Towards an Affordance of Embodied Locomotion Interfaces in VR: How to Know How to Move?

Bernhard E. Riecke*
School of Interactive Arts and Technology
Simon Fraser University, Canada

Daniel Zielasko†
Human-Computer Interaction
University of Trier, Germany

1 Introduction

When we walk through the physical worlds, our locomotion is naturally accompanied by a compelling and embodied sensation of mobility and self-motion - something that is missing from many gaming, telepresence, and VR applications unless users physically move. Physically moving has long been known to enhance spatial orientation performance when compared to imagined locomotion [8, 16, 18] and controller-based movements in VR [8]. With the increasing availability and affordability of mobile head-mounted displays that are untethered and provide inside-out tracking, physically walking in VR becomes increasingly feasible. There are, however, still shortcomings of physical walking in VR that might not be fixable by technical solutions, such as limited free-space walking areas, safety concerns (for standing/walking users), accessibility to users with mobility challenges, fatigue, and comfort. That is, even with improved technologies, many users may still want to sit down for all but very short experiences, or when there is a compelling reason to stand or be upright. Here, we will discuss if and how it might be feasible to provide a compelling sensation of mobility and self-motion for seated VR users to tackle those concerns by utilizing leaning-based locomotion interfaces. We will also discuss obstacles, concerns, and limitations of this approach, and how we might improve those interfaces to make them more intuitive and explorable, without requiring much (if any) instructions.

2 How Could We Create a Clear Affordance of How to Move to Control VR Locomotion?

A number of studies investigated leaning-based interfaces, where users do not walk or use a controller but instead simply lean in the direction of desired virtual travel (while either standing or sitting) to control the simulated self-motion direction and speed [1, 9, 12, 23]. Such leaning-based paradigms have been suggested and investigated as a low- or no-cost alternatives that do not require large free-space walking areas or costly motion simulators, yet provide a least some embodied involvement and vestibular motion cueing compared to using hand- or finger-based controllers [2,4,12,19,21]. Such leaning-based interfaces can improve (at least in some implementations) a number of critical aspects, including immersion and presence [3, 12], navigation and performance [5, 13, 14], enjoyment, engagement, and realism [7, 12], and have considerable application potential in various VR and telepresence/teleoperation scenarios as they free up the user's hands to communicate, interact, or perform other tasks [24]. While some studies did not show a clear effect, many studies indicated that such leaning-based interfaces can also significantly enhance users' embodied sensation of self-motion ("vection") compared to controller-based locomotion, for both standing-leaning [9] and seated leaning [6, 17].

In these studies, though, from all we can tell, participants were always explicitly instructed on how to use leaning to control simulated self-motion. While we are not aware of published studies that explicitly investigate the affordance (perceived action possibility) and explorabiltiy of leaning-based interfaces, already in 1993, Fairchild and colleagues reported that leaning-based locomotion was "found to be amazingly successful with both novice and advanced users" (p.49). Our own pilot testing and observations indicate that indeed users very quickly and intuitively learn how to use leaning-based interfaces even without any instructions – as long as they (even accidentally) start leaning at least a tiny bit, and thus see the immediate effect of doing so (through a closed and low-latency action-perception loop). This happened more frequently when using chairs/stools that provided somewhat flexible seating, such as tiltable sit/stand stools (e.g, commercially available Swopper or MovMan stools, which were investigated as ChairIO [1] or NaviChair [7, 14]), compared to standard non-moving chairs including swivel office chairs. We thus hypothesize that one way to convey the affordance of leaning and other types of upper-body movements is to provide an inherently flexible sitting (or standing) arrangement, to support discoverability and explorablity of the interaction/locomotion paradigm.

3 What Gets in the Way of Clear Affordances? Expectations, Prior Experiences, and Lack of Constraints

Depending on a user's background, prior experiences, expectations, mindset and setting, many users (especially if not used to free-space walking VR experiences), tend to expect a rather passive experience, or at least an experience where the user cannot or does not need to physically move beyond using their fingers or hands - especially when provided with a controller. This might be based on an abundance of seated experiences like watching movies or playing games, or simply being used to only being able to use one's hands (and in VR, head movements). When confronted with a VR experience where physical motion is possible – such as walking, rotating on a swivel chair, or movements on a sit-stand stool like a Swopper (ChairIO, NaviChair) or LimbicChair [22] – we observed many users initially sitting or standing still. Seemingly they either did not anticipate, know, or perceive a clear-enough affordance of the possible movements, and how they might benefit from them.

4 Conclusions and Tentative Guidelines

Even though one might hope that the implicit expectation and bias towards non-embodied experiences might be somewhat reduced over the years to come given the increasing availability and usage of more embodied immersive experiences and technology, we assume that there will always remain some implicit bias towards seated, passive, and not very embodied experiences. To tackle this, we propose a research agenda and exploration of ways to effectively convey how to use more embodied interfaces (or any interfaces really). How can we create clearer affordances similar to physical affordances [15] (e.g., "I can sit on this chair") instead of just relying on learned, culturally conveyed, or virtual/perceived affordances? That is, although by now users with internet access will know that a blue underlined text indicates the learned affordance of clicking on it (as it contains a hyperlink/URL, and they had years of training and getting used to this convention that initially was not obvious at all), in VR we do

*e-mail: b_r@sfu.ca
†e-mail: zielasko@uni-trier.de

This is the author's version of the manuscript. The final version is published as:
Riecke, B. E., & Zielasko, D. (2020). Towards an affordance of embodied locomotion interfaces in VR: How to know how to move? 2020 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW) (pp. 295–296). Presented at the SeatedVR: 1st Workshop on Seated Virtual Reality at IEEE VIrtual Reality, Atlanta, GA, USA: IEEE. doi:10.1109/VRW50115.2020.00066

not have such clear conventions yet. Hence it would be safer and likely more effective to aim for physical affordances and finding ways to ensure they generalize to the larger audience beyond VR and gaming enthusiasts and early adopters.

Part of this challenge is, of course, that without explicit constraints or instructions, it can be difficult to anticipate or imagine what kind of movements are being tracked or used as input to the system. This challenge is similar to those from natural or gestural user interfaces, where gestures or motions typically have to be learned until they become conventions (e.g., swipe or pinch gestures). Hand-held and other physical controllers provide physical constraints indicating what actions are possible - a button can be pressed, a thumbstick pushed, dials turned. By providing a flexible seating interface that indicates clear action possibilities (e.g., this Swopper stool can tilt, so I can shift my weight to tilt it), we might be able to tap into such physical affordances. Future research is needed, though, to investigate how best to convey specific mappings, such as linear or exponential rate (velocity) control, or the need to keep a steady head/body post to keep a constant velocity. Without a physical interface or physical constraints (e.g., for standing-leaning interfaces [9]), we can only rely on users naturally exploring (or swaying, in this case) if we do not want to provide explicit instructions.

Potential approaches and **tentative design guidelines** that seem promising include:

1. utilizing our natural tendency to explore and move, and combine this with interfaces that clearly indicate what movements are possible, such as for flexible/tiltable sit/stand stools;
2. providing low-latency feedback loops such that the effects of our actions are directly perceivable and understandable;
3. utilizing constraints to guide users;
4. utilizing physical affordances (especially until virtual affordances and cultural norms become ubiquitous;
5. using metaphors known from the real world or other common experiences: Similar to the desktop metaphor helping to convey the mouse+screen affordance in early computer days, leaning-metaphors such as surfing [20] could be utilized for VR locomotion;
6. improving input mappings, e.g., by considering and investigating not only conventional but also metaphoric and isomorphic mappings, or by supporting conceptual metaphors [10, 11];
7. showing or demonstrating perceived action possibilities: e.g., when naive users saw the experimenter or another user (or a video of them) using the system for a mere few seconds, they typically immediately "got it" and were ready to use the interface without further instructions.

This list is likely incomplete and needs to be extended in future research. But it shows already that potential solutions and guidelines exist – what seems to be missing is often awareness or understanding of the importance of considering affordances, constraints, and explorablity of the interfaces. Even in situations (like experiments) where instructing users is an option, they typically prefer to try things out right away and skip any instructions.

In the context of immersive experience design (including VR, AR, MR/XR, and telepresence/teleoperation) the affordance, learnability, and explorability of the interaction paradigms is of particular importance, as having to look up/listen to/read instructions or providing textual or auditory feedback can easily break the immersion and presence that is one of the key aspects of those experiences and technologies, yet is fragile and easily disrupted.

References

[1] S. Beckhaus, K. J. Blom, and M. Haringer. ChairIO – The Chair-Based Interface. In *Concepts and Technologies for Pervasive Games: A Reader for Pervasive Gaming Research*, pages 231–264. 2007.

[2] K. M. Fairchild, B. H. Lee, J. Loo, H. Ng, and L. Serra. The heaven and earth virtual reality: Designing applications for novice users. In *IEEE VR, 1993*, pages 47–53, Seattle, USA, Sept. 1993.

[3] J. Freiberg, A. Kitson, and B. E. Riecke. Development and Evaluation of a Hands-Free Motion Cueing Interface for Ground-Based Navigation. In *IEEE VR 2017*, pages 273–274, Los Angeles, CA, USA, 2017. ACM.

[4] E. Guy, P. Punpongsanon, D. Iwai, K. Sato, and T. Boubekeur. LazyNav: 3D ground navigation with non-critical body parts. In *2015 IEEE Symposium on 3D User Interfaces (3DUI)*, pages 43–50, Mar. 2015.

[5] A. Harris, K. Nguyen, P. T. Wilson, M. Jackoski, and B. Williams. Human Joystick: Wii-leaning to Translate in Large Virtual Environments. In *VRCAI '14*, pages 231–234, New York, NY, USA, 2014. ACM.

[6] A. Kitson, A. M. Hashemian, E. R. Stepanova, E. Kruijff, and B. E. Riecke. Comparing Leaning-Based Motion Cueing Interfaces for Virtual Reality Locomotion. In *Proceedings of IEEE Symposium on 3D User Interfaces 3DUI*, pages 73–82, Los Angeles, CA, USA, 2017.

[7] A. Kitson, B. E. Riecke, A. M. Hashemian, and C. Neustaedter. NaviChair: Evaluating an Embodied Interface Using a Pointing Task to Navigate Virtual Reality. ACM SUI '15, pages 123–126, Los Angeles, CA, USA, 2015. ACM.

[8] R. L. Klatzky, J. M. Loomis, A. C. Beall, S. S. Chance, and R. G. Golledge. Spatial Updating of Self-Position and Orientation During Real, Imagined, and Virtual Locomotion. *Psychological Science*, 9(4):293–298, 1998.

[9] E. Kruijff, A. Marquardt, C. Trepkowski, R. Lindemann, A. Hinkenjann, J. Maiero, and B. E. Riecke. On Your Feet! Enhancing Self-Motion Perception in Leaning-Based Interfaces through Multisensory Stimuli. In *ACM SUI '16*, pages 149–158, Tokyo, Japan, 2016. ACM.

[10] A. Macaranas, A. N. Antle, and B. E. Riecke. Bridging the gap: attribute and spatial metaphors for tangible interface design. In *ACM TEI '12*, pages 161–168, Kingston, Canada, 2012. ACM.

[11] A. Macaranas, A. N. Antle, and B. E. Riecke. What is Intuitive Interaction? Balancing Users' Performance and Satisfaction with Natural User Interfaces. *Interacting with Computers*, 27(3):357–370, 2015.

[12] M. Marchal, J. Pettre, and A. Lecuyer. Joyman: A human-scale joystick for navigating in virtual worlds. In *IEEE 3DUI*, pages 19–26, Washington, DC, USA, 2011.

[13] J. Miehlbradt, A. Cherpillod, S. Mintchev, M. Coscia, F. Artoni, D. Floreano, and S. Micera. Data-driven body–machine interface for the accurate control of drones. *PNAS*, page 201718648, July 2018.

[14] T. Nguyen-Vo, B. E. Riecke, W. Stuerzlinger, D.-M. Pham, and E. Kruijff. NaviBoard and NaviChair: Limited Translation Combined with Full Rotation for Efficient Virtual Locomotion. *Transactions on Visualization and Computer Graphics (TVCG)*, 2019.

[15] D. A. Norman. Affordance, conventions, and design. *interactions*, 6(3):38–43, May 1999.

[16] C. C. Presson and D. R. Montello. Updating after rotational and translational body movements: Coordinate structure of perspective space. *Perception*, 23(12):1447–1455, 1994.

[17] B. E. Riecke. Simple user-generated motion cueing can enhance self-motion perception (Vection) in virtual reality. In *ACM VRST*, pages 104–107, Limassol, Cyprus, 2006. ACM.

[18] J. J. Rieser. Access to knowledge of spatial structure at novel points of observation. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 15(6):1157–1165, 1989.

[19] D. Valkov, F. Steinicke, G. Bruder, and K. Hinrichs. Traveling in 3d virtual environments with foot gestures and a multi-touch enabled WIM. In *VRIC 2010*, pages 171–180, Laval, France, 2010.

[20] J. Wang and R. Lindeman. Comparing isometric and elastic surfboard interfaces for leaning-based travel in 3D virtual environments. In *2012 IEEE Symposium on 3D User Interfaces (3DUI)*, pages 31–38, 2012.

[21] J. Wang and R. Lindeman. Leaning-based travel interfaces revisited: frontal versus sidewise stances for flying in 3D virtual spaces. ACM VRST '12, pages 121–128, New York, NY, USA, 2012. ACM.

[22] Y. Zhang, B. E. Riecke, C. Neustaedter, and T. Schiphorst. Perch to Fly: Embodied Virtual Reality Flying Locomotion with a Flexible Perching Stance. In *ACM DIS '19*, pages 253–264, San Diego, CA, USA, 2019.

[23] D. Zielasko, S. Horn, S. Freitag, B. Weyers, and T. W. Kuhlen. Evaluation of Hands-Free HMD-Based Navigation Techniques for Immersive Data Analysis. In *Proc. of IEEE 3DUI*, pages 113–119, 2016.

[24] D. Zielasko, B. Weyers, and T. W. Kuhlen. A Non-Stationary Office Desk Substitution for Desk-Based and HMD-Projected Virtual Reality. In *IEEE VR Workshop on Everyday VR*, pages 1884–1889, 2019.