Symposium Title: Virtual Reality in Behavioral and Perceptual Research

Symposium abstract

There is an increasing interest in using Virtual Reality (VR) in behavioral and perceptual research across multiple disciplines. Part of this interest in VR is based on the possibility of running tightly controlled and reproducible experiments using (if desired) fairly naturalistic multi-modal stimuli, making VR a highly versatile and powerful tool for experimental research. In this symposium, we will combine recent findings with a discussion of the bigger picture and potential issues that arise from using VR as a research tool in behavioral/perceptual research and beyond.

Presenters:

Sarah H. Creem-Regehr - University of Utah, UT, USA; sarah.creem@psych.utah.edu

- Improving distance judgments in virtual environments: What have we learned about perception?

Eric Hodgson - Miami University, OH, USA; hodgsoep@muohio.edu

- Redirected walking during unconstrained navigation

Frank H. Durgin - Swarthmore College, PA, USA; fdurgin1@swarthmore.edu

- Controlled interactivity in the study of perception

Betty Mohler - Max Planck Institute for Biological Cybernetics, Germany; Betty.Mohler@Tuebingen.MPG.de

- Avatars in Immersive Virtual Environments

Bernhard E. Riecke - Simon Fraser University, BC, Canada; ber1@sfu.ca

- Spatial perception and orientation in virtual environments – is virtual reality real enough?

Panelists:

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Presentation Abstracts (short and extended)

Improving distance judgments in virtual environments: What have we learned about perception?

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Short abstract

It is now established that 1) observers underestimate absolute egocentric distance in head-mounted display virtual environments and 2) specific manipulations of displays and response feedback can improve these judgments in some circumstances. A broader question involves the underlying spatial perception mechanisms that allow for these changes. An empirical manipulation of the quality of graphics, which selectively changes verbal but not walking-based distance judgments, will be discussed in the context of understanding the internal representations informing distance estimations. We relate these results to other studies which also use the virtual environment as a tool to examine the nature of the information used in distance perception.

Extended Abstract

In head-mounted display (HMD) immersive virtual environments (VEs), observers consistently underestimate absolute egocentric distance. They walk, throw, and verbally respond as if distances are closer than they are intended to be (Loomis & Knapp, 2003; Mohler, Creem-Regehr, & Thompson, 2006; Richardson & Waller, 2007; Sahm, Creem-Regehr, Thompson, & Willemsen, 2005; Thompson et al., 2004; Willemsen, Gooch, Thompson, & Creem-Regehr, 2008). Now, numerous research studies have explored many of the possible reasons for this systematic effect on distance judgments but single explanations have not been sufficient to completely explain the result (Willemsen, Colton, Creem-Regehr, & Thompson, 2009; Willemsen et al., 2008). Despite this, several ways of improving distance estimations have been established. For example, Kuhl, Thompson, and Creem-Regehr (in press) showed that minification or "zooming out" of the graphics within the HMD led to increased distance estimations without any subjective awareness of the manipulation. It has also been demonstrated that both perceptual-motor and explicit feedback associated with behavioral responses can change subsequent distance judgments within the HMD in some circumstances (Mohler et al., 2006; Richardson & Waller, 2007; Waller & Richardson, 2008).

A broader question involves the underlying spatial perception mechanisms that allow for these changes. In other words, what can manipulations used to improve VE "perception" tell us about the nature of spatial representation and action? To start to answer this question, we present the results of one of our recent studies finding that manipulating the quality of graphics affects verbally reported distance estimations but not visually directed walking.

An intuitive factor that could contribute to distance estimations is the realism of the images presented. The cartoon-like nature of some graphics used in VEs may influence perceptual fidelity by affecting cues for absolute distance such as familiar size. Subjective experience supports this claim, as more realistic, higher graphics-quality rendered spaces seem larger than equivalently sized spaces rendered with less realistic textures and objects. However, Thompson et al. (2004) explored this hypothesis and found no significant difference in egocentric distance judgments between three distinctly different qualities of graphics presented in a virtual environment. The Thompson et al. (2004) study focused on one type of distance estimation, triangulation by walking, in which observers viewed a target and walked indirectly towards that target.

We recently extended this work by asking a question more targeted to perceptual mechanisms, examining whether effects of quality of graphics are generalizable across two different types of response measures (Kunz, Creem-Regehr, & Thompson, in press). Given the striking contrast between one's "sense" of the size of the space and the objective measure of visually directed walking, we questioned whether quality of graphics might affect verbal reports of distance more than a visually directed walking measure. While Thompson et al. (2004) aimed to find an explanation in quality of graphics that could be used to improve performance in VEs, our primary goal was to test whether effects of quality of graphics might inform us about the mechanisms underlying distance estimations as a function of the response required. We conducted two experiments to assess the potential dissociation between visually-directed walking and verbal reports of distance in HMD-based VEs as a function of the quality of graphics. In Experiment 1, we assessed direct blind walking to previously viewed targets in a virtual environment. We used two qualities of graphics conditions: a low-quality graphics model with simple geometry and low spatial frequency tiled textures and a high-quality graphics model with photorealistic textures applied to more complex and realistic computer-generated geometry. This experiment served to test whether the results of Thompson et al. (2004) could be replicated with a different action-based walking measure. In Experiment 2, we utilized the same virtual environment with two qualities of graphics but tested the effects on verbal reports of distance. The results indicate that blind walking was *not* influenced by quality of graphics while verbal reports of distance were significantly improved with the use of high-quality graphics.

We consider several potential explanations for this behavioral dissociation, which are important to consider in the framework of models of distance perception. Broadly, we may think about the behavioral distinctions as reflecting either 1) different internal representations of space or 2) a single representation which has been transformed at the time of judgment. One view supporting different representations follows the *two visual systems hypothesis*, suggesting that there are separable visual pathways for perceptual awareness and action which process visual information differently and lead to different behavioral outcomes. This account would suggest that the verbal reports reflect an awareness of space that the walking-based judgments do not. An alternative account which also supports different representations emphasizes *task specificity,* suggesting that the nature of the response measure may lead the visual system to select different information for distance in constructing a perceptual representation. Following this account, quality of graphics influences some visual cues more than others and may therefore influence perceptual representations and subsequent behavioral responses in a different way. A third explanation follows the single representation view, suggesting that the influence of quality of graphics on verbal reports occurs in a judgment process, rather than at the level of internal representation of distance.

References

Kuhl, S., Thompson, W. B., & Creem-Regehr, S. H. (in press). HMD calibration and its effects on distance judgments. *ACM Transactions on Applied Perception*.

Kunz, B. R., Creem-Regehr, S. H., & Thompson, W. B. (in press). Revisiting the effect of quality of graphics in distance judgments in virtual environments: A comparison of verbal reports and blind walking. *Attention, Perception & Psychophysics*.

Loomis, J. M., & Knapp, J. M. (2003). Visual perception of egocentric distance in real and virtual environments. In L. J. Hettinger & M. W. Haas (Eds.), *Virtual and adaptive environments* (pp. 21-46). Mahwah, NJ: Lawrence Erlbaum Associates.

Mohler, B. J., Creem-Regehr, S. H., & Thompson, W. B. (2006). The influence of feedback on egocentric distance judgments in real and virtual environmnets. *Proceedings of the Third SIGGRAPH Symposium on Applied Perception in Graphics and Visualization*.

Richardson, A. R., & Waller, D. (2007). Interaction with an immersive virtual environment corrects users' distance estimates. *Human Factors, 49*, 507-517.

Sahm, C. S., Creem-Regehr, S. H., Thompson, W. B., & Willemsen, P. (2005). Throwing versus walking as indicators of distance perception in real and virtual environments. *ACM Transactions on Applied Perception, 2*, 35-45.

Thompson, W. B., Willemsen, P., Gooch, A. A., Creem-Regehr, S. H., Loomis, J. M., & Beall, A. C. (2004). Does the quality of the computer graphics matter when judging distance in visually immersive environments? *Presence: Teleoperators and Virtual Environments, 13*, 560-571.

Waller, D., & Richardson, A. R. (2008). Correcting distance estimates by interacting with immersive virtual environments: Effects of task and available sensory information. *Journal of Experimental Psychology: Applied, 14*, 61-72.

Willemsen, P., Colton, M. B., Creem-Regehr, S. H., & Thompson, W. B. (2009). The effects of head-mounted display mechanical properties and field of view on distance judgments in virtual environments. *ACM Transactions on Applied Perception, 6*(2), Article 8.

Willemsen, P., Gooch, A. A., Thompson, W. B., & Creem-Regehr, S. H. (2008). Effects of stereo viewing conditions on distance perception in virtual environments. *Presence, 17*, 91-101.

Redirected walking during unconstrained navigation

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Short abstract

Three experiments are presented that build on a new technique, called redirected walking (Razzaque, 2005), which imperceptibly steers participants towards the center of a tracking space (and away from walls). Redirected walking can extend the navigable space within a virtual environment (VE) without specialized equipment. The present research extends findings from simulated users and small-scale redirection to dynamically redirect real participants freely exploring a large VE. Performance on a spatial task during normal and redirected simulations were compared to assess any detrimental affects of steering. Broad implications for spatial cognition research and other areas are discussed.

Extended Abstract

Virtual reality (VR) has proven to be an invaluable tool for spatial cognition research as it allows experimenters a level of flexibility and control over the environment that is not possible in the real world. As VR technology has improved, its usefulness in this area has only grown. One of the current limitations that faces spatial cognition research with respect to VR is that of physical space constraints. Researchers must choose between implementing a simulated environment that is no larger than their physical lab space or sacrificing participants' natural movements (and their associated sensory feedback) with metaphorical navigation techniques such as pushing a joystick or walking in place. Current techniques to overcome space limitations, such as a multi-directional treadmill, are both prohibitively expensive and come with unintended drawbacks (e.g., an unstable surface and reduced inertial cues). The present research builds on a new technique, called redirected walking (Razzaque, 2005), which enables researchers to dynamically and imperceptibly steer participants towards the center of the tracking space and away from barriers and obstacles at its periphery (e.g., walls or furniture). This technique requires no specialized equipment and instead uses software to introduce small discrepancies between visual and proprioceptive sensory information that are intended to lead the participant in a specific direction.

The present experiments were conducted to address three major aims. The first aim was to demonstrate that redirected walking is feasible in a gym-sized space, or more specifically, the 25 m x 44 m HIVE facility (i.e., Huge Immersive Virtual Environment) at Miami University. Previous research – much of it extrapolated from limited navigation or based on simulated users – has estimated that a minimum diameter of 30 m or 40 m may be required to steer participants imperceptibly. The second aim was to develop a redirection walking algorithm that was fully independent of the simulated environment and of the participants' task, and to implement this algorithm with real (i.e., not simulated) participants. Again, much of the previous work in redirected walking has relied alternatively on simulated users or on real users engaging in limited navigation over small scales and usually following a prescribed path. Two of the present experiments steered participants who were engaged in an unconstrained search task over a large area, and the algorithm was developed to adapt dynamically to spontaneous changes in participants' heading and velocity. The final aim of the present research was to determine whether the sensory discrepancies that are intentionally injected by redirection would interfere with moment-to-moment navigation or with long-term spatial memory. Others have shown that redirected walking does not increase the incidence of simulator sickness when sensory discrepancies are injected at rates that are below detectable thresholds. This work extends that logic to show that spatial learning and performance is likewise unaffected. If redirected walking is to be used as a tool in the investigation of spatial cognition, it is of paramount importance that it does not have detrimental side effects.

Redirected walking promises to be a valuable tool in extending VR's usefulness in the study of spatial cognition. Much of the current spatial literature is focused on navigation and spatial memory for small, room-sized spaces. Redirected walking has the potential to extend the unprecedented level of flexibility and control afforded by VR to the study of building-sized, campus-sized, or even city-sized environments without sacrificing the natural movement and rich sensory feedback afforded by real walking and turning. Implications of the present work will be discussed relative to large-scale navigation, as well as the broader implications for virtual training simulations, digital tourism and heritage, and portable motion tracking systems that eschew traditionally necessary infrastructure and precision requirements.

Controlled interactivity in the study of perception

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Short abstract

We will discuss two examples of how the use of interactive virtual reality (VR) can facilitate understanding of the interaction of visual perception and proprioception. We used wide-area head-mounted VR to study optic flow perception with a walking observer whose visual world is tightly controlled. We have measured changes in psychometric functions for flow-speed, contingent on self-motion using repeated trials In VR. The stimulus is, essentially, a perception-action coupling. More recently, we have used VR to look at failures of orientation constancy to show that they partly derive from biases in the proprioception of head/gaze orientation.

Extended Abstract

The point of virtual devices is to mimic the interactivity of normal perception-action cycles. For immersive virtual reality (VR) in head-mounted displays (HMDs), there are clear limitations in the absolute rendering of large-scale spaces: Space perception in VR is limited for reasons that are still not fully understood (e.g., Loomis & Knapp, 2003). Nonetheless, the power of being able to present a carefully-controlled perceptuo-motor contingency as a stimulus can be accomplished while finessing the limitations of absolute perceptual geometry. We will describe two lines of research using virtual reality in this way.

In our studies of optic flow perception during locomotion, we can present via a head-mounted display (HMD) a virtual hallway that can guide locomotion either without providing optic flow (uniform walls, ceiling and floor) or by providing a specific speed of optic flow. The physical environment in which the participant walked was a hallway 2.5 m wide and 22 m long. The entire space is tracked with an optical tracking system (HiBall) with very high spatial precision and very low lag. Even in the absence of wall texture, the virtual hallway (which is 2 m wide and 200 m long) serves to guide the walking observer.

We can now present an optic flow stimulus on the virtual hallway that the observer is already immersed in. Our stimulus is a virtual world being presented to a walking observer. The observer may end up comparing two different flow speeds while walking. Or he or she may compare a flow speed observed while walking with one observed while standing. Our two important findings are (1) that flow speeds that approximate walking speed, will appear much faster when standing than when walking; walking seems to reduce their speed in a manner consistent with prediction theories (Durgin, Gigone & Scott, 2005), and (2) the speed reduction during walking seems to result in enhanced discrimination among flow speeds near walking speed (Durgin & Gigone, 2007).

To measure optic flow speed discrimination contingent on walking could be attempted while pushing a laptop on a cart. And we really don't know that that wouldn't be sufficient, but VR makes possible the estimation of a psychophysical function for interactive perception during action. The study of this kind of perceptuo-motor contingency would be nearly impossible without the control that VR allows (Durgin, Reed & Tigue, 2007). And because the various stimuli can be the same across different locomotor conditions, problems with space perception in VR are controlled for. We can draw strong inferences about the effect of locomotor condition on perception even if we know the scaling may be somewhat wrong.

The study of geographic slope perception represents another opportunity for looking at interactions between perception and action where VR seems invaluable. Hills look much steeper than they are, and it has been regarded as fact for a number of years that hills appear steeper from the top than from the bottom. However, we observed outdoors that downhill slopes appeared steeper if one stands back from the edge and shallower if one stood close to the edge. This made us want to measure the relationships between optical information and proprioceptive information. After all, if one stands back far enough from the top of a hill, one can look down its surface with gaze nearly parallel to the surface. We considered that the perception of gaze direction should provide a kind of direct estimate of hill slope in this case. Yet it was in this very case that hills, which appear steeper than they really are anyway, look ridiculously steep.

How can one map out this psychometric function with real hills of various slopes? Short of renting a bulldozer and building them, the best sort of experimental control can be obtained in VR, where a hill surface of any orientation, size, and distance can be summoned easily into an immersive experience. Crucially, we can also reposition a person within the VR at will. The specification of where they are with respect to the edge is well-defined visually, but judgments of perceived slope can be obtained without explicitly alerting a person about the manipulation of their distance from the edge of the slope by having to move them.

As we have already pointed out, there are real concerns about the absolute perception of space in VR. These concerns mean that the absolute value of the estimates we record may not reflect the estimates we would get for real hills of the same simulated slopes. The beauty of our design, however, is that it turns out we can nonetheless make pretty strong inferences based on the relationship between estimates given from one vantage point and estimates given from another. Because our theory of the steeper-when-back-from-edge phenomenon depends heavily on the idea that the perceived declination of gaze is overestimated, it turns out we can model this overestimation based on the shifts in the perceived slope functions as a result of perceived gaze orientation.

Indeed, we have also directly measured proprioceptive error for the perceived orientation of the head. When asked to hold one's head at a 45-deg angle, most people achieve no more than a 30-deg inclination of the head. This, we argue, helps to explain why a hill could look so steep as one looks down along it: one overestimates one's gaze declination. Indeed, our VR data showed that a model that took head misperception into account completely explained the back-from-edge effect in VR quantitatively. Note that, once again, the research is about a relationship between two states of motor affairs with respect to the environment (standing positions— and head orientations, in this case), and how these interact with perceptual experience. The motor activity in our studies is not virtual; it is real. Our ability to provide a controlled interactive experience means that we can measure the effects of specific motor and postural states on perceptual experience. In the case of downhill slope perception, we have also validated the patterns of VR results using a complicated experiment with real objects and a real moving cart to reposition people physically. But VR allowed us to sample much more richly throughout the parameter space.

Virtual worlds feel real because they adhere, fairly well, to normal perceptuo-motor contingencies. They can be used to subtly distort those contingencies or to study how people are tuned to them (Durgin, 2009). There are limits to the kinds of inference one can draw from VR, but VR opens up exciting avenues of study by allowing interactive behavior to be studied in a controlled way.

References

Durgin, F. H. (2009). When walking makes perception better. Current Directions in Psychological Science, 18, 43-47.

Durgin, F. H., & Gigone, K. (2007). Enhanced optic flow speed discrimination while walking: Contextual tuning of visual coding. Perception, 36, 1465-1475.

Durgin, F. H., Gigone, K., & Scott, R. (2005). The perception of visual speed while moving. Journal of Experimental Psychology: Human Perception and Performance, 31, 339-353.

Durgin, F. H., Reed, C., & Tigue, C. (2007). Step frequency and perceived self-motion. ACM: Transactions in Applied Perception, 4(1), 1-27.

Loomis, J. M., & Knapp, J. M. (2003). Visual perception of egocentric distance in real and virtual environments (pp 21-46). Lawrence Erlbaum: Mahwah, NJ.

Avatars in Immersive Virtual Environments

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Short abstract

Few head-mounted-display (HMD) virtual environment (VE) systems display a rendering of the user's own body. Subjectively, this often leads to a sense of disembodiment in the VE. In a recent study (Mohler et al., submitted to Presence), we found that the presence of an avatar changed the typical pattern of distance underestimation seen in many HMD studies. Users showed an increase in distance estimations with avatar experience, especially when the avatar was animated in correspondence with their own body-movements. I will discuss the potential for VEs to investigate embodied perception.

Extended Abstract

One important aspect that has been missing from most HMD VEs is the ability to see one's own body. While non-augmented HMDs make it impossible to see one's physical body, current tracking technology has made it possible to render a fully articulated virtual representation of oneself in the virtual world. While having a visual representation of oneself has been shown to lead to a greater sense of presence and realism (Slater et al.), the effects of having an avatar on perception and behavior are unknown. We begin to investigate this problem by first investigating egocentric distance perception within HMD-based VEs (Mohler et al. submitted to Presence). We found after experience with an avatar in a VE, subsequent egocentric distance judgments were less compressed than when given experience simply looking around the VE. Further we found that articulation of the avatar improved distance judgments, while the location (either first-person or third-person) of the avatar did not have an impact on the magnitude of the effect.

We also hypothesized that gaining experience with a self-avatar might lead to more realistic human behavior in VEs. Experimental evidence suggests that knowledge about one's virtual body effects human performance in various tasks such as distance perception, social interaction and the feeling of being part of the environment. In another study (Streuber et al., Eurographics 2009) we investigated the effects of knowledge about one's avatar on task performance on three behavioral tasks: locomotion, object interaction and social interaction. We did not find effects of pre-exposure to a self-avatar on these tasks. We did however find effects of testing environment (VE / real world) and testing order (VE first, real world first) on participants behavior. We will further investigate if presence of the self-avatar during the task (rather than prior to task execution) will cause the performance on these three tasks to be more similar to real world performance.

Immersive VEs provide great potential to investigate embodied perception. In the real world it would be difficult to modify the first-person view of one's own body in a very controlled manner. In addition, it is much easier in the VE to take a different perspective of one's own body (out-of-body experience). Our future studies will modify the timing of the animation, the scaling of the avatar and the method of articulation to attempt to further understand embodied perception and to improve the user experience within immersive HMDs.

References

Mohler, B., H. H. Bülthoff, W. B. Thompson and S. H. Creem-Regehr: A full-body avatar improves egocentric distance judgments in an immersive virtual environment. Proceedings of the 5th Symposium on Applied Perception in Graphics and Visualization (APGV 08), 194-197. (Eds.) Creem-Regehr, S. H., K. Myszkowski, ACM Press, New York, NY, USA (08 2008)

Slater, M., & Usoh, M. Body Centred Interaction in Immersive Virtual Environments. In N. M. Thalmann & D. Thalmann (Eds.), *Artificial life and virtual reality* (pp. 125–148). John Wiley and Sons. (1994).

Streuber, S., S. de la Rosa, L.-C. C. Trutoiu, H. H. Bülthoff and B. Mohler: Does Brief Exposure to a Self-avatar Affect Common Human Behaviors in Immersive Virtual Environments? Eurographics, Proceedings of the 30th Annual Conference of the European Association for Computer Graphics, 4 (in press) (2009)

Spatial perception and orientation in virtual environments – is virtual reality real enough?

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Short abstract

While Virtual Reality (VR) offers many experimental advantages including stimulus control and interaction in flexible, naturalistic multi-modal environments, there is mixed evidence whether humans perceive and behave similarly in computer-simulated environments. I will present and discuss several recent studies suggesting that care should be taken when using VR for perceptual/behavioral research: While naturalistic visual cues can, in principle, be sufficient to allow for real-world-like spatial orientation performance in VR, there is often a strong influence of both the content displayed (e.g., naturalism and cues available in VR) and the context (e.g., display type, size, and FOV).

Extended Abstract

Virtual reality software and hardware is becoming increasingly affordable and powerful, and is increasingly being used in experimental research. In fact, the possibility to conduct tightly controlled and repeatable experiments with naturalistic multi-modal stimuli in a closed action-perception loop suggest that VR could become a powerful yet flexible research tool. Despite increasing computational power and rendering quality, though, it is at least debatable whether humans perceive and behave similarly in real and virtual environments – which is essential for achieving sufficient real-world transfer of experimental results gained in the lab.

In this presentation, I will discuss research studies in three different areas comparing human performance in real and virtual environments: 1) distance perception; (2) spatial updating; (3) spatial Cognition and Reference Frame Conflicts.

Distance perception

Many of our everyday tasks require fairly accurate visual distance perception. And indeed, when participants are asked to judge distances to a visual target by blindfolded walking to the remembered location of the target, they are quite accurate for distances as large as 20m – at least for real-world stimuli. When distances are presented in VR via head-mounted displays (HMDs), though, there is general agreement that distances are largely underestimated, by factors as large as two. Researchers largely agree that there is probably not a single factor explaining the distance compression in HMDs. In particular, Thompson et al. (2004) showed that computer graphics rendering quality did not affect blind walking distance estimates. This was recently confirmed by Kunz et al. (in press): While verbal distance measures improved with increasing rendering quality, blind walking distance estimates did not. In a recent study, we used indirect blind walking estimates for photographic real-world stimuli presented via HMD or different-sized LCD screens (Behbahani, Riecke, &

Shaw, submitted). Unexpectedly, participants showed on average no signs of distance compression for any of the display devices. In fact, distance estimation performance equaled a subsequent real-world condition. While further studies are needed to corroborate these findings, they do suggest that naturalism of the visual stimulus might be able to compensate for (at least some of the) distance compression previously observed in HMDs.

Spatial Updating

When locomoting through our immediate environment, self-to-surround relationships constantly change in non-trivial ways. During normal walking – even when we are blindfolded – a spatial updating process typically ensures that our mental representation stays in at least rough alignment with the surroundings. This spatial updating process is often referred to as "automatic" in the sense that it requires little (if any) cognitive resources or explicit attention, and "obligatory" in the sense that it is difficult to suppress: When instructed to ignore a physical rotation and respond as if still facing the original orientation, participants in Farrell & Robertson (1998) produced considerably higher errors and response latencies than when they were asked to update their mental representation as usual. While it was typically assumed that physical motion cues are required to trigger this updating process, we could show that naturalistic visual cues presented via HMD or immersive projection screen can be sufficient to elicit a similar automatic and obligatory spatial updating process as was previously found for actual walking (B. E Riecke, von der Heyde, & Bülthoff, 2005), without the need for any physical motion cues. When visual cues during the image motions was replaced be a simple optic flow stimulus devoid of any landmarks, though, responses changed and automatic/obligatory spatial updating was no longer observed (B. E. Riecke, Cunningham, & Bülthoff, 2007). This insufficiency of optic flow was later confirmed in a point-to-origin study in VR (Riecke, 2008): When participants were asked to "point back to the origin of locomotion as accurately and quickly as possible" after a visually-presented 2-segment excursion path with an intervening rotation of 30-150deg., the provided optic flow information was clearly insufficient to enable robust spatial orientation or automatic spatial updating: Task difficulty was rated as surprisingly high, and 1/3 of the participants produced striking qualitative errors (e.g., pointing leftwards instead of rightwards) which do not occur in comparable real world locomotion.

Spatial Cognition and Reference Frame Conflicts

Computers permeate our life, and VR is increasingly employed as a powerful research tool in experimental psychology and beyond – yet, there is mixed evidence whether VR really affords natural human spatial perception/cognition, which is a prerequisite for effective spatial behavior. In a real-world study using judgment of relative direction (JRD) measures, Riecke & McNamara (2007) demonstrated orientation-specific interference between participant's actual orientation in an empty rectangular room and their to-be-imagined orientation in a previously-learned room. Do visual stimuli presented in VR produce a similar interference? A recent study suggests that they in fact do not: In a VR replication study, we used a 180°×150° elumens vision station video projection to display an empty virtual (instead of real) test room (Riecke & Moura, 2009). In a real-world learning phase, participants learned the layout of 15 target objects in a rectangular office. In the VR test phase, participants were facing 3 different orientations in the virtual test room (0, 120, 240deg) while performing JRD tasks ("imagine facing X, point to Y"). Although procedures were closely replicated, seeing the virtual environment did not produce the same interference as a comparable real-world stimulus. In fact, the VR stimulus did not produce any significant interference, and several participants reported that it was easy to just ignore the VR stimulus – which was rated as almost impossible in the previous real world experiment. This indicates that visual cues presented in VR do not (at least for the setup used) have the same power and direct influence on our mental representation as do real-world stimuli.

Thus, human spatial perception and cognition seems to (sometimes) behave differently in real and virtual environments, which has critical implications for the usage and usability of VR in research. Nevertheless, experimental paradigms like the ones described above also allow us to assess and improve the effectiveness of VR content and hardware. In fact, the better we understand how the human system perceives and responds to different multi-modal stimuli, the better we can use this knowledge to evaluate and improve VR setups and vice versa: The more effective of a research tool we have, the more empowered we are to conduct high-quality research which fosters our fundamental understanding of human perception, cognition, and behavior in multi-modal, interactive, and thus more natural, life-like situations.

References

Behbahani, P. A., Riecke, B. E., & Shaw, C. D. (2009). Display Size does not Affect Egocentric Distance Perception of Naturalistic Stimuli. In *ACM SIGGRAPH Symposium on Applied Perception in Graphics and Visualization (APGV)*. doi: http://doi.acm.org/10.1145/XXX.

Farrell, M. J., & Robertson, I. H. (1998). Mental rotation and the automatic updating of body-centered spatial relationships. *Journal of Experimental Psychology – Learning Memory and Cognition*, *24*(1), 227-233.

Riecke, B. E. (2008). Consistent Left-Right Reversals for Visual Path Integration in Virtual Reality: More Than a Failure to Update One's Heading? *Presence - Teleoperators and Virtual Environments*, *17*(2), 143-175.

Riecke, B. E., von der Heyde, M., & Bülthoff, H. H. (2005). Visual cues can be sufficient for triggering automatic, reflex-like spatial updating. *ACM Transactions on Applied Perception (TAP)*, *2*(3), 183-215. doi: http://doi.acm.org/10.1145/1077399.1077401.

Riecke, B. E., & McNamara, T. P. (2007). Similarity Between Room Layouts Causes Orientation-Specific Sensorimotor Interference in To-Be-Imagined Perspective Switches. In *Proceedings of the 48th Annual Meeting of the Psychonomic Society* (p. 63).

Riecke, B. E., & Moura, D. (2009). Comparing spatial perception/cognition in real versus immersive virtual environments – it doesn't compare! In *Proceedings of the 50th Annual Meeting of the Psychonomic Society (Psychonomics)*. Retrieved from http://www.kyb.mpg.de/publication.html?publ=4786.

Riecke, B. E., Cunningham, D. W., & Bülthoff, H. H. (2007). Spatial updating in virtual reality: the sufficiency of visual information. *Psychological Research*, *71*(3), 298–313.

Thompson, W. B., Willemsen, P., Gooch, A. A., Creem-Regehr, S. H., Loomis, J. M., & Beall, A. C. (2004). Does the Quality of the Computer Graphics Matter When Judging Distances in Visually Immersive Environments? *Presence - Teleoperators and Virtual Environments*, *13*(5), 560-571.

Kunz, B. R., Creem-Regehr, S. H., & Thompson, W. B. (in press). Revisiting the effect of quality of graphics in distance judgments in virtual environments: A comparison of verbal reports and blind walking. *Attention, Perception & Psychophysics*.

Thompson, W. B., Willemsen, P., Gooch, A. A., Creem-Regehr, S. H., Loomis, J. M., & Beall, A. C. (2004). Does the quality of the computer graphics matter when judging distance in visually immersive environments? *Presence: Teleoperators and Virtual Environments, 13*, 560-571.