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Teleportation without Spatial Disorientation Using Optical Flow Cues

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Figure 1: Teleportation discontinuously translates the user's viewpoint over a distance (A → B). The absence of optical flow reduces VR sickness, but also limits the users' ability to perform path integration, i.e., estimating the distance traveled, which can lead to spatial disorientation. Dash merges teleportation with regular locomotion by quickly and continuously moving the user to a destination (A → C), which generates optical flow that allows for path integration.

ABSTRACT

Teleportation is a popular locomotion technique that lets users navigate beyond the confines of limited available positional tracking space. Because it discontinuously translates the viewpoint, it is considered a safe locomotion method because it doesn't generate any optical flow, and thus reduces the risk of vection induced VR sickness. Though the lack of optical flow minimizes VR sickness, it also limits path integration, e.g., estimating the total distance traveled, and which can lead to spatial disorientation. This paper evaluates a teleportation technique called *Dash* that quickly but continuously displaces the user's viewpoint and which retains some optical flow cues. A user study with 16 participants compares *Dash* to regular teleportation and found that it significantly improves path integration while there was no difference in VR sickness.

Keywords: Virtual Locomotion; Teleportation; VR Sickness.

Index Terms: I.3.7 [Computer Graphics]: 3D Graphics and Realism—Virtual Reality

1 INTRODUCTION

Where moving around freely has been a fundamental appeal of 3D games, implementing this in virtual reality (VR) has been a challenge [31]. Though walking input using positional tracking offers the highest presence [39] and minimizes VR sickness, a major limitation is that it doesn't scale beyond the confines of often limited available tracking space. To explore large VR environments, users must switch to an artificial locomotion technique (ALT) that is activated using a controller. Popular ALTs include teleportation using pointing or Full locomotion (e.g., linear movement using the thumb stick or trackpad). Having to switch between leg and hand input is considered to break presence [22,26], while Full locomotion may induce VR sickness [11,39].

VR sickness, also known as visually-induced motion sickness, is a major concern for the mass adoption of VR [34] and is –among other factors– caused by a sensory mismatch between the visual and the vestibular & proprioceptive systems. Optical flow is the pattern of apparent motion of objects, surfaces and edges caused by relative motion between an observer and the visual scene [19]. A stationary observer of optical flow cues that simulate self-translation or self-rotation will experience an illusion of self-motion called vection – that is a known cause of VR sickness [9]. The precise nature of this relationship as it pertains to artificial locomotion is currently not fully understood [25], though a number of studies have found that VR sickness is more likely to occur using locomotion techniques that generate vection, such as linear and vehicle movement [21,27].

Teleportation is considered a risk-free way of navigating in VR as it discontinuously translates a user to a specified destination; which doesn't generate any optical flow or vection and thus reduces VR sickness [10]. However, it has been argued that teleportation breaks presence [10] since it lets users do something that doesn't exist in real life and it usage can also disrupt intended game play [32]. Besides issues with presence, a current limitation of teleportation is that it can cause spatial disorientation [5,10]. Humans generally navigate using a combination of two skills [40]: (1) path integration, where users update their current position based on an estimate of the direction and distance traveled obtained from visual, vestibular and proprioceptive senses and (2) landmark navigation, where users update their current position when a known landmark is identified [28]. When exploring an unfamiliar environment, humans rely entirely on path integration but build a cognitive map by observing landmarks [37]. Optical flow and vestibular and proprioceptive feedback provide powerful cues about self-motion [6] and are essential for effective path integration [40]. Though path integration is possible without vision it then relies solely on vestibular/proprioceptive cues [29].

Path integration while using teleportation as a VR locomotion method is limited, as users typically stand or sit still so there are no proprioceptive cues, while the discontinuous translation doesn't generate any optical flow. Though heading can be acquired using vestibular feedback, for assessing the distance traveled, a user must rely entirely on a change in the distance perception of landmarks. Landmark perception can be difficult in environments where they are sparse or which contain lots of similar landmarks. A complicating factor is also that the field of view (FOV) of consumer VR headsets (up to 110°) is considerably smaller than the human FOV (i.e., up to 180°) –which significantly impedes landmark perception.

To allow for path integration and to minimize spatial disorientation, this paper evaluates *Dash;* a modified teleportation method that instead of a discontinuous translation uses a quick but continuous translation of the viewpoint to retain some optical flow. A user study using a mobile VR headset (Daydream) evaluates efficiency, path integration and the occurrence of VR sickness when using *Dash* versus regular teleport.

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2 RELATED WORK

Being able to navigate beyond the confines of available tracking space while minimizing VR sickness, cost and maintaining a high presence is considered a major barrier for the mass adoption of VR [31]. Popular ALTs include vehicle movement, Full locomotion and teleportation. Vehicle movement has users enter a vehicle or platform to move larger distances. The vehicle is either controlled by the user using their controller or their gaze or it provides an on-rails experience. On-rails experiences offer limited interaction and presence and are more likely to induce VR sickness, as users have no control over the direction of movement [31]. Full locomotion using a controller (e.g., rate control and steering using thumb-sticks or trackpads) has found to induce VR sickness [11, 39].

Currently the most widely used mechanism to enable virtual locomotion at scale –and that can be integrated with existing positional tracking systems without impeding movement– is teleportation [32]. Though many VR games launch with teleportation as the default ALT, there is an active community of gamers that develop mods that add Full locomotion to these games [13]. Bowman et al. [10] was the first study to discover that teleportation increases spatial disorientation. Spatial awareness was tested using a visual search task, e.g., users first cognitively mapped a space that contained different colored cubes by freely moving around. Then users were automatically moved from one location to another using a different velocity and then had to find a cube of a particular color. This study explored four different velocities (slow, fast, S-curve, infinite) and found that using an infinite velocity (e.g. teleportation) significantly increased target search time but no difference between the other velocities was found. Bakker et al. [5] conducted a similar experiment with participants cognitively mapping various rooms using teleportation or controller input and then asking them to point to a specific object. This study also found that the use of teleportation leads to a worse spatial mapping performance. Cliburn et al. [14] used a similar experimental setup but used a desktop computer instead of an HMD and found that when given a map teleportation users are faster at object recollection than users using a keyboard for navigation.

A few approaches have aimed to improve teleportation. LaViola [26] presents a modification that requires users to step into a location on a map that is rendered at their feet in order to teleport to that location. Freitag et al [18] presents a teleportation mechanism where users have to walk through a portal that appears behind them in order to teleport as to optimize the usage of limited tracking space. Point and teleport [12] allows users to specify their post-teleport orientation.

Most closely related to *Dash* are the following. Jumper [8] is a hands-free form of teleportation on PC VR platforms where users physically jump forward to a location specified by their gaze. The optical flow shown during this jump is similar to *Dash* but it uses a variable velocity. This study investigated spatial awareness but did evaluate path integration or its effect on VR sickness (though because users have to physically jump forward it does generate vestibular/proprioceptive afferent that may minimize VR sickness). Zeleznik [41] presents a teleportation technique that is similar to Dash but no user studies were performed with this. Raw Data [2] is a popular VR game for the HTC Vive/Oculus Rift that implements a teleportation mechanism very similar to *Dash*. However, Raw Data uses a fixed amount of time for the teleport transition regardless of the distance traveled, which in our opinion impedes spatial integration ability. Given that a teleportation mechanism similar to *Dash* is already available in a commercially available VR games, we make no claims regarding its novelty. However, though this type of teleportation has been widely praised [20], there are no studies that have evaluated its effectiveness on reducing spatial orientation or inducing VR sickness, which is what this paper contributes.

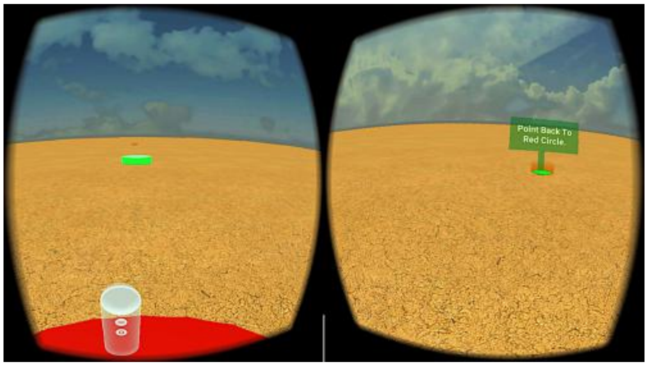

Figure 2: Virtual environment used for the user study. Left: users have to teleport to the green circle (red starting circle is visible) Right: after teleporting, a sign indicates to the participant to point back to their start location.

3 EXPERIMENT DESIGN

The objective of our study was to analyze whether a small amount of optical flow during teleportation enables path integration as to improve spatial orientation while not causing any VR sickness. Prior teleportation studies [5, 10, 14, 24] have all evaluated spatial disorientation using a visual search task where users first cognitively map a space containing landmarks or objects. The use of a visual search task is subject to a number of limitations as it can be argued that this task relies to a large extent on a user's ability to successfully cognitively map a space and to a lesser extent on path integration– which is where differences in the type of locomotion method used matter. Using a visual search task that relies on an existing cognitive map doesn't seem very realistic for many VR applications, such as games, as players predominantly explore new environments without a cognitive map. For this study, we wanted to isolate the effect that optical flow has on path integration ability. To assess path integration, we use the "triangle completion" navigation task that was described in early work on path integration [29]. This task requires participants to travel from a start location to two waypoints, which are non-collinear with the start location. After arriving at the second waypoint, users have to turn around and try to navigate back to their start location.

3.1 Instrumentation

For this study, we decided to evaluate *Dash* on a mobile VR platform. Mobile VR platforms are considered to have limited interaction options [38], but since they only require a smartphone, they have a much larger potential to bring VR to the masses than PC VR approaches [16]. Mobile VR devices, like the Gear VR, have also eclipsed PC VR platforms in terms of sales [15]. Mobile VR platforms currently only support 3 degrees-of-freedom (DoF) input. It has been suggested that mobile VR platforms are more likely to induce VR sickness, because of the lack of apparent translational motion when users move their physical bodies. These specific constraints and popularity of this platform defines a relevant real-world context for *Dash* to investigate.

We implemented our experiment using Google Daydream; a VR platform for Android devices. This platform offers a 1080 x 960 pixels per-eye resolution at 60Hz with a 90° FOV using the Google Pixel smartphone (Snapdragon 821 2.15Ghz Quad-Core). For interaction, Daydream features a wireless inertial sensing 3-DoF remote controller with a touchpad and several buttons. Because Daydream doesn't feature positional tracking, teleportation is a recommended for locomotion by Google's VR guidelines [3]. With the exception of a few, the majority of Daydream apps use teleportation.

3.2 Virtual Environment & Navigation Tasks

We designed our virtual environment for our study using the Unity 3D engine (version 5.5.1) and Google VR SDK. To be able to exclusively focus on path integration, our virtual environment was designed to be devoid of any landmarks or distinguishable visual features. We used a scaling factor of 1:1 to model our virtual environment. The ground plane consisted of a desert like texture and the sky-box featured uniformly distributed and shaped clouds, both generate optical flow but did not contain any specific visual features that would allow for landmark based navigation (see figure 2). We used a bright green circle as a way-point that the user needs to teleport to. Users can only teleport to the green circle so their exact location is always known.

At the start of each navigation task, a red circle is rendered at the participant's feet (see figure 2:left) and a short audio feedback is given to make participants aware of their latest start location. After teleport, a message appears at the pointer that asks participants to point back towards their start location, i.e., the red circle, which has then disappeared (see figure 2:right). For our study, we deviate from the "triangle completion" navigation task [29] in two ways, e.g., early experiments found that pointing back to the start location after two teleports (2-teleport) with a random angle between them was already quite challenging to perform. We decided to include an easier navigation task that only uses a single waypoint to teleport to (1-teleport). This task allows us to isolate path integration for distance traveled from the user's ability to correctly rotate towards their start location, which does to a small extent rely on optical flow perception but to a larger extent on vestibular cues. For rotation, optical flow cues do not vary between visual conditions.

Rather than having users navigate back to the start location, we have participants point to their start location, which we felt was more precise and also helps us maintain an exact location of the user. For the experiment, we used a predefined random sequence of 10 waypoints for 1-teleport and a random sequence of 20 waypoints for 2-teleport. The distance between consecutive waypoints was uniformly randomly varied between 5 - 11 meters as early experiments showed selecting a waypoint that was more than 13 meters away was difficult. For the 2-teleport task, we assume users are most likely to use teleportation to travel in one direction, therefore we constrain the placement of the second waypoint to be within in a 180° FOV of the first way-point. We achieve this by splitting, the 180° range into 10 intervals of 18° and each second waypoint was placed at a random but unique value of $q * 18^\circ$ with $q \in [0, 10]$. Because we have participants switch between 1-teleport and 2-teleport for each teleportation method, the possibility of having participants memorize both sequences is low.

The Daydream controller is used to select the waypoint using a circular pointer (see figure 2), upon which the trackpad needs to be pressed to activate teleportation. Though the controller is only tracked in 3-DoF, using it for selecting a destination to teleport to was not challenging. To avoid accidental input, when pointing back at the start location using the pointer, participants would need to hold down the track pad for 2 seconds. Many existing teleport implementations show a visual arch or line from the controller to the pointer, which helps in manipulating it. Because this visual cue conveys distance, we remove it, as to focus on path integration using optical flow only. Early experiments showed participants were able to easily manipulate their teleportation pointer without this visual arch.

Vection is known to induce VR sickness but we hypothesize that since users are only exposed to optical flow for a very brief time, the likelihood of inducing VR sickness is low. FOV reduction is an effective strategy to minimize VR sickness [17] during locomotion. This strategy is also used by Raw Data which blurs the screen during the teleportation. However, FOV reduction or blurring diminishes the perception of optical flow cues, which users must perceive in order to perform path integration, so this was not implemented to enable path integration. Some teleportation implementation apply a fade in/fade out or motion blur to the instant viewpoint transitions in order to make it less abrupt. It has been argued that this could mitigate VR sickness (though there is no optical flow). Since there are no studies that have analyzed the effectiveness of such transitions on spatial orientation or VR sickness, we used the most commonly used instant viewpoint transition.

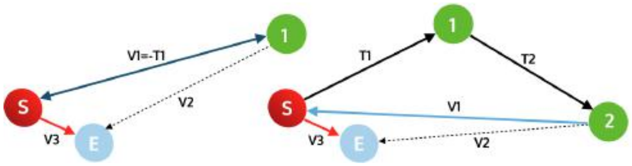

Figure 3: The two triangle completion tasks used in our study: left: 1-teleport, right: 2-teleport. S=start location, ①=1st teleport location, ②=2nd teleport location and E is the user's estimate of S. V3 is the vector between S and E. With optimal path integration, V3=0 and V1 = V2.

3.3 Implementation

To implement *Dash*, we modified an existing popular open source Unity teleportation asset [7]. Using regular teleportation, the player's viewpoint is instantly translated in the next frame update and no optical flow is generated. The idea for *Dash* was to generate a small amount of optical flow (in terms of duration) by using a rapid continuous viewpoint translation. To implement *Dash* a number of design considerations had to be considered regarding the velocity as this affects the amount of optical flow generated and involves trade-offs between efficiency, spatial integration ability and VR sickness. Using a lower velocity generates a longer-lasting optical flow but increases the risk of VR sickness due to vection –while it also increases the time for users to arrive at their destination.

Our study did not evaluate what velocity was optimal for *Dash* because a closely related study on teleportation by Bowman et al. [10] had already explored several different velocities but did not detect a significant difference in spatial awareness between them. Because this study did not assess VR sickness or path integration, it made most sense to select a high travel velocity to limit optical flow exposure as to minimize VR sickness. We needed to consider how to adjust velocity during the translation. Raw Data [2] offers optical flow for a fixed amount of time irrespective of distance, which in our opinion doesn't allow for path integration as users must gauge varying changes in velocity. Locomotion techniques like walking-in-place benefit from using an S-curve for ramping up and ramping down velocity depending on step frequency, as this closely models human locomotion and increases presence [38]. Bowman et al. [10] also explored the use of an S-transition but did not find a difference in spatial awareness with using a constant velocity. Mackinlay et al. [30] explored using a logarithmic curve but do not present results from a user study. Both the Oculus [4] and Google [1] VR design guidelines recommend using a fixed velocity for locomotion and to avoid acceleration.

Using Unity's default rendering options, we tried different velocities to understand how it affects path integration. Because the optical flow duration is fairly short (1.1s at most as selecting targets beyond 11m was difficult) the use of an S-curve or logarithmic is nearly imperceptible and for it to be noticeable we would have to increase the duration, which in order to minimize VR sickness was undesirable. We also felt that path integration becomes more difficult if users have to gauge changes in velocity. We found a constant velocity of 10m/s to work best. Because users travel at most 11m, optical flow exposure is at most 1.1s, which seemed large enough

A	SSQ	DASH-1	DASH-2	SSQ / break	REG-1	REG-2	SSQ	Quest
B	SSQ	DASH-2	DASH-1	SSQ / break	REG-2	REG-1	SSQ	Quest
C	SSQ	REG-1	REG-2	SSQ / break	DASH-1	DASH-2	SSQ	Quest
D	SSQ	REG-2	REG-1	SSQ / break	DASH-2	DASH-1	SSQ	Quest

Figure 4: Blocks for each trial for each group.

to allow for path integration. This short exposure approximates the efficiency of instant teleportation while it hopefully does not induce any VR sickness.

3.4 Procedure

We used a within-subjects factorial design with independent variables teleportation_method, i.e., (regular, *Dash*) with dependent variables; 1-teleport and 2 teleport path integration error (PI-error). The two tasks both measure path integration ability and are not independent variables. To control for order effects, we counterbalanced the order of independent variables tested, e.g., each participant was randomly assigned to one of four groups (A, B, C, D) such that each group contained an equal number of participants. To analyze whether *Dash* induces VR sickness, we used the Simulator Sickness Questionnaire (SSQ) [23]; a standardized questionnaire that quantifies various aspects of simulation sickness. Before the trial participants filled in an SSQ to get a baseline reading. Each trial consists of four blocks, with participant testing one particular teleportation method in the first two blocks and the other in the last two blocks. Each block had 10 navigation tasks, and the first and last two blocks were then randomized for 1-teleport and 2-teleport. We did this so that participants could fill in another SSQ after they completed two blocks using the same teleportation method. Figure 4 shows an overview of the blocks for each trial for each group.

User studies were held in a large open lab space free of any obstacles or interference, and participants were fitted with the Google Daydream headset. Prior to the trial participants performed a brief built-in tutorial containing two 1-teleport tasks and two 2- teleport tasks using their first assigned first teleportation technique to familiarize them with the navigation task. After the first two blocks, participants took off the headset, filled in an SSQ and rested for 15 minutes. Because the Daydream controller tends to drift over time, we re-calibrated prior to each trial and after the first two blocks. The whole trial took about 35 minutes per participant. After the last two blocks, participants filled in a third SSQ followed by a questionnaire that collects demographic information and which aimed to determine a ranking between teleportation methods, based on a number of criteria.

3.5 Measures

For every navigation task, we collect the coordinates of E (see Figure 3). Given the known coordinates of S, ① and ②, we calculate V1, V2 and V3 depending on what teleportation method was used (see Figure 3). We analyze PI-error for both navigation tasks. V3 is the difference vector between the start (S) and the pointed location (E) and its length reflects the PI-error in distance as well as rotation (see Figure 3). Rotation error relies on vestibular cues and optical flow [36] but since our virtual environment was designed to be devoid of any visual features, rotation primarily depends on vestibular cues. However, to focus on the benefits of optical flow during teleportation, we exclude for errors in rotation as this doesn't depend on optical flow cues during teleportation and we only evaluate linear path integration (distance traveled) for which optic flow is the only cue.

For 1-teleport, we calculate PI-error for 1-teleport as $(|V1| - |V2|)/|V1|$. Because we assume linear relationship between pointing errors and target distance, we normalize the difference in length between waypoints by dividing by V1 . For 2-teleport, the error in the second rotation needs to be included as this relies on path integration when the user travels from ① to ② (given that S, ① and ② are non-collinear). To assess PI-error for 2-teleport, we use $|V3|/|V1|$ which is the normalized length of the difference vector V3 and which embodies the error in both distance and rotation.

Table 1: Quantitative results.

	Dash (SD)	**Regular** (SD)
PI-error (1-teleport)	.149 (.10)	.172 (.12)
PI-error (2-teleport)	.527 (.20)	.594 (.25)
Nausea ((max: 200)	6.56 (10.3)	6.56 (7.6)
Oculomotor (160)	6.16 (13.6)	7.58 (9.2)
Disorientation (292)	10.44 (18.7)	11.31 (13.7)
SSQ-total (235)	7.71 (13.1)	9.12 (9.1)

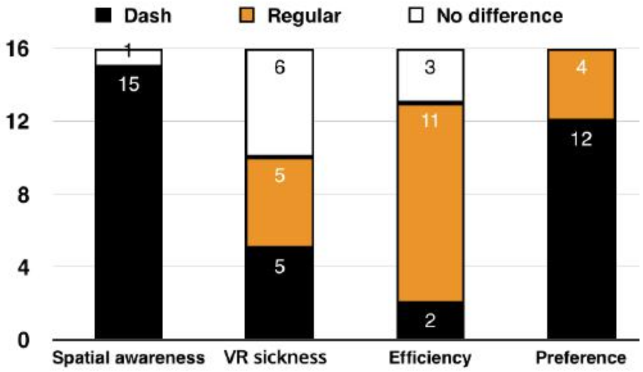

Figure 5: Ranking of teleportation methods on four criteria.

3.6 Participants

We recruited 16 participants (5 female, average age 25.0, SD=4.6) for our user study. All participants had experience with navigating 3D desktop environments. Six participants had no experience with VR, five had some VR experience and five had lots of VR experience. Participants did not report any non-correctable impairments in visual perception (some did have glasses or lenses) or any limitations in mobility. The user study was approved by an institutional review board.

3.7 Results

Table 1 list the average PI-error for 1- and 2-teleport for each teleportation method (e.g. *Dash* or Regular). A one-way repeated measures MANOVA found a statistically significant difference in path integration error between teleportation techniques, ($\boldsymbol{F}_{2,158} = 7.353$, $p < .05$, Wilk's $\lambda = .915$, partial $\varepsilon^2 = .085$), with a significantly smaller error using *Dash*. There was homogeneity of variances, as assessed by Levene's Test ($p > .05$). A Tukey post-hoc analysis found a significant difference for teleportation methods for both PI-errors ($p < .05$). An analysis of pointing errors, by analyzing the sign of $(V1 - V2)$, using a χ^2 test found that users significantly ($p < .05$) underestimated the distance to their start location, though there was no significant difference between teleportation methods.

Regarding VR sickness, a Wilcoxon signed rank test didn't detect a significant difference between total SSQ-total scores ($p > .05$) or any of its sub-scores, e.g., nausea ($p > .05$), oculomotor ($p > .05$) and disorientation ($p > .05$). The average SSQ-Q scores, 7.71 for *Dash* and 9.12 for regular, which had a maximum possible value of

235, would rank between no and mild VR sickness [23].

We also asked participants to rank each teleportation method on four criteria where participants could select "no difference" as a 3^{rd} option. Fifteen participants thought *Dash* helped best maintain spatial awareness, with 1 participant stating there was no difference. Regarding which technique caused VR sickness the most, opinions were split with 5 participants stating *Dash*, 5 participants stating regular teleport and 6 participants stated that none of the techniques caused VR sickness. 11 participants said regular teleport was most efficient, and 2 stated *Dash* was more efficient with 3 saying there was no difference. Regarding preference, 12 participants liked *Dash* the best and the other 4 liked regular teleportation the most. Figure 5 lists the results, and a χ^2 test found the rankings for spatial awareness, efficiency and preference to be statistically significantly different ($p < .05$).

4 LIMITATIONS & DISCUSSION

Our study innovates over existing teleportation studies [5, 10, 14, 24] in that we assess spatial disorientation using a path integration navigation task that doesn't rely on prior knowledge of the environment. Because our navigation tasks don't rely on cognitive mapping ability, it allows for an isolated assessment of the benefits of optical flow during locomotion.

Dash offers a significantly lower PI-error than regular teleport, but the PI-error isn't very large for 1-teleport. The PI-error for 2-teleport significantly increases (250%) and because users often use teleportation multiple times, this difference in PI error will continue to accumulate and grow unbounded over time, as this is an inherent characteristic of dead-reckoning localization. To exclusively focus on path integration, our virtual environment did not contain any visual landmarks, but we are confident our results hold for more realistic virtual environments. Such environments will have more visual landmarks, which reduces the PI error for each teleport, but since these errors accumulate and propagate over time anyway, the benefits of using *Dash* to reduce the PI error for each teleport are evident.

Our study focused on mobile VR platforms because of their popularity and potential to bring VR to the masses. Because we didn't observe a significant increase in VR sickness we believe *Dash* can be used on PC VR platforms that have higher refresh rates, lower latency and offer 6-DoF tracking and which are already less likely to induce VR sickness than mobile VR platforms.

Our study didn't observe a difference in VR sickness, so one can question the necessity of using FOV reduction or motion blur that was implemented in the Raw Data [2]. FOV reduction reduces peripheral optical flow perception and thus mitigates visual-vestibular conflict [17]. However, FOV reduction may also impede spatial navigation performance, e.g., limiting optical flow may impairs path integration (estimating distance traveled) but also limit the perception of landmarks used for orientation. Women are more likely to be VR sick [33] but also rely to a larger extent than men on the perception of visual landmarks for spatial orientation [35]. Future research will develop a better understanding of how FoV reduction affects the relationship between spatial navigation performance and VR sickness and sex differences.

Most participants (n=11) found regular teleport to be most efficient, which made sense as *Dash* was slightly slower. *Dash* moves the viewpoint with a speed of 10m/s and our waypoints varied between 5-11 meters, so it added a fixed amount of time .5 and 1.1 seconds to each teleport, which is negligible given that it enables path integration. Though we designed our user study to be devoid of any visual information that conveys distance, the pointer used for selecting a waypoint does convey distance to some extent.

There was no consensus among the participants' ranking which method caused VR sickness the most (see Figure 5), but quantitative results only found a slight increase in SSQ scores for both methods, with no significant difference between them. Seven participants (all males, all experience with VR) in our study showed no increase in SSQ scores from their baseline. A recent study [33] has found that females are more susceptible to VR sickness. All five participating females showed a small increase in their SSQ scores (no to mild VR sickness), but we didn't enroll enough females to allow for testing whether this difference was significant. Participants were exposed to VR for approximately 20 minutes, which should be long enough to induce VR sickness if participants were susceptible to it [33]. Future work will investigate whether there exists a gender difference in SSQ scores using *Dash* and will aim to include participants that are more sensitive to VR sickness.

5 CONCLUSION

Teleportation is known to cause spatial disorientation, because the absence of optical flow during the instant translation doesn't allow for estimating the distance using path integration. We evaluate *Dash* –a modified version of teleportation– that quickly but continuously translates the user's viewpoint, and which generates a small amount of optical flow. A user study that compared *Dash* to regular teleport found *Dash* to allow for significantly better path integration, while there was no significant increase in VR sickness.

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