Integrating Continuous and Teleporting VR Locomotion into a Seamless "HyperJump" Paradigm

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1 Introduction

Virtual reality comes with many promises. It allows us to explore the world in ways that were not possible before, like flying untethered or teleporting, experiencing a dream-like state while fully awake, or having a world that responds to our every whim through the blinking of our eyes or gesture of our hands. To fulfill many potentials it bears, it should allow users to navigate freely through the virtual world they create.

A virtual reality interface ideally should warrant a fun, compelling and immersive experience. The interface should feel natural. It should minimize cybersickness. It should allow users to perform additional actions while navigating, like looking around by directing our heads and eyes in the direction other than our travel path, or using hands to interact with the virtual objects while navigating [19]. It should also support automatic spatial updating in a manner comparable to the real world.

Based on these criteria, leaning-based interfaces, one method of continuous locomotion, perform well on many fronts. The interface provides partial body-based sensory information and effectively reduce cybersickness [4, 13]. Existing studies also show that partial body-based interface enhances spatial perception and orientation [7, 13], the sensation of self-motion, i.e. vection [9, 14], immersion [11], presence and engagement [7–9] compared to interfaces with no body-based sensory information. At the same time, it performs comparably with standard device-based interfaces [18]. Further, for leaning-based interfaces the hands are free (and can be used for interaction) and the looking direction is independent of the travel path. However, they can cause physical exhaustion when used for an extended period [2]. As cybersickness effectively limits the maximum acceleration and speed that can sensibly be used for leaning-based interfaces, large-scale navigation might simply take too long or become boring/annoying.

To tackle these limitations, we propose a hybrid interface (HyperJump) that automatically adds intermittent jumps once the user reaches a threshold velocity where users are more likely to get cybersick. Distance travelled with teleportation can be changed to any degree as it does not create optical flow during the travel and thus avoids cybersickness [5]. However, the same lack of optical flow causes spatial disorientation [3, 5, 16]. We hypothesize that combining two interfaces will help to mitigate cybersickness without affecting spatial updating capabilities.

Farmani and Teather [6] investigated the impact of discrete movements (short repeated jumps) and observed decreased cybersickness when discrete movements were applied for either rotational and translational viewpoint motion. The study also did not find any significant difference in spatial awareness between the translational snapping and the continuous motion. However, the experiment was mostly focused on cybersickness and did not involve complex spatial orientation tasks. The trial consisted of 10 trivial pointing tasks (pointing back to the origin after moving in a straight path) and 4 point back to the origin after a 2-segment excursion. In our daily lives spatial updating allows us to more easily navigate and interact with our immediate environment, and supports complex activities like playing sports, hiking or driving [10, 12, 17]. Thus, it is essential to evaluate if the interface supports spatial updating in more ecologically valid settings. Our study compares spatial updating supported by leaning-based interface vs. a controller for non-trivial locomotion in a highly realistic city environment. In addition, we investigated the effect of adding short iterative jump to both interfaces ("HyperJump").

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2 Methods

2.1 Interfaces

In this user study, we investigated the effect of adding iterative jumps to two continuous methods: leaning-based and controller-based, which is still the most common interfaces for locomotion in large-scale virtual environments. All interfaces were used in seated condition and had physical rotation. The interfaces are explained in detail below. The boldface represents the shorthand for the interfaces.

2.1.1 Continuous Method of Navigation

HeadJoystick: Participants leaned their upper body as if it was a joystick to translate in the desired (i.e., leaning) direction [2, 18], up to a virtual speed of 10m/s mimicking inner city driving speeds.
Controller: Participants use the default Oculus controller thumbstick to translate in the desired direction up to a virtual speed of 10m/s. We implement controller-directed steering where the controller's forward direction determines the forward direction of the movement, i.e. the user can rotate the controller, physically rotate, or press the thumbstick sideways to change the moving direction.

2.1.2 HyperJump: Hybrid Navigation Method

HeadJoystick-Teleport: It works like a HeadJoystick up to the virtual continuous translation speed threshold of 5m/s. Leaning further adds a jump of 1-8 meter every .5 second, on top of their continuous translation of 5m/s. Leaning further increases jump distance, but not frequency.
Controller-Teleport: It works similar to HeadJoystick-Teleport but with a controller.

2.2 Experimental Design and Procedure

Virtual Environment and Task: A virtual model of part of downtown Tübingen, Germany, was used to provide a naturalistic complex

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Figure 1: (A) One of the virtual paths in the experiment. (B) The top-down view of part of Tübingen on which path (A) is based. Participants start from the red circle, move to the subsequent red crosses and point back to the previously visited places in random order as prompted by the program. (C) Trivial pointing task (not included in the analysis) where participants point and indicate the distance to the target

environment [1]. Four different non-intersecting paths were created so that participants travelled a unique path with each interface.

As seen from the path in Fig. 1A, the participant started from the red circle. They performed trivial pointing (Fig. 1C) to two targets from that spot to familiarize themselves with the task and make sure that they learn the targets. After completing the pointing task, they would follow 10 waypoints to the next target. The program would then prompt them to point and estimate the previously visited targets' distance in random order. In total, they perform non-trivial pointing from four locations along each path [15].

The experiment used a within-subject design where every participant took part in all four conditions with a different path for each interface. A latin-square design with blocking of partial-body-based interface (HeadJoystick, HeadJoystick-Teleport) and controller-based interface (Controller, Controller-Teleport) was used to account for ordering effect and varying path difficulties.

3 Results

The obtained data were analyzed using 2×2 repeated-measures ANOVAs with the independent variables interface **embodiment** (leaning-based vs. controller-based) and **teleportation** (no jump vs. jump). Since there was no significant interaction in any case, only main effects are reported.

Absolute Pointing Error: It is used to assess how accurately participants knew where they were within the environment. It was measured by averaging (14 per interface) the absolute difference between the pointing direction (pointer's yaw) and the actual direction. ANOVA revealed a trend for the average absolute pointing error to be reduced for leaning-based ($M = 30.3°, SD = 16.3°$) compared to controller-based interfaces ($M = 35.5°, SD = 18.8°$) which reached marginal significance, $F(1,17) = 3.64, p = .074, \eta_p^2 = .176$. I.e. controller-based interfaces causes a 17% increase in pointing error. There was no significant effect of teleportation, $F(1,17) = .186, p = .672, \eta_p^2 = .011$, see Fig. 2A.

Absolute Ego-Orientation Error: One of the major reasons for absolute pointing error can be participants' misperception of their current ego-orientation. Average of the signed pointing error from each pointing location was used to calculate the absolute ego-orientation error. Then, it was averaged (4 per interface) for each interface. ANOVA revealed that using leaning-based interface ($M = 20.5°, SD = 14.5°$) significantly improved ego-orientation over controller-based ($M = 28.6°, SD = 20.9°$), $F(1,17) = 9.57, p = .007, \eta_p^2 = .360$, i.e. a 39.5% improvement. There was no significant effect of teleportation, $F(1,17) = .160, p = .694, \eta_p^2 = .009$, see Fig. 2B.

Absolute Distance Error: It was measured by averaging the absolute difference between the participant's estimated distance and

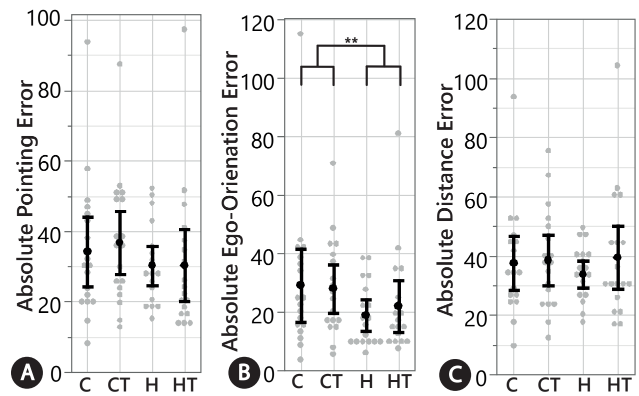

Figure 2: The black dots and bars represent means and 95% CI for (A) Absolute Pointing Error (B) Absolute Ego Orientation Error (C) Absolute Distance Error. The gray dots represent the error averaged for an interface for each participant. C = Controller, CT = Controller-Teleport, H = HeadJoystick, HT = HeadJoystick-Teleport.

actual distance from the pointing location. ANOVA revealed no significant effect of embodiment, $F(1,17) = .207, p = .655, \eta_p^2 = .012$ or teleportation, $F(1,17) = 1.96, p = .180, \eta_p^2 = .103$, see Fig. 2C.

4 Discussion and Conclusion

Using a photo realistic environment coupled with a naturalistic spatial updating task allows us to better assess the spatial updating capabilities of the interface and make stronger claims. Though previous works have shown improved spatial orientation using leaning-based interfaces compared to controller [7, 13], our experiment is the first to show a significant difference between the interfaces with a spatial updating pointing task in a realistic environment.

There have been no studies that evaluated spatial updating performance when adding teleportation to continuous methods of travel. Our findings indicate that Hyperjumps did not negatively affect spatial updating capabilities compared to their respective continuous interfaces. It is not possible to prove through null hypothesis testing that the jumps do not have any effect on spatial orientation, but the p-value and effect size suggest a negligible difference when HyperJump is introduced to the interface. Our results corroborate Faramani and Teather's finding of minimal difference between continuous vs discrete movement [6] and extend it to a more ecologically valid task and environment. Given the discrete movements help combat cybersickness [6] and do not compromise the spatial updating, it encourages us to further evaluate the interface for high speed, large scale virtual navigation.

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