Am I Moving Along a Curve? A Study on Bicycle Traveling-In-Place Techniques in Virtual Environments

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A Study On Bicycle Traveling-In-Place Techniques In Virtual Environments

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Abstract. There are many techniques for locomotion and navigation that can support the exploration of large virtual environments in a limited physical area. Previous studies focused on measuring curvature gains and bending gains applied to the walking direction in the real world. However, the effects of different moving techniques and their relationship with shapes and patterns of virtually moving paths have not been studied extensively before. In this study, we present our experimental results on how users perceive two different traveling-in-place techniques with different bending gains of moving paths using a hybrid electric bike simulator. Moreover, the impact of different factors including road textures, road widths, and road curve directions and their relationships with the techniques are investigated. Generally, users could travel along a curve without noticing with a point of subjective equality (PSE) at bending angle $\beta = 1.42^o$, and a just-noticeable difference (JND) of 0.75^o for a movement at around 20 km/h during 5 seconds. In addition, movement technique, curve direction, and future travel path significantly affected how they perceived the curvature of their travel path.

Keywords: Curve Perception · Locomotion · Virtual Reality · Traveling-in-place · Human Perception · Redirected Walking.

1 Introduction

Virtual reality (VR) is becoming more and more popular. It has been applied in many different fields and circumstances from research communities to users' daily activities. Modern VR systems can be operated in immersive desktop setups but also allow for natural walking movements within limited spaces of a couple of meters. However, if the virtual space is larger than the physical space, locomotion and traveling techniques have to be introduced. How to travel in large virtual environments is still a challenging task and subject to a lot of research.

Locomotion techniques can be classified into three categories: walking-in-place [27], natural walking (eg. redirected walking [20]), and using different virtual locomotion metaphors or mechanical systems (eg. teleportation [1] and treadmills [4]). In order to reorient users in virtual environments, different reorientation techniques were developed. One of the techniques is to use an external device, eg. a joystick while on a treadmill. However, such techniques are not very natural, can cause simulation sickness, and might reduce the users' sense of presence.

Actual 1:1 walking interfaces stimulate proprioceptive and vestibular cues more appropriately than other locomotion interfaces in virtual environments [19]. Unfortunately, they can't always be applied. If the real space is very small, walking-in-place and virtual locomotion metaphors are the most effective techniques. For very large spaces, users can travel at a higher speed with vehicle simulators. Many of those simulators have limited degrees of freedom when compared to their real-world counterparts. E.g., popular bike interfaces often lack the actual ability to turn (or lean) to change direction, a long enough straight path has to be provided for users to travel.

In this study, we focus on figuring out how to develop a locomotion interface for large virtual environments supporting two traveling-in-place techniques infinitely. In particular, we investigate to what extent travel path bends with different rotation gains are considered as curved in virtual environments. In addition, we compare the difference in perceiving the applied gains between *"pedaling"* and *"throttling"* techniques. The effects of road materials, road width, and road directions on perceiving the amount of degrees by which travel paths are bent, called "*curved-ness*" level, were also examined. Moreover, we explore how participants perceive the environment, make decisions, experience simulation sickness and a sense of presence.

This paper is structured as follows. Section 2 presents related work, Section 3 describes our experiment design and procedure. Section 4 and 5 present the experimental results and discussion. We conclude our study in Section 6.

2 Related Work

Users can change their position and orientation in virtual environments, while they are naturally walking and reorienting in the real world. However, the virtual environment is often larger in its extent or scaled compared to the users' physical area. There are locomotion techniques, called redirected walking, which were developed to address this problem. These techniques manipulate users' movement in the virtual world by relocating and reorienting continuous or discretely with subtle or obvious changes in the virtual environment [30]. This can lead users to perceive to be moving on a straight path, while their actual travel path in the real world is curved or bent.

To reorient users, different visual manipulation techniques (eg. rotation gains [20, 28]) and other sensory effects [18] are applied. There are two different notions of curvature gains or rotations gains. The first notion is represented by radii, which is used to indicate the physical space required for a specific redirected walking technique. However, it was argued that radii do not scale in a linear way with how the manipulation is applied and should not be used to compare different gains [24]. On the other hand, the second notion refers to the amount of rotation angles applied on a particular walking distance and is usually presented in units of ^{o}/m; rotation gains measured as angle per meter can be converted to individual radii [24]. In different conditions, research groups found different thresholds of undetectable bending gains. Steinicke et al. [29] found a imperceptible bending gain could be up to 2.6 ^{o}/m. 4.9 ^{o}/m and 15.4 ^{o}/m have been found in studies by Grechkin et al. [7] and Langbehn et al. [10] respectively. In a revisited study, Rietzler et al. [24] figured out that users can virtually go straight ahead boundlessly in a 6m x 6m physical area. In addition, their real travel paths can be bent up to 20 ^{o}/m. In this study, we present rotation gains in both of these notions.

There are also studies investigating detection thresholds and effects of additional sensory feedback and specific tasks. Bruder et al. [3] studied redirected walking on cognitive tasks, while Matsumoto et al. [11] investigated the effects of negative haptic cues supporting users to walk infinitely and turn freely. Paludan et al [17] found that the number of objects in the virtual environment scene did not perceptibly affect users on detecting rotation gains. In addition, there are studies examining rotation gains perception with the effect of audiovisual feedback by Nilsson et al. [15] and redirected driving with a wheelchair by Bruder et al. [2]. There is a study by Kim et al. on redirected jump in a micro gravity virtual environment with a cable-driven system [9]. They showed that users could leap up to virtual stairs in the virtual environment while they jumped on a flat floor in the their real world. To sum up, there are available reviews on redirected walking and natural walking in virtual environments [13, 16]; however, traveling-in-place techniques have not been surveyed yet.

For walking-in-place techniques, users can move in the virtual environments by mimicking the movements of their body in the real world, while they do not change their physical position [27, 5, 35]. Besides these techniques, the movement of users is controlled or manipulated by mechanical systems or using external input devices, eg. joystick or wand, while their position in the real world is not actively changed. In order to reorient, users can directly rotate their physical body or head and their orientation in the real world is recorded and mapped to their virtual orientation [27, 34, 31]. In addition, their orientation can be applied with different rotation gains [21]. However, users can not always reorient their direction, especially when walking on a treadmill or performing locomotion in a one-way direction. Terziman et al. [32] revisited the walking-in-place procedure and present a novel technique, called "Shake-Your-Head". This technique can stimulate different locomotion postures which include forwarding, jumping and crawling, an turning dependent on the rotation of the head. Williams et al. [36] presented a walking-in-place technique using a Wii balance board. In this technique, data from an orientation sensor is used to orient users' direction in virtual environments. There were two different gesture inputs, namely wiping and tapping, for walking-in-place locomotion by Nilsson et al. [14]. Interactive portals which are placed by making ray-casting selections with a pointing device are used to reorient users in the virtual world [6]. In addition, they found that users can reach to their desirable position with only one reorientation. There are efforts on developing new walking-in-place techniques, mechanical supported locomotion, and walking metaphors to increase performance. However, it is reported that locomotion techniques which are natural and include users' physical manipulation induce higher sense of presence, reduce simulation sickness, and increase performance while reducing manipulation time [34, 30, 23].

Although, there is a wide extensive research effort on locomotion techniques in virtual environments. We could not find any study of bending detection on users moving on a curved path in virtual environments while they are traveling in a stationary position with a fixed straight ahead direction in the real world. In addition, the effects of additional factors such as textures and sizes of travel paths have not been studied before. In this study, we address these issues.

3 Experiment

3.1 Experiment Setup

We conducted an experiment in a laboratory environment using a hybrid bike simulator. The simulator could be operated in both traveling-in-place techniques supported by a real electric bike. A 36V/350W power supply adapter was used to power the bike when participants performed *the "throttling" movement technique*. The movement speed of the simulator was calculated and recorded by a speedometer. This included a Hall sensor, and a magnet on the back flywheel and an Arduino Nano board. The simulator provided airflow by a fan attached at 90cm from the head of the bike. The fan was powered by a 12V/150W motor with three slender plastic blades. The generated airflow could be perceived from participants' hip to their head and arms. In our experiment, the speed of airflow was stimulated and equal to the movement speed of the bike through a Unity3D and an Arduino Uno board.

Users see the virtual environment through a Dell Visor head-mounted display (HMD). This HMD supports inside-out tracking and comprises two 1440 x 1440 pixels resolution liquid crystal displays. The headset had a refresh rate at 90 Hz and can provide 105^o field of view.

3.2 Experiment Design

In this study, we used the method of constant stimuli in Yes-No tasks. The experiment is mainly designed based on two traveling-in-place techniques and rotation gains. A multi-factorial 2x5x2x2x2 design was applied with two techniques for locomotion in virtual environments, five rotation gains, two curve directions, two road materials, and two road widths (independent variables).

- The *traveling-in-place technique* (movement technique) was how people traveled in the virtual environments when they did not change their position in the real world. In this study, we investigated two different techniques, namely *"pedaling"* and *"throttling"* as in a study of Tran et. al. [33]. For *"pedaling"*,

Fig. 1: Experiment Setup. Our experiment was conducted with a bike simulator. The simulator comprises of an electric bike with a head mounted display, a fan, and a speedometer.

users have to directly power their movement by cycling using their feet. Or, they can control their movement speed by hand twisting the throttle grip with the *"throttling"* technique. The speed of these movement techniques was higher than walking speed, so we named them traveling-in-place techniques.

- The *rotation gain* (β) was the level at which the moving path was curved. After pilot tests, there were five different gains chosen. We found 0.25, 0.5, 1, 1.75, and 2.5 degrees, see Fig. 2. The gains were applied to the travel path in for five seconds with a movement speed 20 km/h and a path of 27.78 m in length.
- The *curve direction* was the direction towards which the travel path was curved: *"left"* or *"right"*.
- The *road material* was the pattern of the travel path. There were two different road appearances in our experiment. Either a paved road with a marked line (*"paved"*) or a dirt road without any markings (*"dirt"*).
- The *road width* was the horizontal size of the path. We considered two different road widths in our experiment: 2m (*"small"*) and 4m (*"large"*).

The entire experiment was divided by the traveling-in-place techniques into two different blocks. For each block, participants would perform one of the two

Fig. 2: Five different rotation gains applied to the travel path in our experiment. From left to right: $\beta = 0.25$, 0.5, 1, 1.75, and 2.5 degrees, respectively.

techniques. For example, they would travel by “pedaling” in the first block (B1), then perform “throttling” in the second block (B2). The order of performing traveling-in-place techniques was counter-balanced, whereas the representation order of rotation gain, curve direction, road material, and road width was randomized.

All participants did wear the aforementioned HMD while riding the bike and performing the experiment trial. They were requested to maintain their movement speed at around 20 km/h during trials. There were three main steps for each experiment trial. In the first step, each participant initially experienced a ride on a straight path for five seconds, then, traveled on a path which was curved by the rotation gains in the next step. In the final step, the participant was required to respond to the question: “*Did you perceive the recent path as curved?*”. If the participant perceived that they had recently traveled on a curved path, a “Yes” response was saved, otherwise, a “No” response was recorded. The travel path for this step (“*after trial path*”) could be *“straight”* or *“curved”* as the same rotation gain as the path in the second step. For this reason, the travel path in the last step was considered as an additional independent variable. After this step, a new trial started and the participant was requested to perform the same procedure. An illustration summarizing the travel paths for each experimental trial is shown in Fig. 3. In addition to the participants’ responses, their real velocity during the experiment was recorded. The response and real velocity were examined as dependent variables in our experiment.

Participants performed forty (5x2x2x2) combinations of 5 rotation gains, 2 curve directions, 2 road materials, and 2 road widths for each experiment block. For each combination, they were asked to decide each time for each type

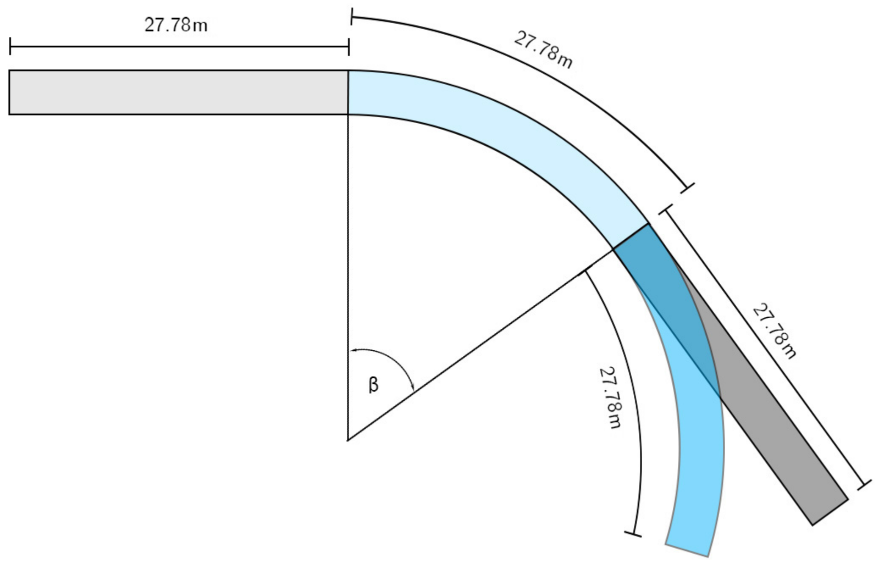

Fig. 3: Illustration of travel paths for the experiment trial. For each trial, participants would move on a 27.78m straight path or be traveling at 20 km/h for 5 seconds, before riding on a 27.78m curved path. After experiencing the bending path, they have another 5 seconds to travel at 20 km/h on either a curved or bent path.

after trial path if the path was perceived as curved. In total, each participant accomplished 80 (40x2) trials and responses for each block.

3.3 Participants and Experiment Procedure

There were thirty-two university students (22 male, 8 female, and 2 would not say) taking part in our experiment. They were from 18 to 22 year-old (M = 20.26, SD = 1.55). Seventeen participants frequently rode bikes, whereas twenty-eight often travel by motorcycles, electric bikes, scooters, or mopeds. Twenty-two volunteers reported that they had tried a head-mounted display and eight of them had experienced a ride in virtual environments. All participants had normal or corrected-to-normal vision and no participants reported any issue with their vestibular system. All volunteers were compensated for their participation.

When a participant arrived, they were randomly assigned to one of two groups. In the first group, participants performed block B1 before block B2. Otherwise, participants in the second group completed block B2 first, then block B1. After the assignment, they were presented with a document about experiment details and requirements. They were requested to carefully read the document and make their decision on whether to take part in our experiment. After agreement, they were asked to sign a consent form and were given a brief introduction document. The consent form included their agreements and responsibilities, while the

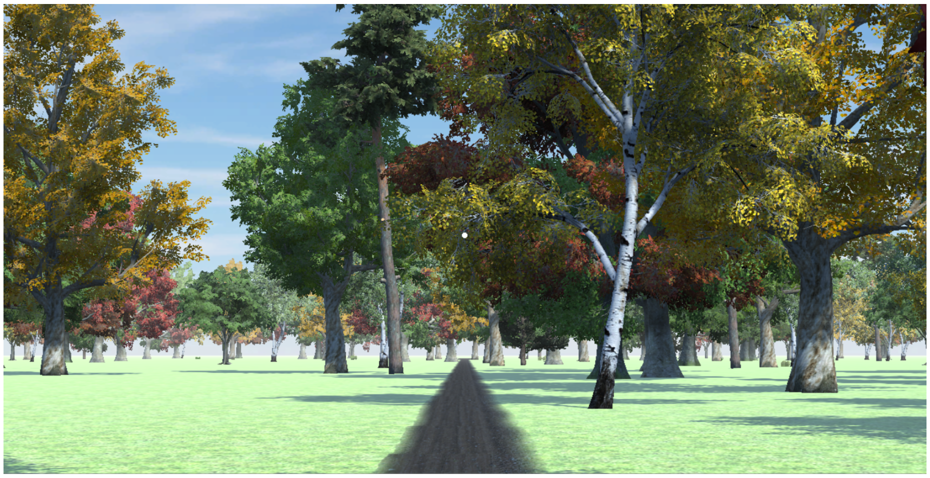

Fig. 4: Representation of our experiment virtual environment. In this virtual environment, users could see their traveling path, different types of trees, and the blue sky with clouds. In addition, their virtual avatar and a virtual bike corresponding to their current movement technique are also shown. However, their visible distance is not far in order to preventing them from guessing based on the shape of the path in the distance.

introduction form was used to ascertain their experience with virtual reality and real-world transport. They, then, were trained with two different traveling-in-place techniques, while encountering different road materials and widths. During the training session, they were instructed to get familiar with the virtual environment and to maintain their moving speed at around 20 km/h. After training, they took a break for 5 minutes before performing the experimental blocks.

For each experiment block, they were asked to perform 80 trials. Each trial had three different steps. Firstly, they had 5 seconds to experience locomotion on a straight road. They, then, moved on a curved path. This path was bent with one of the rotation gains. At the final step, they were traveling on a straight or curved path which was the same as in the previous step while responding to answer the question: “Did you perceive the recent path as curved?”. If they agreed, they were instructed to select the virtual “YES” button by moving a small cursor in their view to that button and press a green button next to the left hand grip of the bike. Otherwise, they were asked to select “NO”. It took about 20 minutes to perform one block. After finishing a block, they had a 5 minute break and answered a collection of three questionnaires. These questionnaires included a Simulator Sickness Questionnaire (SSQ) [8], the Igroup Presence Questionnaire (IPQ) [22, 25], and a feedback questionnaire in order to investigate how participants perceived the experiment and the traveled path as curved. The total time for our experiment was about 70 minutes. In summary, our experiment procedure is presented in Table 1.

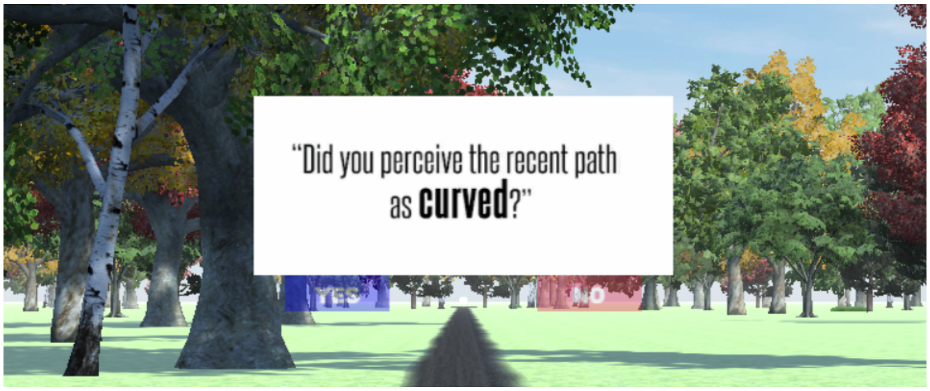

Fig. 5: Users had to make their decision after each experimental trial.

Table 1: Experiment procedure.

Step	**Time (min)**
Instruction and informed consent	10
Training	5
Break	5
Experiment with the 1st block	20
Questionnaire and Break	5
Experiment with the 2nd block	20
Questionnaire	5

3.4 Hypotheses

For the experiment design, we would like to figure out detection thresholds of rotation gain at which users travel on curved paths, but perceiving as straight. That is to answer the question:

"*To what extent are users unaware of a bend while traveling on a curved path?*"

In addition, the contributions of movement techniques, road materials, road widths, road directions are also addressed. For these factors, we want to identify the difference between each condition of each factor and their impact on users' perception leading to two research questions:

"*To what extent does each factor affect users' perception?*"

and

"*To what extent does each condition of each factor contribute to the perception of bends?*".

4 Results

4.1 User responses

All of participants' responses were analysed using MathWorks MATLAB and SAS. We used psignifit 4 toolbox [26] in order to fit our psychophysical data with a logistic function. All parameters for the fitting process were set free, while asymptotes were additionally assumed to be equal. The point of subjective equality (PSE) is the point participants randomly choose between "Yes" and "No" response and is set at 50% proportion of "Yes" responses (or threshold level at 0.5). In addition, the just-noticeable difference (JND) is the difference range of stimuli for participants to be detectable. The JND was calculated by half of the distance between threshold levels 0.75 and 0.25. Overall, we found $PSE = 1.42$ and $JND = 0.75$ with the fitted psychometric curve for the whole experiment presented in Fig. 6.

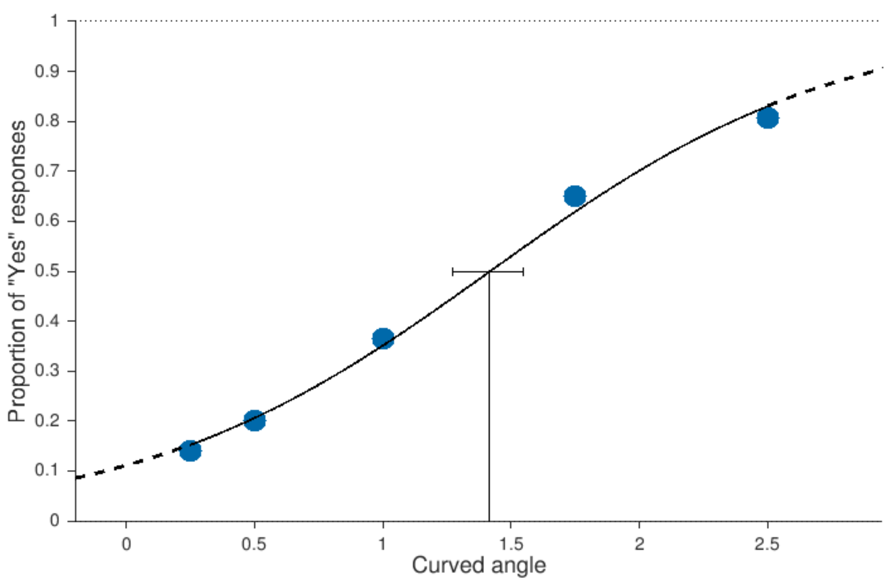

Fig. 6: The psychometric function fitted for the whole experiment psychophysical data with the point of subjective equality (PSE) indicated by the vertical central line with confidence intervals. Overall, the PSE is biased to 1.42.

The PSEs and JNDs for each condition of the independent variables are shown in Table 2. For the movement techniques, users could not discriminate whether the travel path was straight or curved when they traveled at around 20 km/h on 1.49^o. In addition, the range of detectable stimuli for this technique is 0.82. On the other hand, the PSE and JND for "throttling" is biased to 1.35 and

0.5 respectively. The psychometric curves fitted for each movement technique is showed in Fig. 7.

Moreover, Fig. 8 presents the sigmoid functions fitted for the curve direction.The users could perceive the straight and curved path as identical when the bent angles are 1.52° and 1.26° for "left" and "right" respectively. The JNDs are 0.76 and 0.52 for these directions in the same order. In addition, if the rotation gains are set to 1.52° for *"dirt"* and 1.33° for *"paved"* road material, the participants would perceive a curved path as straight. The ranges of noticeable stimuli for these road materials are 0.48 and 0.65, respectively. The psychometric functions fitted for both *"dirt"* and *"paved"* are showed in Fig. 9.

The sigmoid functions fitted for the road width and after trial road variables are illustrated in Fig. 10 and Fig. 11 respectively. For the road width factor, the subjects cannot distinguish between the bent path with 1.35° and 1.49 ° and the straight path for *"small"* and *"large"* condition, respectively. Their discernible dimensions of stimuli are 0.7 and 0.74 For the after trial road, *"curved"* has the value of PSE at 1.25, whereas that of *"straight"* is at 1.55. The values of detectable stimuli ranges for these conditions are 0.47 and 0.79 respectively.

Table 2: PSE and JND for each condition of independent variables.

Factor	**Condition**	**PSE**	**JND**
movement technique	pedaling	1.46	0.82
	throttling	1.35	0.5
direction	left	1.52	0.76
	right	1.29	0.52
road material	dirt	1.52	0.48
	paved	1.33	0.65
road width	small	1.35	0.7
	large	1.49	0.74
after trial road	curved	1.25	0.47
	straight	1.55	0.79

In addition, PSEs and JNDs of each subject for each independent variables and the interactions between movement technique and the other independent variables were estimated. We conducted ANOVA analyses in order to find significant effects of the independent variables and their interactions.

The analysis of one-way interaction showed that there were significant effects of movement technique, curve direction, and road after trial ($p < .05$). Tukey post-hoc tests were conducted for these variables. For movement technique, *"throttling"* had significantly higher PSE than *"pedaling"*. The PSE for *"right"* was significantly smaller than for *"left"* curve direction. With road after trial, *"straight"* had a significantly higher PSE value than *"curved"*. On the other hand, we could not observe any significant impact of the independent variables on the value of JND.

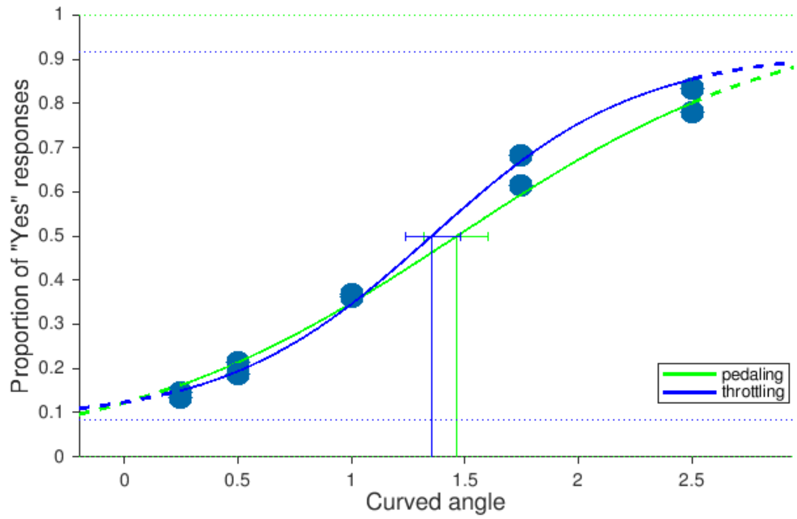

Fig. 7: The psychometric functions fitted for each condition of movement technique and the vertical central lines indicate their PSEs with confidence intervals. Overall, the PSEs are biased to 1.46 for "pedaling" and 1.35 for "throttling".

The two-way interaction analysis results showed significant effects for the interaction between movement technique and road after trial ($p < .05$). The Tukey post-hoc test showed that *"straight"* road after trial had significant higher PSE than *"curved"* for all of the movement technique. However, we did not observe any significant effects of movement technique and other independent variables on the PSEs and JNDs.

The relationship between participants' responses and their decision time was analyzed using Spearmans rank-order correlation. The result of this analysis showed that their association was monotonic. The relationship was weak and negative (r_s = -0.11, $p < .01$). Therefore, we can conclude that there was a weak correlation between users' decision time and their responses.

4.2 Questionnaires

All participant feedback on the questionnaires was examined using Friedman tests. We conducted Wilcoxon signed-rank tests as post-hoc tests for significant difference.

Overall, we did not observe any significant difference between traveling-in-places in SSQ responses. Most participants reported none to slight symptoms for all of the conditions. In addition, there was also no significant difference in responses for components of the IPQ. All participants reported that they felt

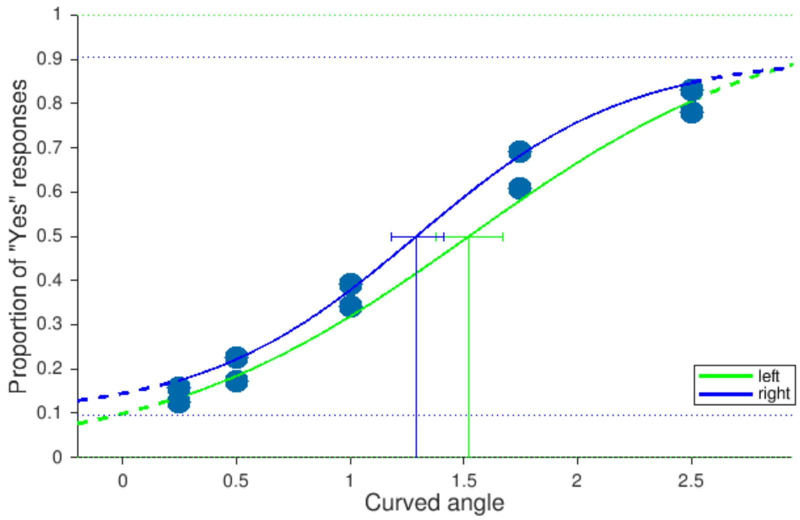

Fig. 8: The psychometric functions fitted for each condition of curve direction and the vertical central lines indicate their PSEs with confidence intervals.Overall, the PSEs are biased to 1.52 for "left" and 1.29 for "right".

a sense of presence while performing our experiment. They paid attention on performing trials and made selection decisions carefully.

Participants' feedback showed that they felt the experiment trials were normal or easy to finish. In addition, they reported to perceive as traveling in the virtual environment. Moreover, they used mainly the shape of the travel path ahead to judge whether their recent travel path was curved. For the paved pattern road, users used the line marker in the center of the road to decide, whereas the shape of the travel path was utilized for dirt road pattern.

4.3 Discussion and Conclusion

The results of our experiment showed that subjects could travel on a curved path while perceiving it as straight. In general, they cannot distinguish between a straight path and a curved path which is bent by $\beta = 1.42^{o}$. In addition, we found that different conditions of independent variables have different values for PSEs. There was a significant difference in PSEs between the conditions. The PSE for "pedaling" was significantly smaller than "throttling". It was reported that participants had to put much effort on maintaining their moving speed at around 20 km/h. In addition, it was more difficult to keep the speed for "pedaling" than "throttling". In addition, the HMD moved more for "pedaling" when the participants were performing the experiment. This could affect how the subjects focused on observing their travel path. This means that the more users

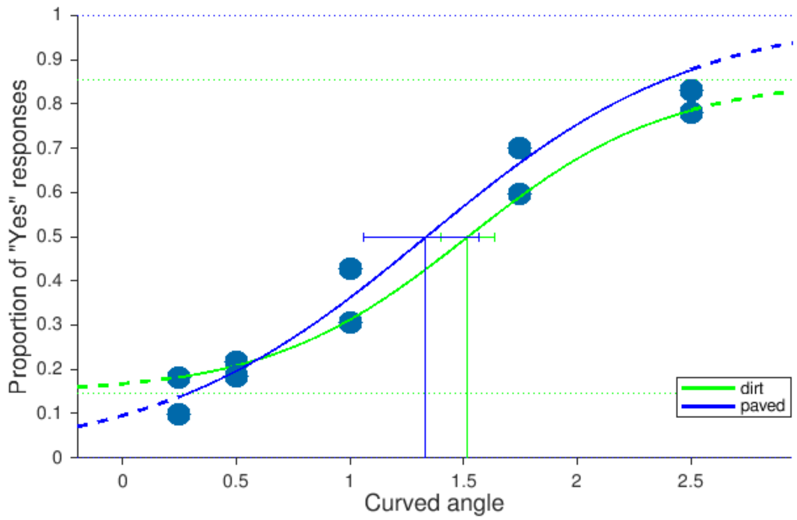

Fig. 9: The psychometric function fitted for each condition of road material and the vertical central lines indicate their PSEs with confidence intervals. Overall, the PSEs are biased to 1.52 for *"dirt"* and 1.33 for *"paved"*.

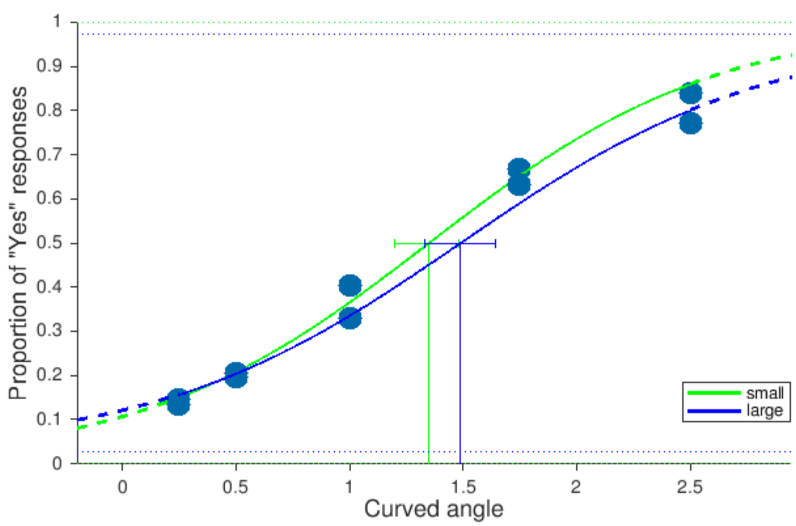

Fig. 10: The psychometric functions fitted for each condition of road width and the vertical central lines indicate their PSEs with confidence intervals. Overall, the PSEs are biased to 1.35 for *"small"* and 1.49 for *"large"*.

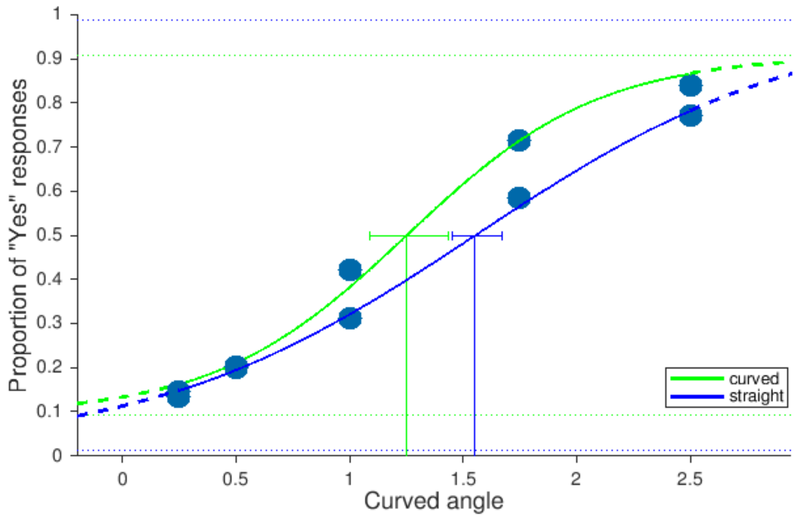

Fig. 11: The psychometric functions fitted for each condition of after trial road and the vertical central lines indicate their PSEs with confidence intervals. Overall, the PSEs are biased to 1.25 for *"curved"* and 1.55 for *"straight"*.

paid attention on their travel path, the higher the chance that they perceived a curved travel path.

In addition, conditions of curve direction had significantly different PSEs. This outcome can be explained by participants' habits. The reason is that all of the recruited participants were from a country driving on the right hand side of the road. Although, participants were traveling in the middle of the travel path for the whole experiment, their habit on driving on the right could have led to lower PSE for the "right" curve direction. This means that they were focusing more on the right side of the road than the left side. We additionally observed that subjects probably judge their travel path as straight or curved based on their future travel path ahead. They reported that the changes in road shape were used as cues to perceive whether they were moving on a curved path. Our experiment showed similar results with the curved road after trial had significantly lower PSE than the straight one. Because there would be a straight travel path for the next trial after this travel path.

Although, there were significant differences in PSEs between some of the independent variables for participants' responses, the JNDs were not significant different between them. Conditions of the independent variables were changed; however the range of curved angles must be changed in order for participants to detect that they recently traveled on a curved path was consistent and not significantly different or affected by them. This means that the noticeable range of stimuli is identical for all of the participants. In addition, the subjects were careful and concentrated on performing our experiment. They did not suffer from severe symptoms of cyber-sickness even though they were traveling on a curved path in the virtual environment while they were stationary in the real world. Overall, users might travel around a circle in the virtual environment without having any serious sickness and the radius of the circle should be measured based on the PSEs and JNDs values.

In general, users cannot detect that their moving path which could be bent by up to 1.42^o for a length of 27.78m or 0.05 ^{o}/m is curved when they are traveling at around 20 km/h in the virtual environment, regardless of different conditions of the travel path and the shape of the road ahead. This shows that users can travel along a circle with 1120.9m in radius while they still perceive that they are traveling on a straight path. In general, we observe that the unnoticeable bending angles for all of the conditions of the factors are around 0.05 ^{o}/m except for "*straight*". The gain for this condition is at around 0.06 ^{o}/m. The values of different thresholds for the conditions of the independent variables are presented in Table 2. These values are significantly smaller than those found for redirected walking techniques in the studies of Grechkin et al. (4.9 ^{o}/m) [7], Langbehn et al. (15.4 ^{o}/m) [10], Rietzler et al. (20 ^{o}/m) [24], and Steinicke et al. (2.6 ^{o}/m) [29]. The reason for this significant difference can be that the participants had to travel at a dramatically higher speed than walking speed in the virtual environment. This proves that users are more sensitive to travel on a bent path for higher movement speed as presented by Neth et al. [12]. In addition, the shape of the future travel path has a significant impact on how users perceive the "*curved-ness*" level of their moving path.

Unfortunately, the bike system does not have a resistant force for the flywheel. So, participants felt pedaling with this simulator be lighter than normal. As a result, they could reach to the speed of 20 km/h easier and faster with the system. In addition, this also made them hard to keep their moving velocity at baseline. Also, participants did not feel pleasant for a long travel with the bike because the bike seat was not soft and comfortable.

In conclusion, we present our experimental results on how users perceive two different traveling-in-place techniques with different bending angles of virtual moving paths. Moreover, we also investigated the impact of different factors including path textures, path widths, and bent directions, and the shape of future travel path and their relationships with the techniques. We observed that users could perceive their moving path as straight while they are traveling along a curve bent by up to 0.05 ^{o}/m at around 20 km/h . In addition, the factors which include movement technique, curve direction, and after trial path significantly affected how they perceive the curvature of their moving path.

The results of our study can inform the development of new locomotion techniques in virtual environments, especially for seated and stationary users and contribute to the design of new virtual environments supporting infinite travel. In the future, we plan to investigate potential disorientation issues on users in navigation tasks while traveling on curved paths.

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