In Proceedings of the 10th International Conference on Virtual Worlds and Games for Serious Applications.
Würzburg, Germany, 2018

Comparison of Teleportation and Fixed Track Driving in VR

Páll J. Líndal*, Kamilla Rún Jóhannsdóttir*, Unnar Kristjánsson*, Nina Lensing†
Anna Stühmeier†, Annika Wohlan† and Hannes Högni Vilhjálmsson*
*Center for Analysis and Design of Intelligent Agents (CADIA)
Reykjavik University, Iceland
pall.jakob.lindal@gmail.com, kamilla@ru.is, unnar12@ru.is, hannes@ru.is
†Applied Cognitive and Media Science
Universität Duisburg-Essen, Germany
nina.lensing@freenet.de, anna.stuehmeier@web.de, annika.wlan@gmail.com

***Abstract*—Comfortable locomotion in VR based games is crucial. Simulation sickness, caused by fast optical movement, lag or mismatch in forces, threatens this comfort and fosters a negative attitude towards further VR experiences. The design of the locomotion interface has a direct impact on the likelihood of inducing sickness. General paradigms and guidelines are being adopted by the game development community, but more data is needed. We use both subjective and objective methods to compare two common modes of travel, teleportation and driving along a fixed track. Our results show that teleportation causes fewer symptoms of sickness and leaves a more positive impression of VR.**

***Index Terms*—Virtual Reality, Locomotion, Teleportation, Rail Movement, Motion Sickness, Simulation Sickness**

I. Introduction

Virtual Reality (VR) is one product of the rapid development and enormous improvements in computer and display technologies made over the last three decades [1]. VR allows users to both develop and experience a wide variety of environments (e.g. [2]) and it has been used for a number of applications, such as visualization during planning of new buildings, as part of therapy requiring controlled stimuli and of course all kinds of games. The head mounted VR display has had a recent revival, with greater quality and affordability than ever before. It is a great option for experiencing and interacting with highly graphical and immersive computer-generated environments [3]. But, a few limitations and weaknesses have stood in the way of greater adoption. One of the most prominent weaknesses is the risk of simulation sickness when using the headset, commonly caused by fast optical movements, slow or no response (lagging) and mismatch in forces [4].

The way that a user moves or traverses the virtual environment has impact on the likelihood of getting sick, and therefore the design of the locomotion interface becomes a crucial part of any VR experience [5]. Research has already been published on some of the locomotion paradigms (e.g. [5], [6], [7], [8]), but data is still lacking for some classic methods. The current study is the first to focus on a rigorous comparison between teleportation and driving along a fixed track, two locomotion methods that exist in games today. This choice was driven by the need to solve user locomotion in a large city environment, where driving seemed like a relatively natural choice, but raised some concerns about the VR experience [9]. The study sets out to answer which method is less likely to make users sick, as well as answering which method leaves the users with a more positive association towards VR experiences.

II. Related Work

Head mounted VR displays have been shown to elicit simulation sickness to a higher extent than other less immersive approaches, such as 2D or stereoscopic 3D [10]. Simulation sickness is a well known phenomenon in VR, involving a variety of adverse symptoms, like nausea, headache and dizziness, experienced from real or apparent motion [6]. As a result, the sickness negatively affects the VR experience both physiologically and psychologically, and the after-effects can last for hours [11].

As a challenging issue to achieve friendly and acceptable VR experience, simulation sickness has been fairly extensively studied throughout the years and guidelines for avoiding experiences that induce it have been developed (such as those published by the headset developers). One of the most prominent causes of simulation sickness is the visuo-vestibular conflict, i.e. a mismatch between sensory systems involved in motion perception [12], and there is a growing interest in how to deal with this mismatch.

Mode of traveling within the virtual environment has been shown to play an important role in this regard. [5] identified four types of locomotion techniques used in VR, two of them use some form of physical interaction (either real-walking within a limited space or walking-in-place where users remain stationary and step-movements are translated into VR motion) while for the other two, the user is artificially moved within the VR. For the more commonly used game controller based movement, the user navigates freely and continuously through the VR using an analog stick (popular method for console gaming). This technique has been studied extensively, however, due to the user being stationary, it is more prone to cause simulation sickness compared to other locomotion methods [6]. An alternative mode of locomotion in VR without introducing some actual physical interaction, is teleporting [7], a method that has now become a mainstream VR locomotion technique. When teleporting, the user travels from one place inside the VR environment to another, by pointing the head or a tracked controller to a given spot and is instantly moved to that location (often with a transition effect). As teleporting does not involve simulated continuous movement, studies show it to be less likely to cause sickness than the classic free movement with a game controller [6]. Langbehn et al. compared three modes of locomotion in VR, joystick, teleportation and redirected walking [8]. Subjective ratings showed that participants preferred teleportation and redirected walking over joystick. Motion sickness was also grater for joystick compared to the other two locomotion techniques. However teleportation is also known to cause discomfort due to spatial disorientation [13], [14].

Most studies on the effects of different virtual locomotion techniques on simulation sickness rely on well established subjective measures such as the Simulator Sickness Questionaire (SSQ) [15], but very few have focused on the physiological responses, such as cardiovascular reactivity [16]. Cardiovascular responses, in particular heart rate (HR) have been examined in relation to the individual's sense of presence and immersion in VR. Studies have shown that with increased presence there is a corresponding increase in HR as a reaction to certain stressful or demanding situations presented in the VR environment (see for example [17]). As such, greater presence seems to call for more physiological reactivity compared to lesser sense of presence. But HR has also been looked at in relation to motion sickness or cyber sickness. Studies have linked motion sickness both to decreased HR [18] and increased HR [19]. But no studies have compared cardiovascular reactivity to VR for two different modes of travel.

In the area of both automobile and aviation research, physiological measures, including HR are frequently used to measure mental workload, drowsiness and stress [20]. Studies have for example, linked higher HR with increased mental effort and attention both during a driving task and when piloting a simulated airplane [21], [22], [23], [16], [24], [25]. Decreased HR however, has been linked to fatigue and drowsiness [26]. Furthermore, performing simple tasks for a prolonged time in a driving simulator has also been linked to decreased HR [27].

This current study will compare two locomotion methods that have not been formally compared before: Teleportation and driving along a fixed track. It uses SSQ and the Associations Towards VR survey [28] as subjective measures of the experience, but it also includes heart rate as a physiological component.

III. Method

A. The Stimulus

Because of the urban theme of an ongoing research effort [9], the virtual environment chosen for this study was a residential neighborhood, influenced by the neighborhoods created by Lindal and Hartig [29]. The view is shown in 1 and the layout of the environment is shown in Figure 2. The environment was developed in Unity3D® and presented on

Fig. 1. The virtual environment from the point of view of a subject traveling down the street. The subjects in the Teleporting group also see a green marker on the ground in front of them, indicating the target of a teleport. Subjects in the Tracking condition travel along the center of the street, with no further visual markers.

TABLE I
Track movement configuration.

Parameter	Value	Description
Look Dist.	35m	Look ahead distance to rotate towards.
Rot. Smooth	2	Magnitude of rotation in turns.
Max Velocity	$2m/s$	Maximum movement velocity.
Max Accel.	$2m/s^2$	Maximum movement acceleration.
Decel. Rate	2	Fixed weight to decrease velocity by.

an Oculus Rift® DK2 headset. Subjects were able to look in any direction by turning their head, but they were never required to look back, to facilitate a seated setup. Ambient urban background audio was played through headphones put on just before the VE started running. The application ran on a desktop with an NVIDIA 980 graphics card, and an Intel i7 processor. The version of Unity used to build the application was 5.3.4f1. At any given time, the subject could interact with the environment using at most one select *move* keyboard button.

1) Navigation Modes: Each subject experienced one of two possible navigation modes, controlled by the *move* button:

Track: In track mode, the subject's movement is restricted to a fixed path which passes through a series of control points along the middle of the road. The subject is able to freely look around from their current position. When *move* is pressed, the subject will begin moving along the path. While the button is pressed, the velocity will increase to a *Maximum Velocity* (see Table I). When the button is released, the speed is gradually decreased to a stop. Progress along the path is described in terms of total length traveled, and interpolation is used to compute the subject avatar's absolute position and rotation. Additional factors such as *Rotation Smoothness* and *Look Ahead Distance* are added to alleviate discomfort during sharper turns along the path.

Teleport: In teleport mode, the subject is able to freely navigate the environment by way of head look and input combined. The subject's head look direction is used as a

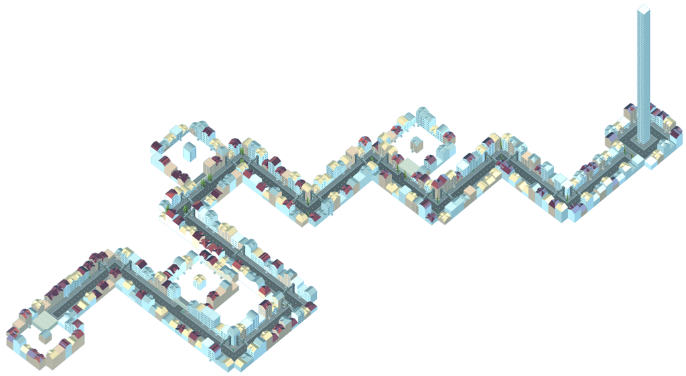

Fig. 2. The entire layout of the city used in the study. Subjects travel through the streets from the left-most plaza to the right-most plaza (ca. 1 km). Their goal is to reach the tall tower, which is visible from most places along the way to help with orientation. There is never a need to face backwards, to facilitate the use of a seated VR setup.

Fig. 3. Teleport Sequence. 1) The subject initiates teleport with button. 2) The VR display fades to black 3) The subject's avatar is moved to the teleport location. 4) The display remains black per delay parameter. 5) Display fades back in.

TABLE II
TELEPORTATION CONFIGURATION.

Parameter	Value	Description
Fade Time	0.6s	Length of screen fade in/out.
Fade Delay	0.4s	Time delay between fades.
Fade Color	black	Fade out color.

pointer to the location to move to, and pressing the *move* button will initiate teleportation. A location is considered valid when it is a) within *Maximum Teleport Distance*, b) does not intersect with environment geometry such as trees, and c) is relatively flat (ground). A colored sphere appears on the location being pointed as a visual indicator of whether that location is a valid teleport surface. Depending on the location being valid, the sphere is colored green and red respectively. When the pointer moves outside the maximum distance, the sphere gradually turns invisible. When a player initiates teleport, they will (assuming valid location) start a transition consisting of the screen fading to black, their avatar being moved to the new location, and the screen fading back in (see Figure 3 and Table II).

2) Visual Quality: The quality of the 3D environment was tuned with respect to three concerns. Firstly, perceived realism. This includes lighting effects made to simulate real world conditions. Secondly, reduction of visual artifacts such as aliasing and flickering, some of which were considered likely to draw the user's attention undesirably or cause discomfort. And thirdly, to maintain application performance consistently high or to the extent that no head tracking lag is felt by the user (minimum frame rate of 75fps). See Table III for individual settings. *Anti Aliasing* is used here to minimize distant object flickering (trees, windows etc.) noted to cause discomfort. High *Shadow Resolution* avoids visibly blurry shadows. *Shadow Distance* is a compromise between performance and visual quality. *V Sync* is enabled to keep the frame rate consistent and prevent jarring changes.

TABLE III
IMPORTANT GRAPHICAL SETTINGS.

Setting	Value
Anti Aliasing	*8x Multi Sampling*
Shadow Resolution	*High*
Shadow Distance	*150*
V Sync	*Every V Blank*

B. Experimental Design

A mixed two (mode of traveling; track driving versus teleportation) x three (time; pre-test versus post-test versus follow-up test) repeated measures design was implemented for the questionnaires. For heart rate a two (mode of traveling; track driving versus teleportation) x four (time in VR; min 1-4) repeated measure design was implemented. Both analyses controlled for time spent in the VR and the HR analysis controlled for the individuals' HR level at baseline.

C. Participants

The sample consisted of 40 students (47.5% women) at Reykjavik University. The participants ranged in age from 21 to 27 years old (M = 24.65, SD = 1.85) and where recruited through university email advertisements and direct approach. Participants were randomly assigned to the two virtual traveling conditions. Ten women and 10 men were assigned to the tracking condition and 9 women and 11 men were assigned to the teleportation condition No statistical differences were found between the groups in age, frequency of playing computer games, previous experience with virtual reality or tendency to experience motion sickness. Participants did not receive any credits or rewards for their participation.

D. Measures

1) Simulator Sickness Questionnaire (SSQ): An English version of Kennedy et al.'s Simulator Sickness Questionnaire (SSQ) [15] was used to measure current sense of simulator sickness before, right after and one hour after the environmental treatment. The SSQ has been used previously in numerous studies on virtual interactive environments (e.g. [11], [6] and [30]) and includes 16 items which measure the SSQ score, that indicates the overall extent of symptoms. The statement was "Please describe your feelings at this moment..." and the responses to items (e.g. "general discomfort", "difficulty focusing") were given on a 4-point scale (0 = absent, 3 = severe). For the SSQ with multiple items, the consistency (Cronbach's alpha) for the three measuring points were as follows: pretest, 0.712; post test, 0.794; follow-up-test, 0.896. The questionnaire can provide more specific diagnostic information through three sub scales: nausea, oculomotor and disorientation. Each sub scale included seven items. Internal consistencies (Cronbach's alpha) for the pretest measures were as follows: for nausea, 0.438; for oculomotor, 0.625; for disorientation, 0.257. Internal consistencies for the post-test measures were as follows: for nausea, 0.747; for oculomotor, 0.707; for disorientation, 0.701 and the internal consistencies for the follow-up measures were as follows: for nausea, 0.804; for oculomotor, 0.806; for disorientation, 0.862. With such a low internal consistency in the pretest for both for nausea and disorientation, these two sub scales were excluded from further analysis.

2) Associations Towards Virtual Reality: Based on de Liver et al.'s Associations Towards VR survey [28], a list of 8 words; four positive (happiness, loveliness, joy and friendliness) and four negative (disgust, sadness, horror and hate), was used to measure the associations towards VR. The statement was "Virtual reality evokes in me the feeling of..." and responses to items were given on a 4-point scale (1 = not at all, 4 = very much). For the four positive items, the internal consistencies (Cronbach's alpha) for the three measuring points were as follows; pretest, 0.763; post test, 0.858; follow-up, 0.823. But, for the four negative items the internal consistencies for the three measuring points were poor: pretest, 0.152; post test, -0.145; follow-up, 0.020. The list that consisted of negative words was, therefore, excluded from further analysis.

3) Heart Rate: A beat-to-beat blood pressure monitoring system, Finometer® PRO was used for an on-line real time measure of cardiovascular reactivity [31]. The Finometer® PRO is a stand-alone, relatively non-invasive, monitoring solution. The Finometer® uses a finger cuff for measuring the pulse but the absolute accuracy of the measured variables is calibrated using an upper arm cuff measurement. Weight, age, and height is entered into the system for accurate calculation of derived variables. The system provides a variety of cardiovascular measures at a sampling rate of 200 Hz. The variable used in the present research was heart rate (HR).

E. Procedure

Upon arrival, participants were seated in a quiet laboratory, introduced to the study and then provided an informed consent. Participants then briefly tried the Oculus Rift® VR headset, and had an introduction to the functioning of their assigned locomotion control. After that the participants were attached to the Finometer® PRO and a baseline measure was carried out for 5 minutes. Then the participants answered background questions on a screen, followed by the pretest questionnaires. Before going into VR, participants were asked when navigating, to imagining themselves on their way to work. They were encouraged not to rush down the street, look around and enjoy the trip. After the assigned virtual travel, they completed the post-test questionnaires. It took around 50 minutes to complete the procedure depending on duration of the virtual experience. One hour after completing the experiment, participants received a follow-up survey via email that they had previously been asked to complete. Participants were instructed to complete the follow-up survey as soon as they received it.

F. Preparation for Statistical Analysis

The SSQ total scale score and oculomotor sub-scale score were computed in line with instructions on weights as presented in [15]. Regarding the length of the virtual experience between the two conditions, the results indicated a significant difference as the participants spent less time within the virtual environment when teleporting (X = 335 seconds, SD = 141.8) than when tracking (X = 525 seconds, SD = 24.9) ($p < 0.001$). As a longer duration within virtual environments has shown to increase simulator sickness (e.g. [32] and [33]), and therefore affect physiological and subjective outcomes, the duration of the virtual experience is treated as a covariate in the following analysis.

IV. Results

A. Effects on Simulator Sickness

As indicated in Table IV and in Figure 4, the simulator sickness symptoms increased during the virtual experience i.e. from pretest to post-test in both conditions, with the shift higher in the tracking group than in the teleporting group. After the virtual experience, the participants in both groups recover to some extent without reaching the initial level after one hour. For the SSQ total, there is a significant quadratic interaction between the time and mode of travel, while controlling for the VR exposure duration, $F(1.37) = 8.04$, $p = 0.007$, partial $\eta^2 = 0.178$. When focusing on the oculomotor subscale of SSQ (general discomfort, fatigue, headache, eyestrain, difficulty focusing, difficulty concentrating and blurred vision), the picture is quite different (see Figure) 5 as the symptoms among those in the tracking group increased during the virtual experience while the teleporting group showed a slight decrease. After the virtual experience both groups reported a slight decrease in sense of sickness. An RM-ANOVA analysis indicated a significant quadratic interaction between the time and mode of traveling when controlling for the duration within the virtual reality F(1,37) = 7.75, p = 0.008, partial $\eta^2 = 0.173$.

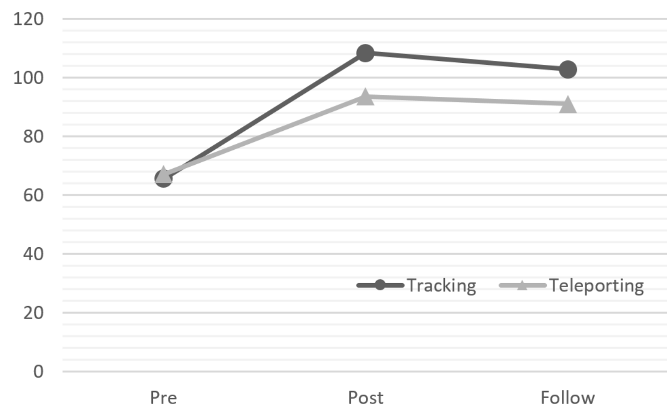

Fig. 4. The total Simulator Sickness Questionnaire (SSQ) score (vertical axis) measured for subjects in the tracking condition versus subjects in the teleporting condition. Measurements were taken before exposure (*Pre*), right after the exposure (*Post*) and then after at least an hour had passed in a follow-up (*Follow*) (horizontal axis). There is a significant quadratic interaction between the time and mode of travel at p = 0.007.

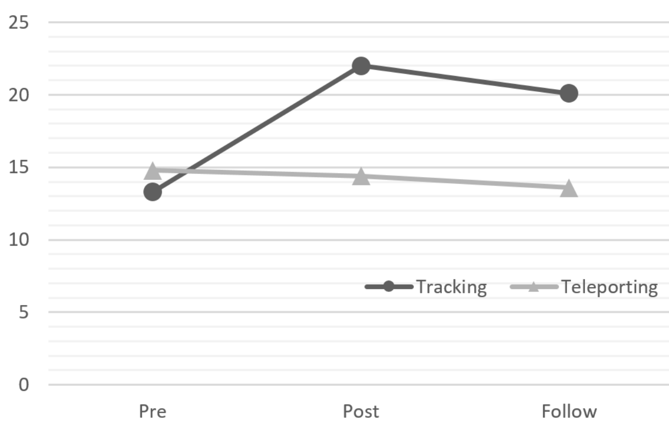

Fig. 5. The total score of the Oculomotor sub-scale of the SSQ score (vertical axis), measured for subjects in the tracking condition versus subjects in the teleporting condition. As before, horizontal axis is the time of measure. There is a significant quadratic interaction between the time and mode of travel at p = 0.008.

B. Effects on Associations Towards VR

At the pretest, the participants reported a moderate level of positive attitude towards VR. As indicated in Table V and shown in Figure 6 the positive associations towards virtual reality show a slight decline over time among those using teleporting while there is a substantial decrease within the tracking group. The results indicated a linear interaction between the time and mode of travel on positive associations towards VR when controlling for the duration of the VR exposure, F(1,37) = 5.45, p = 0.025, partial $\eta^2 = 0.128$.

TABLE IV
DESCRIPTIVE STATISTICS FOR SIMULATOR SICKNESS SYMPTOMS.

		Tracking			Teleporting		
		Pre	Post	Follow	Pre	Post	Follow
SSQ Total	M	65.7	108.5	102.9	67.20	93.7	91.1
	SD	11.89	29.60	31.63	8.46	12.75	16.60
Oculo-motor	M	13.3	22.0	20.1	14.8	14.4	13.6
	SD	17.19	23.06	24.75	11.13	13.89	16.79

TABLE V
DESCRIPTIVE STATISTICS FOR POSITIVE ASSOCIATIONS TOWARDS VR.

		Tracking			Teleporting		
		Pre	Post	Follow	Pre	Post	Follow
Positive Association	M	2.58	2.33	2.30	2.51	2.49	2.45
	SD	0.65	0.74	0.69	0.63	0.79	0.66

C. Effects on Heart Rate

The effects on heart rate at minutes 1 through 4 into the VR exposure are summarized in Table VI and Figure 7. The analysis revealed a non significant main effect of time. The main effect of group approached significant F(1.32) = 3.306, p = 0.078, $\eta^2 = 0.094$, alpha = 0.05. As can be seen in Figure 7, HR is higher for those individuals using the teleportation mode compared to those using the track driving. There was also a significant cubic interaction between group and time in VR, F(1.32) = 8.026, p = 0.008, $\eta^2 = 0.201$.

TABLE VI
MEAN HEART RATE (BEATS PER MINUTE).

	min 1	min 2	min 3	min 4
Tracking	69.1	68.4	70.4	70.0
Teleportation	71.8	72.8	71.2	73.6

V. DISCUSSION AND CONCLUSION

This study casts light on the effect of two VR locomotion techniques, track driving and teleporting, on simulation sickness using both subjective and objective measures.ss

The results show that participants experienced increasing simulation sickness in both tracking and teleporting conditions. But in line with previous results (e.g. [6]) and expectations, those in the teleporting conditions experienced less symptoms during VR exposure than those using tracking. Furthermore, when just focusing on the oculumotor sub-factor, the symptoms tended to slightly decrease during the VR navigation within the teleporting group while the tracking group experienced the opposite. After VR exposure, both groups showed declining symptoms, as one would expect.

Participants' positive associations towards virtual reality were moderate prior to the VR exposure. For the teleporting group they remained quite steady during the VR navigation as

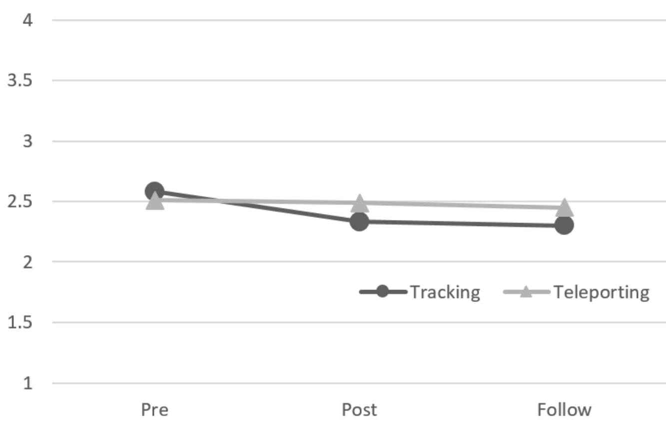

Fig. 6. The Positive Associations Towards VR score (vertical axis) measured for subjects in the tracking condition versus subjects in the teleporting condition. Measurements were taken before exposure (*Pre*), right after the exposure (*Post*) and then after at least an hour had passed in a follow-up (*Follow*) (horizontal axis). There is a significant linear interaction between the time and mode of travel at p = 0.025.

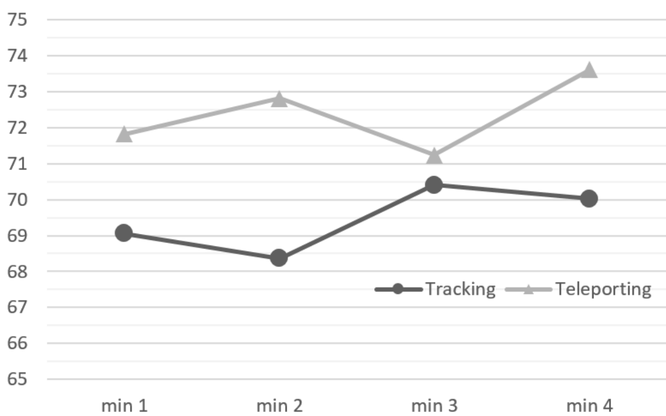

Fig. 7. Mean heart rate shown on the vertical axis (as beats per minute) and the time of measurement from the start of the VR exposure on the horizontal axis. Shown both for subjects in the tracking condition and in the teleporting condition. The main effect of the group of subjects approached significance at p = 0.078.

well as in the follow-up testing. On the other hand the positive associations decreased within the tracking group during the VR experience and remained lower during the follow up. These results show, in line with expectations, a negative correlation between experienced simulation sickness and positive associations towards VR during the VR exposure. However, while the experienced sickness declined after the exposure ended, the level of positive association remains unchanged, indicating a more lasting emotional effect.

Participants' heart rate profile during the VR exposure differed for the two groups after controlling for baseline HR levels, as well as the exposure duration. HR tended to be higher for the teleportation group compared to the tracking group (approached significance at p=.078). It is possible that during the teleportation process more mental effort was needed in order to compensate for potential loss of spatial orientation previously noted in relation to teleportation [13]. This should be investigated further.

In conclusion, these results show that teleportation would be a better choice for a VR locomotion method than driving along a fixed track. Teleportation caused fewer symptoms of sickness and left a more positive impression of VR. The study is not without limitations however. One should be careful when generalizing to other implementations of teleportation and driving, as these are subject to a number of tuning parameters that can affect the outcome. An effort was made to make both as smooth as possible though. A further limitation is that while the follow-up surveys were sent to subjects one hour after the experiment ended, and they asked to answer right away, there is no guarantee that they did.

Finally, the study does not isolate what it is about each implemented method that may be the most beneficial factor (for example, teleporting provided more freedom of movement, in addition to jumps). This is a comparison of two common and complete methods, and further studies are needed to provide deeper insights and fully map out the different paradigms.

Acknowledgments

The authors would like to thank Prof. Dr. Nicole Krämer for her input and support. This project was made possible by a student exchange program between Reykjavik University and Duisburg-Essen University, as well as grants from the Icelandic Research Fund (#141814-052) and the Icelandic Technical Development Fund (#163925-0611).

References

[1] M. Portman, A. Natapov, and D. Fisher-Gewirtzman, "To go where no man has gone before: Virtual reality in architecture, landscape architecture and environmental planning," *Computers, Environment and Urban Systems*, vol. 54, pp. 376 – 384, 2015.

[2] G. Chryssolouris, D. Mavrikios, D. Fragos, and V. Karabatsou, "A virtual reality-based experimentation environment for the verification of human-related factors in assembly processes," *Robotics and Computer-Integrated Manufacturing*, vol. 16, no. 4, pp. 267 – 276, 2000.

[3] S. Davis, K. Nesbitt, and E. Nalivaiko, "A systematic review of cybersickness," in *Proceedings of the 2014 Conference on Interactive Entertainment*, ser. IE2014. New York, NY, USA: ACM, 2014, pp. 8:1–8:9.

[4] K. Goode, "Creating rich dynamic vr gameplay," in *Talks of the Develop:Brighton Conference*, 2015.

[5] C. Boletsis, "The new era of virtual reality locomotion: A systematic literature review of techniques and a proposed typology," *Multimodal Technologies and Interaction*, vol. 1, no. 4, p. 24, 2017.

[6] J. Habgood, D. Moore, D. Wilson, and S. Alapont, "Rapid, continuous movement between nodes as an accessible virtual reality locomotion technique," in *Proceedings of IEEE Virtual Reality*. IEEE, 2018.

[7] E. Bozgeyikli, A. Raij, S. Katkoori, and R. Dubey, "Point & teleport locomotion technique for virtual reality," in *Proceedings of the 2016 Annual Symposium on Computer-Human Interaction in Play*. ACM, 2016, pp. 205–216.

[8] E. Langbehn, P. Lubos, and F. Steinicke, "Evaluation of locomotion techniques for room-scale vr: Joystick, teleportation, and redirected walking," 2018.

[9] P. J. Lindal, H. Miri, U. Kristjansson, K. R. Johannsdottir, T. Hartig, and H. H. Vilhjalmsson, "Testing the restorative potential of future urban environments using vr technology - the cities that sustain us project," in *Proceedings of the 24th Annual Conference of the International Association for People-Environment Studies (IAPS24)*, 2016.

[10] F. Weidner, A. Hoesch, S. Poeschl, and W. Broll, "Comparing vr and non-vr driving simulations: An experimental user study," in *2017 IEEE Virtual Reality (VR)*, March 2017, pp. 281–282.

[11] L. Dziuda, M. Biernacki, P. Baran, and O. Truszczynski, "The effects of simulated fog and motion on simulator sickness in a driving simulator and the duration of after-effects," *Applied Ergonomics*, vol. 45, no. 3, pp. 406 – 412, 2014.

[12] A. Kemeny, P. George, F. Merienne, and F. Colombet, "New vr navigation techniques to reduce cybersickness," *Electronic Imaging*, vol. 2017, no. 3, pp. 48–53, 2017.

[13] D. A. Bowman, D. Koller, and L. F. Hodges, "Travel in immersive virtual environments: An evaluation of viewpoint motion control techniques," in *Virtual Reality Annual International Symposium, 1997., IEEE 1997*. IEEE, 1997, pp. 45–52.

[14] N. H. Bakker, P. O. Passenier, and P. J. Werkhoven, "Effects of head-slaved navigation and the use of teleports on spatial orientation in virtual environments," *Human factors*, vol. 45, no. 1, pp. 160–169, 2003.

[15] R. S. Kennedy, N. E. Lane, K. S. Berbaum, and M. G. Lilienthal, "Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness," *The International Journal of Aviation Psychology*, vol. 3, no. 3, pp. 203–220, 1993.

[16] J. Laarni, N. Ravaja, T. Saari, S. Böcking, T. Hartmann, and H. Schramm, "Ways to measure spatial presence: Review and future directions," in *Immersed in Media*. Springer, 2015, pp. 139–185.

[17] M. Meehan, S. Razzaque, B. Insko, M. Whitton, and F. P. Brooks, "Review of four studies on the use of physiological reaction as a measure of presence in stressfulvirtual environments," *Applied psychophysiology and biofeedback*, vol. 30, no. 3, pp. 239–258, 2005.

[18] K. Zużewicz, A. Saulewicz, M. Konarska, and Z. Kaczorowski, "Heart rate variability and motion sickness during forklift simulator driving," *International Journal of Occupational Safety and Ergonomics*, vol. 17, no. 4, pp. 403–410, 2011.

[19] M. S. Dennison, A. Z. Wisti, and M. DâĂŹZmura, "Use of physiological signals to predict cybersickness," *Displays*, vol. 44, pp. 42–52, 2016.

[20] G. Borghini, L. Astolfi, G. Vecchiato, D. Mattia, and F. Babiloni, "Measuring neurophysiological signals in aircraft pilots and car drivers for the assessment of mental workload, fatigue and drowsiness," *Neuroscience & Biobehavioral Reviews*, vol. 44, pp. 58–75, 2014.

[21] G. Borghini, G. Vecchiato, J. Toppi, L. Astolfi, A. Maglione, R. Isabella, C. Caltagirone, W. Kong, D. Wei, Z. Zhou *et al.*, "Assessment of mental fatigue during car driving by using high resolution eeg activity and neurophysiologic indices," in *Engineering in Medicine and Biology Society (EMBC), 2012 Annual International Conference of the IEEE*. IEEE, 2012, pp. 6442–6445.

[22] T. C. Hankins and G. F. Wilson, "A comparison of heart rate, eye activity, eeg and subjective measures of pilot mental workload during flight." *Aviation, space, and environmental medicine*, vol. 69, no. 4, pp. 360–367, 1998.

[23] J. Hooijer and B. Hilburn, "Evaluation of a label oriented hmi for tactical datalink communication in atc," *NLR Technical Publication TP*, vol. 96676, 1996.

[24] B. Mehler, B. Reimer, and M. Zec, "Defining workload in the context of driver state detection and hmi evaluation," in *Proceedings of the 4th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. ACM, 2012, pp. 187–191.

[25] M. W. Scerbo, "Stress, workload, and boredom in vigilance: A problem and an answer." 2001.

[26] F. Biondi, J. R. Coleman, J. M. Cooper, and D. L. Strayer, "Heart rate detection for driver monitoring systems," Tech. Rep., 2017.

[27] S. K. Lal and A. Craig, "A critical review of the psychophysiology of driver fatigue," *Biological psychology*, vol. 55, no. 3, pp. 173–194, 2001.

[28] Y. de Liver, J. van der Pligt, and D. Wigboldus, "Positive and negative associations underlying ambivalent attitudes," *Journal of Experimental Social Psychology*, vol. 43, no. 2, pp. 319 – 326, 2007.

[29] P. J. Lindal and T. Hartig, "Architectural variation, building height, and the restorative quality of urban residential streetscapes," *Journal of Environmental Psychology*, vol. 33, pp. 26 – 36, 2013.

[30] J. Frommel, S. Sonntag, and M. Weber, "Effects of controller-based locomotion on player experience in a virtual reality exploration game," in *Proceedings of the 12th International Conference on the Foundations of Digital Games*, ser. FDG '17. New York, NY, USA: ACM, 2017, pp. 30:1–30:6.

[31] J. Jansen, J. Schreuder, J. P. Mulier, N. Smith, J. Settels, and K. Wesseling, "A comparison of cardiac output derived from the arterial pressure wave against thermodilution in cardiac surgery patients," *British journal of anaesthesia*, vol. 87, no. 2, pp. 212–222, 2001.

[32] R. S. Kennedy, K. M. Stanney, and W. P. Dunlap, "Duration and exposure to virtual environments: Sickness curves during and across sessions," *Presence*, vol. 9, no. 5, pp. 463–472, Oct 2000.

[33] B.-C. Min, S.-C. Chung, Y.-K. Min, and K. Sakamoto, "Psychophysiological evaluation of simulator sickness evoked by a graphic simulator," *Applied Ergonomics*, vol. 35, no. 6, pp. 549 – 556, 2004.