Design and Evaluation of Travel and Orientation Techniques for Desk VR

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ABSTRACT

Typical VR interactions can be tiring, including standing up, walking, and mid-air gestures. Such interactions result in decreased comfort and session duration compared with traditional non-VR interfaces, which may, in turn, reduce productivity. Nevertheless, current approaches often neglect this aspect, making the VR experience not as promising as it can be. As we see it, desk VR experiences provide the convenience and comfort of a desktop experience and the benefits of VR immersion, being a good compromise between the overall experience and ergonomics. In this work, we explore navigation techniques targeted at desk VR users, using both controllers and a large multi-touch surface. We address travel and orientation techniques independently, considering only continuous approaches for travel as these are better suited for exploration and both continuous and discrete approaches for orientation. Results revealed advantages for a continuous controller-based travel method and a trend for a dragging-based orientation technique. Also, we identified possible trends towards task focus affecting overall cybersickness symptomatology.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction techniques; Computing methodologies—Computer graphics—Graphics systems and interfaces—Virtual reality

1 INTRODUCTION

Virtual Reality (VR) offer unique possibilities for experiencing 3D virtual content, from 3D imagery visualization to the creation of virtual models and exploration of large scenes. These environments often come in varied sizes, ranging from a small room to an open world. While natural metaphors such as walking can be desirable, they are often limited by hardware and/or available physical space, and they may also lead to fatigue, reducing user performance. For this reason, ergonomics are an important factor intrinsic to VR, which can be addressed by looking into research in related contexts, such as the work by Bachynskyi et al. [3], who investigated performance and ergonomics of common surfaces, such as smartphones, tablets, laptops and large displays.

The issue of fatigue can be addressed in some cases by exploring VR experiences bound to a seated position [42]. Indeed, seated and desk VR have been target of recent research [39, 40, 43], including applications such as information visualization [35, 36], and radiology [34]. In particular, locomotion is one of the challenges of seated VR due to the impossibility to perform real walking.

Depending on the type of experience (e.g. seated or standing), the use of head and controller movements for artificial locomotion may be explored differently, considering the different physical constraints [25, 29]. Nowadays, even consumer-grade VR headsets often feature some type of positional tracking. If controllers are included, this means that both head and hands can be tracked through either outside-in or inside-out methods.

Another challenge of VR in general is cybersickness. When the movement in the VE does not match the physical one, users may experience motion sickness, nausea, and/or other symptoms. Therefore, moving the user in the VE while seating still is bound to a conflicting sensory input.

In this work, we explore ways to make users retain an immersive VR experience while seated, without sacrificing physical comfort or wellbeing, focusing on navigation. We evaluate a set of techniques, both for travel and orientation, to assess which work best for desk VR. Some techniques are based on previous works, adapted to desk VR, while others are novel proposals making use of natural touch and gesture metaphors. For this, we explore both VR controllers and a large touch-sensitive surface, separately. With this interactive surface, we aim to increase users' comfort by allowing them to use their hands similarly to what is done in typical desktop scenarios with mouse and keyboard, which have been successfully used for prolonged interactive sessions.

Therefore, our contributions are as follows: (1) a set of movement techniques for desk VR, covering both Travel and Orientation, which can be useful for interaction designers and researchers; (2) a user evaluation that provides information about performance, comfort, confidence and other factors that contribute to the user experience; (3) a set of guidelines for developing future movement techniques for desk VR, based on the results of our evaluation.

2 RELATED WORK

Our work builds on prior research mainly regarding navigation within immersive VEs. Additionally, we will cover some works regarding cybersickness and ergonomics to better frame our choices.

2.1 Current navigation techniques

Navigation techniques can be divided into two categories: Discrete and Continuous. Discrete techniques set the user's orientation or position as explicitly specified, without an in-between transition. Continuous techniques rotate and move the user over time. In addition, each navigation tasks can be divided into two parts: Travel and Orientation. Travel allows the user to explore the environment, while Orientation allows the user to change to where they are facing in said environment. Finally, each technique implementation is typically tied to an input method.

2.1.1 Travel

The most natural approach for navigating in VR is real walking [23]. However, due to requirements such as limited space or physical effort, it might not always be feasible or the best choice. Also, it has been shown that techniques that require no physical locomotion can achieve comparable performance to real walking [31].

Another frequently used method, due to its simplicity, is Teleportation [7, 12]. It is a discrete Travel method between two points and is often mentioned as one of the least prone to cybersickness [17]. Despite this, it is often the least preferred as well, as it lacks the immersion of typical room-experience VR and can cause disorientation due to the non-gradient change in surroundings. Within this method, several variants exist to improve on some of its downfalls, such as the use of transition effects [24]. Additionally, there have been

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versions that adapt it into a semi-continuous form, such as Pulsed Interpolation [28], by interpolating positions between both origin and destination, or even a fully continuous version, such as Linear Motion [24, 33], similar in nature, but with a smooth movement between points instead.

In contrast, other methods act on a given direction instead of a specified destination. This direction of movement can be specified using different approaches, such as gaze, hand / controller, torso, or even a virtual body [25, 41]. Then, the user moves continuously as long as the input is held. This method of continuous movement can be used in its raw form, but it is often abstracted to a medium. In one example, Medeiros et al. [25] explored a flying carpet metaphor, allowing for both vertical and horizontal travel, fitting a static movement situation. Video games use this type of medium frequently [16], in which context is given for the chosen implementation. These include battle mechs, vehicles, roller-coasters, and others. It appears to reduce disorientation and increase immersion compared to Teleportation. Unfortunately, these continuous methods without the corresponding physical sensations often present a significantly higher likelihood of cybersickness [9].

In addition, functional extensions exist to help in specific parts of movement. One such example is the Jumper metaphor [5]. The typical behavior is natural walking for short travel, and a Teleportation-like mechanic is used to cover large distances. This is achieved by an alternative input method, allowing a choice of either Travel mode on demand. Adhikari et al. [1] also combined continuous movement with teleportation by adding intermittent teleports once the user reaches a threshold velocity. Alternatively, a multi-scale approach can be used for the same effect [2,8,21]. Instead of Teleportation, the modeled eye distance is changed to increase the distance perception of their surroundings, making the VE appear smaller and allowing for more substantial translations for the same motion. This method, however, is not always convenient, as indoor navigation requires special workarounds to allow the user to see the environment.

It is also worth mentioning a movement method not meant for VR during its conception. Drag'n Go [26, 27] is intended for use on small interactive surfaces. By touching on a wall or solid object, the user can then interpolate between that location and their initial position by dragging the finger towards the bottom of the screen. While not designed for VR, we argue that this technique can be adapted and suited for desk VR.

When it comes to input, Discrete travel methods tend to rely on a pointing or node-based system. Usually, pointing methods use a VR controller and a ray or an arched trajectory [12]. The translation can be applied with a button press. Since the pointing mechanism relies on a platform hit, it limits travel to existing surfaces, as it is impossible to perform a selection where nothing exists.

For Continuous methods, several more input methods are used, although most are only intended for horizontal movements. This is the case of the typical joystick-based movement, a common and straightforward implementation [16]. It can use various hardware solutions and is standard for non-VR applications, such as video games, most notably using analog sticks in console controllers. By pushing an analog towards an intended direction, the user can move towards it at a velocity determined by the distance from the center.

Another possible method is leaning [7, 14, 29], which can be used both while standing or seated. Moving the body towards, away, or to the sides of a reference point results in a similar solution to a joystick, where the user moves in the respective direction. Zielasko et al. [38] explored several ways for navigating immersive environments while seated, focusing on continuous techniques with which users can move according to the viewing direction. They found that leaning or using a pedal to control translation speed performed best. However, these joystick-like techniques have very different implications, such as fatigue and physical discomfort, and should not be combined into a single category. Indeed, leaning the body can reduce cybersickness related symptoms when compared to a regular joystick [14, 29].

In addition to these methods, gestures can also be used for movement interactions. These can be read through the use of touch surfaces or other sensors that can capture air gestures. For the latter, a Leap Motion or motion capture device can be used. One particular implementation, finger-walking-in-place (FWIP), distinguishes itself by attempting to map regular walking to a motor-equivalent action [19, 20]. Different iterations use different configurations, but all consist in using two fingers on a touch surface and simulate walking similar to the movement of legs. Another implementation is the Airplane method [4], where the user extends their hands forward and, through Leap Motion capture, moves forward and backward by opening and closing their hands, respectively. It also allows for velocity control by finger count in one of the open hands.

There are also input methods based on specific hardware. For example, Nybakke et al. [30] resorted to a motorized wheelchair in which the user can move around. Walking by Cycling [11] makes use of cycling biomechanics that translate into walking motion while the user remains seated. This allows for fine control of movement while leaving the hands free for other tasks.

Some of the previous methods require an additional method of specifying the direction of movement. Medeiros et al. [25] used Gaze-Oriented Steering and Hand Steering. They resort to the head and hand orientation, respectively, to specify the direction of movement and a button to prompt movement

2.1.2 Orientation

A typical VR experience does not require orientation methods, since the natural orientation captured by the headset is often enough [31]. This can be true even for seated experiences [14]. However, in certain situations in which the user might be restricted from rotating physically, such as when seated in front of a desk, a re-orientation method is required to allow access to the virtual world beyond their peripheral field of vision. Similar to Travel, it also includes both Discrete and Continuous methods. Continuous methods consist in continuously rotating the users' virtual body over time. This can be done using different approaches, such as joystick variations [9,14,31] or amplified head rotations [32]. Discrete methods, however, include specifying the final direction to re-orientate towards, or stepped rotations [9], which can be useful for reducing cybersickness.

Habgood et al. [16] explored several commercial games with varied reorientation approaches. Some are directly related to the movement medium, such as vehicles. One existing type of implementation is through head input. This is convenient in a VR headset setup, as the hardware required is always present. Taking an initial head orientation into account, looking to the sides will rotate the user towards that side. As already mentioned, another explored method is a straightforward rotation through an analog stick, applying to both continuous and stepped variants.

Lastly, there are methods of orientation within Travel methods, such as AngleSelect Teleport, Curved Teleport, and HPCurved Teleport [12]. In these, the user also selects the final orientation of the virtual body.

2.2 Cybersickness

Cybersickness is one of the well-known problems introduced by fully immersive VR [23]. In the case of seated VR settings, in which the users tend to assume more stable positions, but may still navigate through the world, the likelihood of suffering from cybersickness increases. Games are an example of such cases.

Habgood et al. [16] analyzed a large pool of games, addressing issues associated with the implementations, most notably motion sickness caused by the method of movement and overall user experience. According to the authors, "short, fast movements in VR (with no acceleration or deceleration) don't appear to induce significant feelings of motion sickness for most users. This seems to be true of both rotational and positional movement". The authors further explored this idea [15], concluding that time spans of 300 milliseconds or less should be used.

Another approach to help reduce cybersickness while increasing presence is to use virtual metaphors for real life objects. Examples include virtual limbs and desks [43], with varying degrees of effectiveness, or the work by Feuchtner [10] that looked into a variety of factors, including hand representation or realism, extension of the limbs, and their disparities between real world and virtual world counterparts.

2.3 Discussion

Some of the previous methods are not be feasible for desk VR experiences. Examples include some approaches that follow the Magic Carpet [25] metaphor that require users to be standing. On the other hand, approaches that have specific requirements [11, 12, 30] can be difficult to become widely adopted. Additionally, Buttussi et al. [7] studied the Leaning method, and found no significant improvements over Teleport and Joystick, while bringing other aspects into account such as spine fatigue.

Point & Click techniques appear very similar to each other. They offer fairly good positional control, and are not prone to motion sickness. They serve as a good benchmark for comparison. However, we focus on continuous methods of Travel as they are more adequate for exploring the VE while maintaining spatial awareness and collecting information about the user's surroundings. Nonetheless, some specific variations were considered, such as the Orientation mechanic by Funk et al. [12], as they show good acceptance. Directional input techniques, often implemented as a joystick, are very common [16, 25]. They usually suffer from significant motion sickness, and acceptance seems to vary by implementation. This could be due to the fact that many also use continuous rotation.

Another method worth considering is FWIP [19], especially with two-handed input. It can potentially lead to more precise control. VR methods aside, the Drag'n Go method proposes an interesting alternative to the other techniques, and can be adapted into a VR environment through use of the user's gaze.

3 Proposed Techniques

We propose a set of VR travel and orientation techniques for when the user is seated in front of a desk. Some are adaptations of currently existing techniques which were not originally designed for this scenario, while others are new proposals. Besides exploring the now commonplace VR controllers, we also explore touch gestures on a surface in front of the user, similarly to Sousa et al. [34].

The interactive surface has the potential to increase user comfort, since users can perform gestures on a physical horizontal surface instead raising their arms [3]. This allows users to rest their arms and avoid the "gorilla arm" effect [22]. Also, the use of touch surfaces is ideal for exploring gestures based on natural metaphors, such as dragging, which can make the interfaces easier to learn and use [37]. Although this requires additional instrumentation of the user's desk, we believe that interactive desks can become commonplace in a near future, as the hardware cost is relatively low (our 32" multi-touch frame cost less than 130 Eur) and they offer immense interaction potential that can increase everyday productivity.

Since we aim at techniques that require reduced physical effort, we did not consider approaches that rely on actions such as leaning [7] or cycling [11].

3.1 Travel

For travel, we present three techniques. All of them are continuous, as previously discussed.

3.1.1 Continuous Directional Movement

The Continuous Directional Movement technique (Figure 1) consists on the user pointing a VR controller in the intended direction of movement, similar to the Hand Steering approach by Medeiros et al. [25]. The method uses the controller's direction as the movement's direction and, when pressing the trigger, the user will move in the indicated direction. The intensity of the trigger pull determines the final velocity. When fully pressed, the user moves at 5 m/s in the intended direction, decreasing linearly to a full stop with the release of the trigger.

3.1.2 Dog Paddle

The Dog Paddle technique (Figure 2) uses repeated gestures on a touch surface to move the user in the direction of of their gaze. It's based on the same concept of motor equivalence behind the FWIP technique [19], but with a higher focus on its ergonomic aspect and control. While FWIP aims at defining traveling speed, Dog Paddle explores a 1:N mapping for manipulating user's position through dragging actions, thus allowing for more precise movements, which would not be possible with the range of individual fingers' motion. Also, as Kim et al. [19] pointed out, dragging is less tiring than finger-walking. The touch surface reads the movement of each dragging hand (identified by five touch points near each other), similar to the dog paddle swimming technique, and directly moves the user proportionally, which is pre-defined, towards head direction. Each 40 cm of hand travel (which is the height of the interactive touch surface used) corresponds to a movement of 65 m in the VE. Smaller

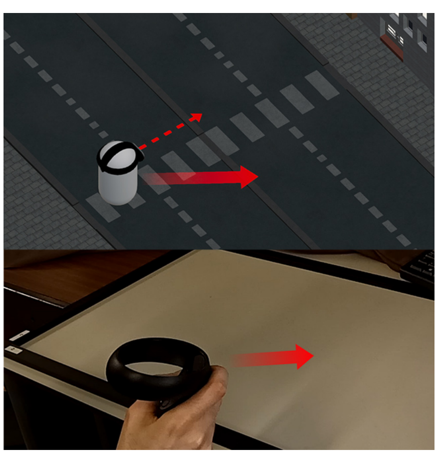


Figure 1: Continuous Directional Movement.

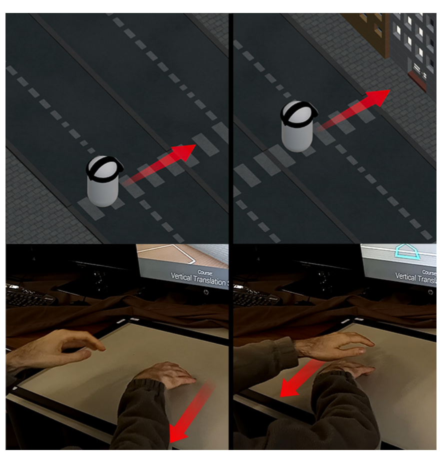


Figure 2: Dog Paddle.

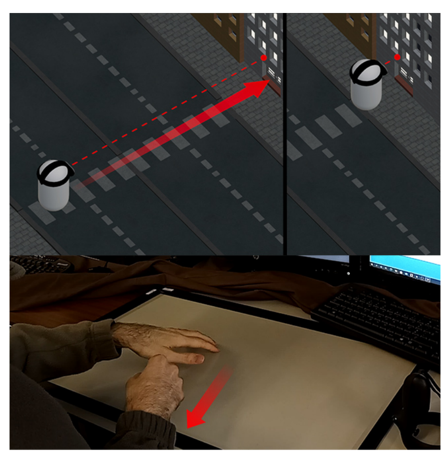


Figure 3: Drag'n Go.

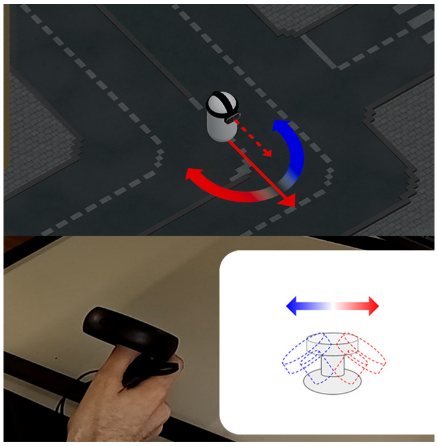


Figure 4: Continuous Directional Rotation.

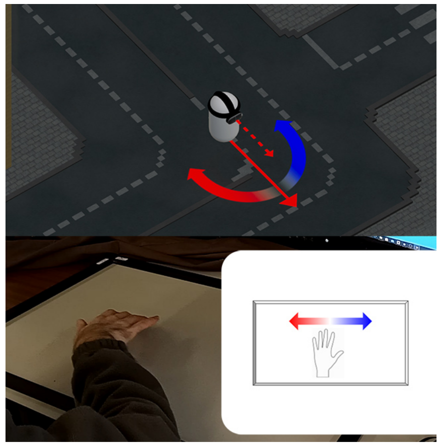


Figure 5: Tactile Surface Dragging.

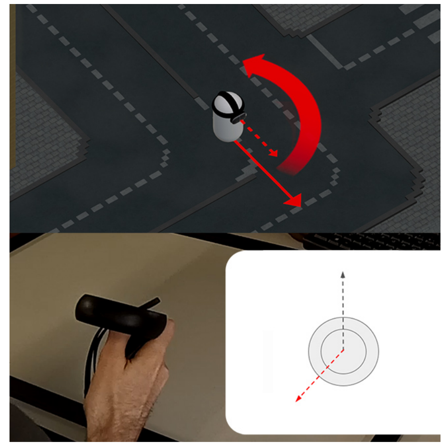


Figure 6: Choose & Click.

or larger movements are mapped linearly. Head direction is also taken into account when input is received from the surface to account for possible misalignment with hand movement, as the user cannot see their hand gestures directly.

3.1.3 Drag'n Go

This method is a VR adaptation of the Drag'n Go approach [27]. Similarly to the previous technique, this method reads the user gesture to move in the user's gaze direction (Figure 3). However, the final position is determined in the moment the gesture begins, resulting from a ray cast from the user's head, inheriting its direction, to the first point of collision with any object of the scene. The end point will be fixed until the hand gesture ends, that is, until the user stops touching the interactive surface. Until then, the user can drag the hand freely, towards the bottom of the surface to reach the end point, or upwards to pull away from the starting position. The distance between the starting touch position and the bottom end of the interactive surface is mapped to the distance between the original VE position and the ray cast target. This way, the higher the gesture starts on the surface, the greater the degree of precision and the slower the movement becomes. The main difference between this technique and Dog Paddle is that the latter uses a constant mapping, while that from Drag'n Go will vary according the target selected. This can lead to faster movements while avoiding the repetitive nature of Dog Paddle but can, in turn, reduce movement accuracy. If the gesture starts while not looking at a valid object or wall, the end point is defined as 50 meters forward from the user's perspective.

3.2 Orientation

As far as orientation is concerned, we present four techniques, two continuous and two discrete.

3.2.1 Continuous Directional Rotation

The Continuous Directional Rotation technique (Figure 4) consists in the user indicating the direction of rotation, which is applied over the vertical axis of the user, through the use of an analog stick present on the VR controller, as used in some commercial games [16]. It is possible to indicate the direction and intensity. By pushing the analog stick completely to the left, the user rotates to the left at a rate of 60 °/s, and vice versa by pushing to the right. The rotational velocity changes linearly through the horizontal axis of the stick, and the vertical axis is ignored.

3.2.2 Tactile Surface Dragging

The Tactile Surface Dragging technique (Figure 5) consists in reading a gesture over a tactile surface and convert that gesture into a rotation over the vertical axis of the virtual body. By dragging one hand horizontally over the surface, the user proportionally rotates towards the opposite direction, similar to the regularly used smartphone swipe, as if the user was actually dragging the VE. For a full horizontal swipe, the user rotates 160º over the 71 cm of total width of the used tactile surface.

3.2.3 Choose & Click

The Choose & Click technique (Figure 6) consists in pointing towards the intended final direction of rotation through the use of the analog stick present in the VR controller. The final direction is defined by the vector formed between the center of the analog and the final position of the stick. After defining the directions, and without releasing the stick, the user can then press a button to confirm the rotation. This rotation is done in 150 ms, as suggested by Habgood et al. [15], regardless of its amplitude.

3.2.4 Gaze Convergence

Contrary to the previous technique, the Gaze Convergence technique (Figure 7) uses the final orientation of the head instead of the analog stick. The final direction of the virtual body is defined by the head direction, allowing the user to simply look in the intended orientation. This way, by confirming the action with a button, the user's virtual body rotates towards the orientation of the head at the moment of the button press. Again, this rotation is executed within 150 ms.

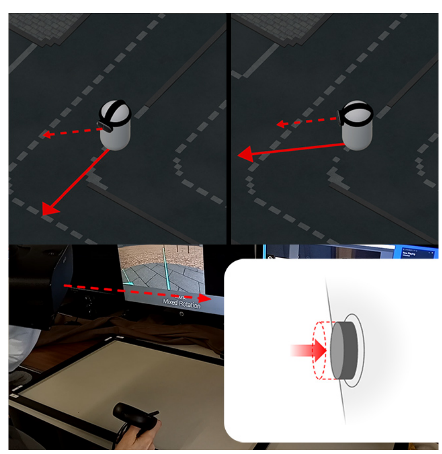


Figure 7: Gaze Convergence.

4 User Evaluation

In order compare the presented techniques, we conducted a user evaluation. In this section we describe the tests' prototype, method, tasks, and participants. Since testing every combination of the proposed techniques would be unfeasible, leading to extremely long sessions, we once again split them into Travel and Orientation categories.

4.1 Prototype

In order to evaluate the proposed techniques, we developed a prototype in Unity 2020.3.19. The virtual scene consists of an urban environment. We used of an Oculus Rift S headset and the corresponding controllers, and a 32" 16:9 infrared multi-touch frame placed on a desk in front of the participant (Figure 8). The touch frame supports up to 10 simultaneous points of contact, and has a reported latency of 8 to 15 ms.

4.2 Method

We evaluated Travel and Orientation techniques separately. Each type will have its own tasks, done separately and repeated for each method. All participants experimented all techniques, performing a set of tasks for each. The order of the techniques tested by each participant followed a Balanced Latin Square distribution to make sure it did not affect test results. For each technique, participants was allowed a short amount of time (1 minute) to freely explore it before beginning the set of tasks. After the last task of each technique, the participants would take a break from the VR environment and fill out a questionnaire. Each test session took between 45 and 60 minutes.

The questionnaire aimed to measure user satisfaction, task load and discomfort. It was created based on existing standards such as SUS [6], NASA-TLX [13] and SSQ [18] but, as the combination of all these would render an excessively long set of questions for each technique, the total amount of questions was reduced to 16 (those from Table 1 plus one asking an overall rating and another about cybersickness symptoms). In addition, we made observations during task execution. Regarding objective measures, We analyzed task performance by measuring time, distance traveled, and rotation covered. These were recorded directly through the developed prototype, starting at the beginning of each task, as soon as the participant starts interacting with the prototype.

4.3 Tasks

We created a total of four Travel tasks and three Orientation tasks. These were repeated for each technique. During each task, the participant is given the current checkpoint direction and order. Depending on the task category, either Travel or Orientation are tested, locking the other alternative. When Orientation is locked, the participant can still look around, but the virtual body will not rotate. When beginning a task, the participant is placed at the starting point and both categories of movement are locked. When they they input an action that would make them move in a specific task - movement intent -, the respective movement is unlocked, and they can perform the task. Time is counted from this moment on until they complete the task.

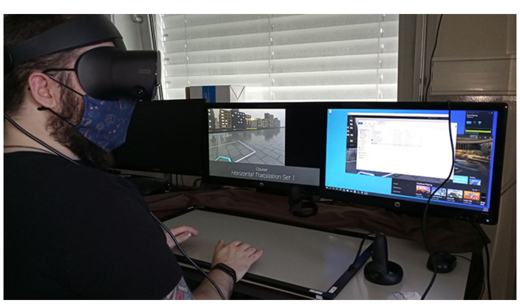
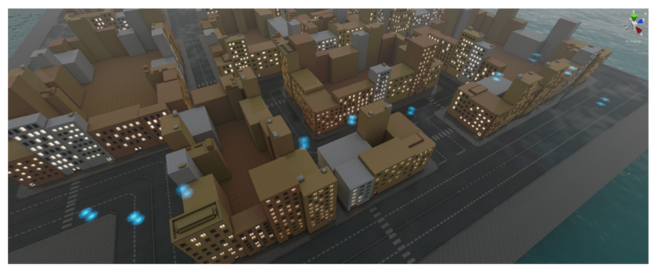


Figure 8: Participant using our prototype.

4.3.1 Travel

The tasks used to test Travel methods feature a set of ordered cylindrical checkpoints, which the participant must go through to complete the task. In order to reach a checkpoint, the participant must come to a full stop while inside it. On success, the participant receives an audio cue, the current checkpoint fades, and the next checkpoint changes color to yellow. Any remaining checkpoint not yet active appears in light blue. The next checkpoint is always positioned in front of the user, even if below or above, since it is not possible to re-orientate. Also, a heads-up display shows the current checkpoint number, with an arrow on top pointing towards it. The user's virtual body collides with buildings and objects, but it is not affected by gravity. Thus, vertical movement works identically to horizontal movement.

The first Travel task (Figure 9a) is a mixed set of vertically and horizontally placed checkpoints. It focuses on testing common flying movements and allowing further familiarization with the technique. The total minimum distance the participant must cover is 554 meters, with a span of 140 meters horizontally and 139 meters vertically. The second task (Figure 9b) is mostly a set of horizontally-spread checkpoints. It focuses on planar movement. The total distance needed to be covered is 433 meters, with only a span of 150 meters horizontally. The third Travel task (Figure 9c) includes a set of vertically-spread checkpoints. It focuses on height adjustment and bypassing vertical obstacles. The total distance the participant must



(a) Mixed task, starting on the right-most checkpoint.

(b) Horizontal task, starting on the right-most checkpoint.

(c) Vertical task, starting on the right-most checkpoint.

Figure 9: Travel tasks of the user evaluation.

Figure 10: Orientation checkpoint (left), Orientation task (right).

cover is 297 meters (21 meters horizontally and 113 meters vertically). Finally, the fourth Travel task had only a single checkpoint on the opposite side of the city from the start, 950 meters apart from the start. The user is only told to reach it as fast as possible by any means. This task is focused on technique learning capabilities and input exploration, as well as overall experience, and prolonged flight movement.

4.3.2 Orientation

The tasks used to test Orientation methods feature a set of traffic-sign-shaped checkpoints which the user must align their virtual body with (Figure 10), and a predefined set of rotation angles that the user is expected to move. For a given checkpoint, the user must align their virtual body with the pole of the sign within an error of two degrees. To help with this, a visible line extends from the virtual body. When this line matches with the pole of the current checkpoint, the pole will fill with a yellow line, and outline the sign. This action takes 2 seconds to complete, and can be interrupted if the user misaligns the virtual body with the checkpoint, setting the checkpoint to its original state. After completing a checkpoint, a rotation angle is chosen from the predefined set of angles, and the new checkpoint is created at that angular distance from the previous checkpoint.

The first Orientation task is a mixed set of both small and large rotations, resulting in a total of 540º of rotation over seven checkpoints. This task does not have a particular focus when it comes to evaluation. It should act as a baseline for the other tasks. The second Orientation task is a set of small rotations only, for a total of 175º of rotation over seven checkpoints. This task focuses on evaluating short and precise rotations. The third and last Orientation task is a set of large rotations only, for a total of 490º of rotation over four checkpoints. This task focuses on evaluating quick changes of direction.

4.4 Participants

We gathered 12 participants, seven of which were male and the remainder female. Eight were aged between 18 and 25, three were between 26 and 32 years old, and one was in the 49 to 62 years-old interval. Eight did not have any previous experience with VR, two experienced it rarely (less than once per month), and two used VR daily. Only two participants reported knowing that they suffer from vertigo.

5 Results

During the user evaluation sessions we registered objective performance measures, questionnaire responses and observations made during tasks. In this section we analyze and discuss our results.

5.1 Task Performance

As performance measures, we collected time elapsed for completing the tasks, total path length (for Travel tasks only), and total rotation (for Orientation tasks only). To assess normality, we conducted a Shapiro-Wilk test. For normally distributed data, we used the one-way ANOVA with repeated measures to test for statistically significant differences. We determined sphericity through Mauchly's Test of Sphericity. In the cases the data was not spherical, we applied Greenhouse-Geisser correction. If the data was not normally distributed, we used a Friedman Test with the Wilcoxon Signed-Rank post-hoc test. All post-hoc results were applied a Bonferroni adjustment (we report corrected p-values).

Starting with Travel times (Figure 11 (top)), in the mixed task ($F(2,16) = 12.523, p < .001$), Drag'n Go (DnG) was statistically significantly slower than both Continuous Directional Movement (CDM, $p = 0.12$) and Dog Paddle (DP, $p = .020$). However, in the horizontal task ($\chi^2(2) = 11.167, p = .004$), only CDM was significantly faster than DnG ($Z = -3.059, p = .006$). In the vertical task ($F(2,18) = 30.062, p < .001$), CDM was much faster than both DnG ($p < .001$) and DP ($p < .001$). Finally, on the long task ($F(1.192, 10.729) = 72.369, p < .001$), DnG was significantly faster than both DP ($p = .044$) and CDM ($p < .001$). DP was also faster than CDM ($p < .001$) this time.

As for path length (Figure 11 (bottom)), in the mixed task ($F(1.088, 6.526) = 19.491, p = .003$), DnG had a significantly larger path length than both CDM ($p = .009$) and DP ($p = .017$). This was the same for the horizontal ($F(1.019, 6.113) = 16.332, p = .006$, $p = .016$ and $p = .026$, respectively) and vertical tasks ($F(2,14) = 23.463, p < .001$, $p < .001$ and $p = .022$, respectively). Additionally, CDM had a significantly shorter path than DP as well ($p = .043$). There was no statistically significant differences in the long task.

Regarding task times for the Orientation tasks (Figure 12 (top)), in the mixed Orientation task ($F(1.418, 11.345) = 47.428, p < .001$), Choose & Click (C&C) performed worse than Continuous Directional Rotation (CDR, $p < .001$), Gaze Convergence ($p < .001$), and Tactile Surface Dragging (TSD, $p < .001$). Same applies for the large Orientation task ($F(3,30) = 28.219, p < .001$, $p = .002$,

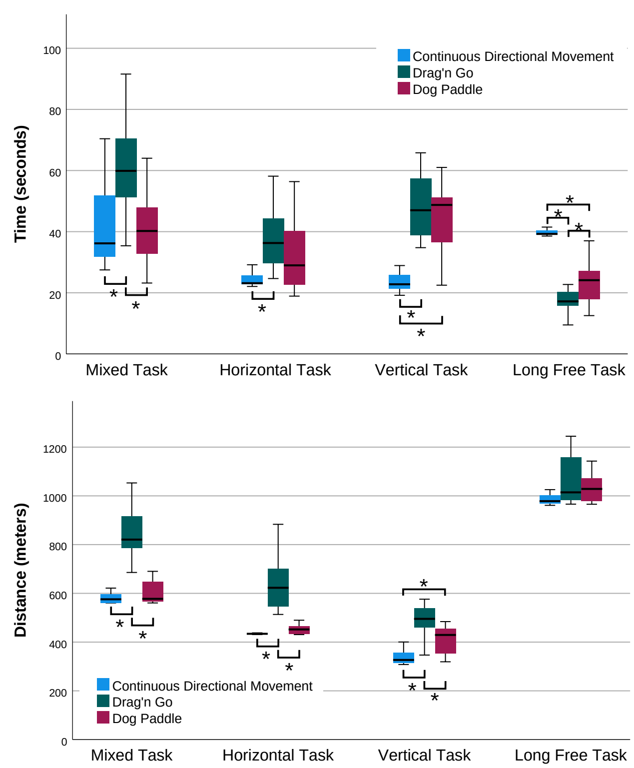


Figure 11: Average Travel task time (top) and distance covered (bottom). * indicates statistically significant differences.

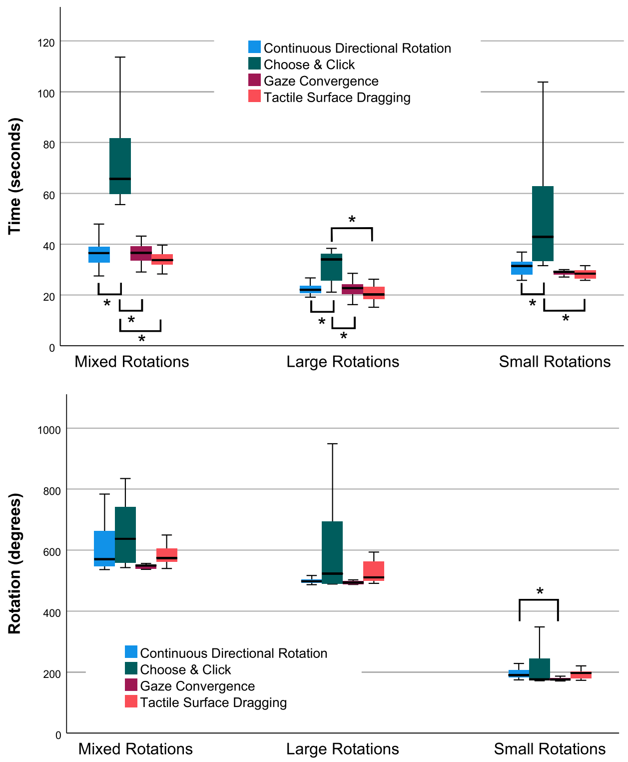


Figure 12: Average Orientation task time (top) and total user rotation (bottom). * indicates statistically significant differences.

$p < .001$ and $p < .001$, respectively). The small Orientation task ($\chi^2(3) = 11.914, p = .008$) only had C&C performing worse than CDR ($Z = -2.981, p = .018$) and TSD ($Z = -2.934, p = .018$).

Finally, for the total rotation (Figure 12 (bottom)), the only statistically significant result of all three tasks was on the small Orientation task ($\chi^2(3) = 8.067, p = .045$), where Gaze Convergence had a smaller total rotation than Continuous Directional Rotation ($Z = -2.803, p = .030$).

5.2 Questionnaire Results

For questionnaire data, we used the Friedman Test together with the post-hoc Wilcoxon Signed-Rank test using the Bonferroni correction. Results are reported in Table 1. For technique rankings, there was no statistical significant differences for either Travel or Orientation techniques.

Regarding participants self-assessment, they believed that, in the Travel tasks, they performed worse ($\chi^2(2) = 15.436, p < .001$) with DnG than with CDM ($Z = -2.911, p = .012$) and DP ($Z = -2.652, p = .024$). CDM also required less effort ($\chi^2(2) = 7.171, p = .028$) than DnG ($Z = -2.491, p = .039$) to reach that level of performance. Users felt more confident ($\chi^2(2) = 12.162, p = .002$) with CDM than DnG ($Z = -2.701, p = .021$), and also found the first to be less mentally demanding ($\chi^2(2) = 11.118, p = .004$) than the latter ($Z = -2.694, p = .021$). They also felt their pace was more rushed ($\chi^2(2) = 7.000, p = .030$) with DP than with CDM ($Z = -2.414, p = .048$). As for technique assessment, participants found CDM easier to use ($\chi^2(2) = 10.231, p = .006$) than DnG ($Z = -2.598, p = .027$), as well as easier to learn ($\chi^2(2) = 8.424, p = .015, Z = -2.598, p = .027$).

Concerning Orientation techniques, participants said they performed significantly worse ($\chi^2(3) = 25.041, p < .001$) with C&C than with CDR ($Z = -2.988, p = .018$), GC ($Z = -2.676, p = .0.42$), and TSD ($Z = -3.130, p = .012$). C&C, compared to CDR and TSD, also required more effort ($\chi^2(3) = 21.088, p < .001$, $Z = -3.084, p = .012$ and $Z = -2.848, p = .024$ respectively), left the users less confident ($Z = -2.675, p = .042$ and $Z = -3.048, p = .012$, respectively), and was more mentally demanding ($\chi^2(3) = 14.798, p = .002$, $Z = -2.680, p = .042$ and $Z = -2.701, p = .042$, respectively). GC was significantly more physically demanding ($\chi^2(3) = 9.620, p = .022$) than CDR. Continuing with technique assessment, CDR and TSD appeared to be significantly easier ($\chi^2(3) = 21.233, p < .001$) than C&C ($Z = -2.971, p = .018$ and $Z = -3.097, p = .012$, respectively). Participants also evaluated TSD as being more confidence inspiring ($\chi^2(3) = 16.735, p < .001$) than C&C.

5.3 Observations

During each participation, observations were registered regarding participants' behavior and comments.

There were issues with the finger and hand tracking of the touch surface. As it uses infrared sensors to detect an interruption of a beam, it had issues when the user did not lift their hand high enough, or fingers came too close to each other, more so when both hands came near one another. This was particularly frustrating during Dog Paddle tasks, as it would often act as if both hands were only one, causing a sudden jolt in the opposite direction of movement. So the real performance of Dog Paddle can potentially be improved if these hardware limitations are addressed. The other tactile techniques were far less affected, since Drag'n Go does not have a two handed method, and Tactile Surface Dragging is significantly less sensitive and had a broader area to work with.

Continuing with Dog Paddle and Drag'n Go, a shared behavior across all participants was that they instinctively used a very small portion of the touch surface, as it is possible to see in Figure 8. Even with Drag'n Go, where they could benefit from a higher degree of precision, they appeared to favor short, quick motions. In addition to this, users had a tendency to not aim at any object in particular, or at the checkpoint, or at the floor when using Drag'n Go. The exception was during the last Travel task. They would often plan ahead and purposefully aim at far away objects, with varying degrees of efficiency.

There were a few complaints around the gaze-dependent techniques. One user reported slight neck pain during the vertical task with both Dog Paddle and Drag'n Go techniques, as well as when using Gaze Convergence for larger angles. There were also other users who showed discomfort during gaze-oriented techniques, either physical or cybersickness. Another recurring complaint about Gaze Convergence was counter-rotation after applying the new orientation. At least two participants mentioned becoming disoriented when returning to center, but not while rotating. The same two participants did not have the same complaint with Choose & Click, which uses a very similar rotation system.

Finally, there were some complaints about the Dog Paddle input re-orientation based on the gaze's own orientation. Five people said it was counter-intuitive. In addition, some users tried to move perpendicularly to the gaze direction, which was not possible.

One particular user which declared upfront that suffered from vertigo claimed that they only started noticing that symptom after realizing they were not experiencing vertigo even after a full set of tasks, which include vertical and flight sections over building roofs.

5.4 Discussion

As far as ease-of-use, efficiency and convenience goes, Continuous Directional Movement had a clear advantage over its competitors. In mixed, horizontal and vertical tasks, it showed a statistically significant time and path length advantage over Drag'n Go, and an advantage trend over Dog Paddle, even as far as statistically better in the vertical task. Also, it does not suffer from neck-related

Question	Travel			Orientation			
	CDM	DnG	DP	CDR	C&C	GC	TSD
How well do you think you performed?	$7(1)^{*}$	$5(1)^{*\dagger}$	$6(3)^{\dagger}$	$6.5(1)^{*}$	$4.5(2)^{*\dagger\ddagger}$	$6(1)^{\dagger}$	$6.5(1)^{\ddagger}$
How much effort did it require to reach your level of performance?	$1(2)^{*}$	$3.5(2)^{*}$	3.5(4)	$1(2)^{*}$	$5(2)^{*\dagger}$	3(4)	$2(2)^{\dagger}$
How do you feel about your performance?	$7(1)^{*}$	$4.5(3)^{*}$	6(3)	$7(1)^{*}$	$3(3)^{*\dagger}$	6(2)	$7(1)^{\dagger}$
How mentally demanding was the task?	$1(1)^{*}$	$3(3)^{*}$	2(3)	$1(1)^{*}$	$3.5(3)^{*\dagger}$	2(3)	$1.5(1)^{\dagger}$
How physically demanding was the task?	2(1)	2(2)	3.5(4)	$1(1)^{*}$	2.5(2)	$3(4)^{*}$	1.5(2)
How rushed was your pace on the task?	1(3)	3(4)	3.5(5)	1(4)	4(2)	4.5(4)	2(4)
I would like to use this technique frequently.	4(1)	3(3)	3(3)	5(2)	3(2)	4.5(3)	4(3)
I found the technique unnecessarily complex.	1(0)	1(1)	1.5(2)	1(0)	2.5(3)	1(1)	1(0)
The technique was easy to use.	$5(0)^{*}$	$4(2)^{*}$	4(2)	$5(0)^{*}$	$3(2)^{*\dagger}$	5(2)	$5(0)^{\dagger}$
I think that I would need the support of a technical person to be able to use this technique.	1(1)	1(2)	1(1)	1(0)	1(1)	1(1)	1(0)
I would imagine that most people would learn to use this technique very quickly.	$5(1)^{*}$	$4(2)^{*}$	4(2)	5(0)	3(3)	4(2)	5(1)
I found the technique very cumbersome to use.	1(1)	2(2)	2(3)	1(1)	3(4)	1.5(3)	1(0)
I felt very confident using the technique.	5(1)	4(2)	4(2)	5(0)	$3(2)^{*}$	4.5(2)	$5(0)^{*}$
I needed to learn a lot of things before I could get going with this technique.	1(0)	1(1)	1(1)	1(0)	1(2)	1(1)	1(0)

Table 1: Questionnaire's results. Reporting medians and interquartile ranges. *, †, and ‡ indicate statistically significant differences.

issues, as it uses the hand rather than the head to establish a direction of movement. It also fares well in user evaluation, often doing better than Drag'n Go, and trending slightly above Tactile Surface Dragging. The major issue it had in performance was that, unlike the other methods which allow to go as fast as you can swipe, Continuous Directional Movement was limited to the speed limit set at full-trigger pressure, and possibly a conservative one at that. There were suggestions from some participants to add an extra button to allow for a "boost", increasing the maximum speed of travel. This may indeed improve task performance, but can be applied to almost all techniques.

As for rotation, it was not as clear cut. Except for Choose & Click, all did reasonably the same, performance-wise. However, **there is a trend towards Tactile Surface Dragging as the best method overall**. It shares the user score trend from Continuous Directional Rotation and efficiency trend of Gaze Convergence, but is not statistically significantly better than its counterparts.

Regarding discomfort symptoms, it is hard to obtain conclusive answers. Two participants did not experience any symptom during all tasks and tests. Only one method in each category experienced Moderate (or higher) symptoms, and only once each. **The onset of symptoms was overall low, and some were hard to distinguish, making observation error-prone.** Even more interestingly, some users reported that some symptoms only showed up during their first techniques, and would disappear even before a full set of tasks was complete. Still, some trends could be observed. Both Drag'n Go and Continuous Directional Rotation were the only ones to experience moderate symptoms in each of their categories. In addition to this, Continuous Directional Rotation fared noticeably worse with Dizziness compared to the remaining methods. In the end, we should also take into account the fact that most users had little to no VR experience.

One interesting point that came up during testing was vertigo. Two users claimed to have issues in real life with vertigo, and yet, they experienced it sparingly. More interestingly, one claimed they had not felt vertigo until mid way. This gave us an idea, as to whether **having the user focused on the task could alleviate cybersickness.** Continuous Directional Movement has a slight trend of worse cybersickness than Dog Paddle, but generally better usability. At the same time, Choose & Click required a lot of precision and focus to get the correct orientation to complete the checkpoints, but generally lower symptom occurrence, despite significantly higher task duration.

In addition to this, **we speculate that direct-action inputs may reduce the onset of symptoms.** For example, Dog Paddle has noticeably lower number of occurrences of slight nausea compared to Continuous Directional Movement, despite the movement itself being similar but jerkier. The same comparison can be made between Continuous Directional Rotation and Tactile Surface Dragging, but for Dizziness and other symptoms in general. It is possible that, by having the user expect some sort of visual response directly from an action, it may reduce the severity of symptoms.

It was noticed that, in the Orientation tasks, the threshold of two degrees could be too conservative. It would be interesting to test further with a higher threshold. It was also noted that even though the surface occupied a significant portion of the working table, the tendency was to use a small area close to the body, with small but short movements. This could be the subject of further research as well.

6 Conclusions and Future Work

Desk VR limits the type of interactions we can have with the virtual environment. To improve on those limits, we looked at current solutions for movement techniques that do not require full-body movement and proposed some of our own. We conducted a set of user tests to evaluate those techniques.

Despite the relatively low number of participants, the results provided a set of insights that can be useful for those interested in using these methods or researching new ones. There was a trend towards Tactile Surface Dragging as the best method overall for Orientation tasks, and Continuous Directional Movement had clear advantages in terms of ease-of-use, efficiency and convenience for Travel tasks.

It was interesting to observe that the onset of discomfort symptoms was overall low, and that using direct inputs and having the user focused on the task seemed to have an influence on that. Both of these are topics for future work, as well as further developing a control scheme that somehow includes both Continuous Directional Movement and Tactile Surface Dragging.

Future improvements to the work could include increasing the number of participants, to strengthen the significance of these findings. Additionally, further exploring the combination of proposed techniques - e.g. using a touch surface with a controller or pairs of controllers - could lead to other techniques of interest.

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