, $r = .74$. A Friedman test showed a significant effect of the locomotion method on enjoyment scores, $\chi^2(3) = 31.681$, $p < .001$. Enjoyment ratings for FT were significantly higher than ratings for TPM, $p = .037$, as well as ratings for GM, $p < .001$. Further, FPT elicited significantly higher enjoyment than GM, $p = 0.013$. E^2I total score was significantly influenced by the locomotion method, $\chi^2(3) = 35.240$, $p < .001$. The participants rated FT significantly higher than FPT, $p < .001$, as well as TPM, $p = .013$, and GM, $p < .001$. For an overview of the E^2I scores see Figure 5.

6.3 Affective State

Valence, arousal, and dominance scores were not normally distributed. A Friedman test revealed a significant effect of the locomotion method on valence scores, $\chi^2(3) = 28.587$, $p < .001$. Pairwise comparisons revealed that FT led to higher scores compared to TPM, $p = .009$, and compared to GM, $p < .001$. Arousal scores were not influenced by the locomotion method, $\chi^2(3) = 5.632$, $p = .131$. The locomotion method influenced dominance scores, $\chi^2 = 28.921$, $p < .001$. Participants rated FT higher than GM, $p < .001$. For an overview of the SAM scores see Figure 6.

6.4 Qualitative Results

The comments of the participants confirm the quantitative results of the user study. Several participants stated that GM and TPM were too slow to be able to fully explore the environment. Similarly, one participant reported that they liked FT most because they could control the mode best and reach the desired destination fastest. Further, one participant noted that they "felt discomfort as soon as they started going backwards" when using TPM.

6.5 Summary of Results

Overall, the results of the study showed that free teleport locomotion led to less discomfort than touchpad locomotion and guided locomotion, but not compared to fixpoint teleport. Regarding E^2I scores free teleport elicited higher presence than fixpoint locomotion and guided locomotion as well as highest enjoyment and E^2I total score compared to the other locomotion methods. Similarly, free teleport led to higher valence and dominance ratings in comparison with the other techniques. In summary, free teleport provided the best player experience and guided locomotion was overall rated worst.

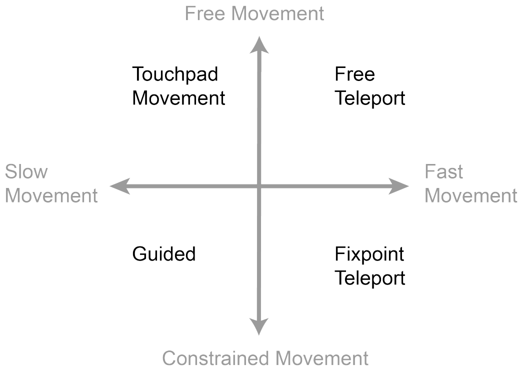

Figure 7: The examined locomotion techniques can be divided into fast/slow and free/constrained locomotion.

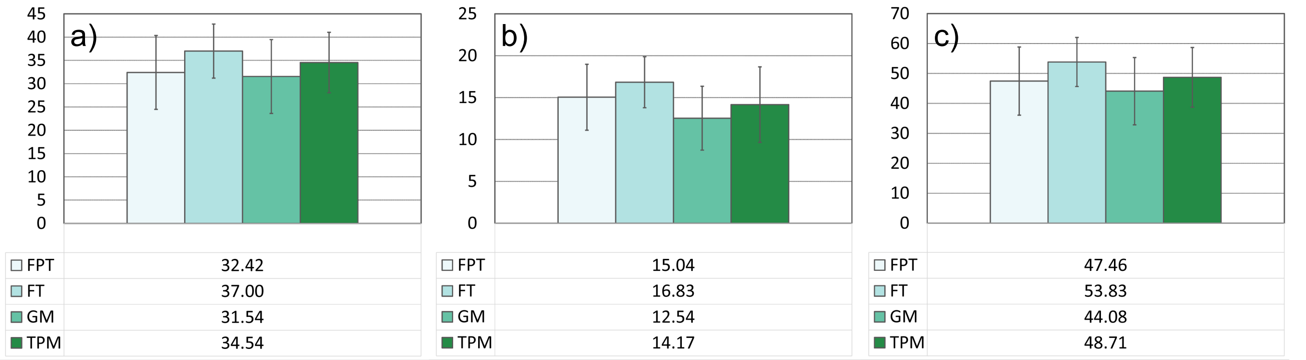

Figure 5: Overview of the (a) E^2I presence, (b) E^2I enjoyment, and (c) E^2I total scores for fixpoint teleport locomotion (*FPT*), free teleport locomotion (*FT*), guided locomotion (*GM*), and touchpad locomotion (*TPM*). Displayed values are means while error bars indicate ± standard deviations.

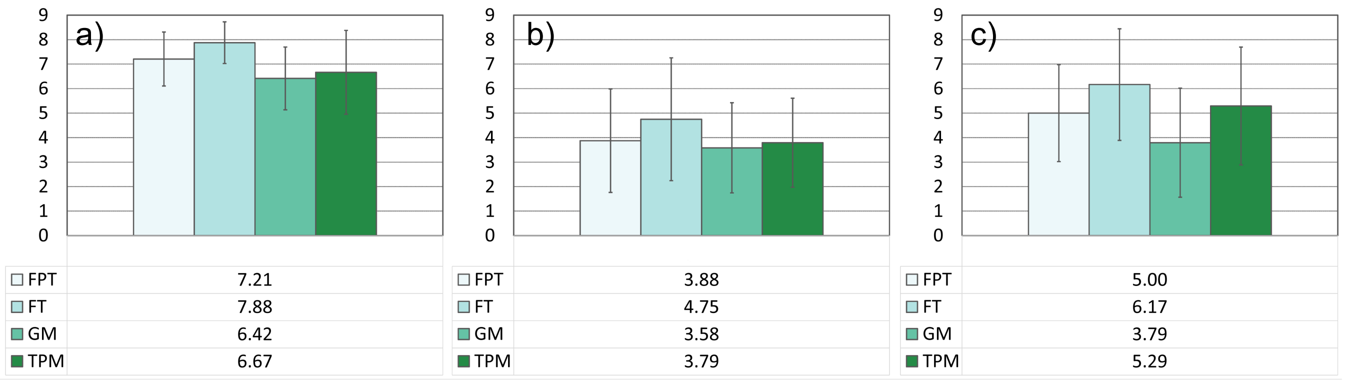

Figure 6: Overview of the SAM scores for (a) valence, (b) arousal, and (c) dominance for fixpoint teleport locomotion (*FPT*), free teleport locomotion (*FT*), guided locomotion (*GM*), and touchpad locomotion (*TPM*). Displayed values are means while error bars indicate ± standard deviations.

7 DISCUSSION

Although in this study free teleport locomotion provided the best player experience of the compared locomotion methods, these results are based on a specific implementation of the techniques. For example, we chose to implement indirect locomotion on the touchpad and we chose to implement automatic locomotion that is similar to rail shooter locomotion. However, other implementations could have been possible as well and different implementation of other methods might lead to different results. Similarly, we chose to limit the speed of these methods to values that are deemed comfortable. However, some participants noted that this speed was too slow. Thus, for an optimal experience it seems necessary to let players decide themselves what thresholds they consider suitable.

In this study, free teleport locomotion provided overall the best player experience of the examined locomotion techniques. Qualitative results suggest that this might be due to the fact that it was a fast and free method to explore the virtual environment. When looking at the characteristics of the locomotion methods we can classify a technique depending on its speed (fast vs. slow) and its degree of freedom (free vs. constrained) (see Figure 7). In our study the technique was rated better the faster and the more free it was. Another possible explanation might be the absence of optical flow for the teleportation modes.

Participants had to rate locomotion methods in a game that promotes exploring. It might be possible that free teleport performed so well as it is best suited for such a game due to its parameters. In another game that promotes different kind of game play, e.g. VR wave shooters, other results might be possible. Aspects such as discomfort might be independent of the game. Therefore, we plan to conduct further studies in future work to examine if the results are generalizable to other games. Moreover, we plan to conduct a follow-up study examining if the effect of the locomotion techniques can be broken down to underlying factors of the method, i.e. if factors like locomotion speed and freedom actually are the parameters that influence the experience what might be suggested by the results.

8 CONCLUSION

In this work we presented an examination of the effects of four first person controller-based locomotion methods on player experience in VR games. We implemented *VRZoo*, a virtual environment that players could explore with four locomotion techniques popular in current VR games. Results show that free teleport locomotion provides the best experience. It elicited less discomfort than an automatic locomotion method and touchpad locomotion and provided the highest scores for enjoyment, presence, and affective state. The results of this work can help guide developers and researchers implementing first person locomotion in VR experiences. In future work we plan to further identify parameters (e.g. locomotion speed) influencing experience in more detail.

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