Research Statement

Using several approaches, my research examines how humans perceive, learn, and navigate spaces in natural, virtual, and visually impoverished environments. My research program focuses on visual space perception and spatial cognition, with an emphasis on the role of body representations and actions. This research serves two goals: to test mechanisms of perception-action processing underlying spatial perception and cognition and to apply this knowledge to address relevant real-world problems.

Space perception in real and virtual environments

As my research program has evolved, I have developed the view that the methods used to address basic science questions also open important applied questions about the methods themselves. The use of virtual environments (VEs)—computer generated scenes that envelope and move with an observer—is a good example of this. I use VEs to manipulate the world in ways that allow us to test spatial cognition mechanisms, but I also study behavior in virtual environments as an important problem in itself. From an applied perspective, the utility of a VE for potential applications—such as training, education and rehabilitation—increases with perceptual fidelity, the likelihood that people perceive and act as if they were in a real environment. I have outlined this approach in a recent review, Perceiving Scale in Virtual Environments: How theory and application have mutually informed the role of body-based perception (Creem-Regehr et al., 2015)*. Here, we argue that VEs provide both an opportunity and a challenge for the study of space perception and spatial cognition. The opportunity is that VEs provide a methodology that is both controlled and ecologically valid, placing observers in simulated but realistic spaces that can be manipulated more easily than the actual “real world”. The challenge is that in order to use this methodology effectively, we must determine whether viewers perceive spaces in VEs in ways that resemble the real world. In fact, we found in over a decade of research that distances are underestimated in immersive VEs when compared to the real world. In other words, virtual worlds often appear smaller than intended. My colleagues and I have published a body of work that has aimed to try to understand this systematic distance underestimation effect by examining numerous factors including the technology limitations, visual cues, response measures, and calibration of actions. These investigations serve an applied goal of improving the perceptual fidelity of VEs and at the same time, they also contribute to our basic understanding of space perception and action.

One example of this is our more recent examination of influences of the visual body on space perception. Until relatively recently, despite the immersive and head-tracked nature of the head-mounted display VE, very few VE systems actually represent the viewer’s body within the VE itself. In Mohler et al. (2010), we published one of the first papers that introduced a virtual body—an avatar—into the VE to test its influence on space perception. We found that experience viewing an avatar that was animated in correspondence with the observer’s movements showed a marked improvement on distance estimations. Since then, our lab has been pursuing the question of how virtual (and real) worlds are scaled to dimensions of the body (e.g., Creem-Regehr et al. 2014; Jun et al. 2015; Gagnon et al., 2015) to influence judgments of affordances, or one’s capability to act. Our results have informed both theories of embodied perception and the applied problem of improving perceptual fidelity in VEs. Together, this work has been continuously funded through NSF since 2000.

Low vision space perception and spatial cognition

My work in low vision is part of a larger interdisciplinary research project funded by NIH (across Univ. of Minnesota, Utah, and Indiana University) aimed at creating a design tool that has the ability to identify optimal environmental settings that are “visually accessible” to the diverse population who have uncorrectable vision loss. The ability to navigate through new environments is critical for independent living and is a major challenge for those with uncorrectable vision loss, a population of about 4 million
Americans, expected to double by 2030. My contribution has been on the perceptual and cognitive science of this project, to determine how spaces are perceived and how spatial layout is learned in profound low vision. Our earlier work aimed to understand the capabilities of 3D space perception under conditions of simulated severely degraded acuity and contrast sensitivity. We first established, surprisingly, that individuals viewing single targets on the ground with severely reduced acuity are able to blind walk accurately to the target location, showing that they were able to estimate distances to targets that they could barely detect (Tarampi et al., 2010). Given this result, we then examined the visual cues that are relied upon under these viewing conditions, and extended this work to contexts where objects are not perceived to be on the ground, and to distance judgments that are made while traveling through space (Rand et al., 2011, 2012, in prep). Our current work is examining more complex spatial tasks of navigation and spatial memory under degraded viewing conditions, both degraded acuity/contrast and reduced field of view (Rand et al., 2015; Barhorst-Cates et al 2016, 2017). With this direction, I aim to determine how people use landmarks to learn novel spatial layout while navigating with severely impaired vision, with the goal of then using this information to help in the design of new assistive technologies or strategies that can facilitate spatial learning, rather than simply provide online directions or support to avoid obstacles (goal of my current R01 submission).

Individual differences in spatial learning and navigation

I have had a long-standing interest in both small-scale (mental rotation) and large-scale (navigation and memory) spatial abilities seen in some of my earlier work on imagined self- and object-transformations made in the real-world and adapted computer displays used in fMRI (e.g., Creem-Regehr et al. 2007). More recently, I am a co-PI in a large NSF IBSS (across Psychology, Anthropology, and Geography) grant that examines individual differences in many of these abilities from an evolutionary psychology, cross-cultural perspective. The driving hypothesis is that mobility influences these differences in spatial abilities and navigation. We are defining and studying “mobility” in a number of ways, such as through self-report measures of how many places people have traveled, to a much more detailed mobility survey of the reasons why people travel, to explicit measurements of exploration through virtual travel and real-world GPS measures. Our findings suggest that mobility does matter in large-scale spatial task performance. For example, Padilla et al. (2017, PBR) found that while males showed the typical advantage seen in a virtual water maze (spatial memory task), this sex difference was reduced for more mobile females. In addition, we found in Gagnon et al. (2016; under review) that the type of spontaneous exploration performed in a virtual landscape influenced later memory and navigation in that environment. This work has broader impacts of addressing disparities seen in participation in STEM fields that are tied to differences in experience and abilities with spatial tasks.

Cognition of visualization

A final area of research that has grown as a focus for me over recent years is the study of how complex visualizations of data are perceived and understood. My colleagues and I received funding from the NSF CISE program to examine the visualization of uncertainty. This project is truly interdisciplinary as we have 9 PIs on the project (across 4 universities) with expertise ranging from the mathematical modeling of uncertainty quantification, to visualization in computer science, to cognitive psychologists studying perception and decision making. Our work in my lab has primarily asked the question of how the visual features of different types of visualizations influence decision making. We have found that depicting the same data but with two broadly different methods—summary or ensemble displays—changes the interpretations of naïve viewers with respect to size, intensity, and perceived damage of hurricane forecasts (e.g., Padilla et al., 2017, CR:PI). Although this grant is coming to an end this year, this work has fueled my further interest in integrating perception, decision-making and visualization research, and I have several ongoing projects that will continue with my visualization collaborators.
Current and future directions

Rapid advancements and growing interest in VE technology makes new research in space perception and navigation exciting to pursue. Our most recently awarded grant from the ONR (with Vanderbilt University) supports a new direction of research that extends from my previous work with Virtual Reality to Augmented Reality (AR). Here, we are asking questions about how affordances for actions are perceived when the action may be performed on a virtual object displayed on top of the real-world environment. Once we establish whether affordances through AR can be perceived as those completely in the real world, we will test whether affordances can be highlighted to facilitate learning through navigation. This work has implications for understanding how developing AR technologies can be used for spatial training in multiple ways.

Related to this advancing technology is the recent availability of commodity-level head-mounted-displays (HMDs) and controllers that we use to display and interact with the virtual environments. These HMDs, such as the Oculus Rift and the Vive have opened up many more opportunities for the study of perception and action in VEs. One area of research that my colleagues and I are pursuing is the study of children’s perception in VEs. We know very little about how children perceive and act in virtual environments because until recently, the technology was heavy, sized for adults, and not usable by children. We have begun to ask the question of whether children at different ages—particularly in different stages of physical growth—perceive and/or calibrate spaces differently than adults. Our recent projects suggest that the paradigms that we have used with adults can be adapted for children, and also that there may be some differences in way children perceive capabilities for action in VEs. One direction of research will be to manipulate perceived body size with avatars as we have with adults, to test the hypothesis that children who are undergoing rapid physical changes in body size will be differentially influenced by manipulations of the size visual avatar bodies or body-parts compared to adults.

VEs also provide a means to pursue my interest in the question of how the presence and goals of other agents influence our perception and representation of space. In Creem-Regehr et al. (2013), my co-authors and I outlined the possible relationships between perspective taking and the perception of others’ affordances. In ongoing work, I am using a new paradigm that we developed to combine judgments of other’s affordances with a perspective-taking task. Here, the aim is to define when perspective-taking is required for judging other’s potential to act, and when it may not be. The ability to judge what others can see and do is an important aspect of spatial cognition and this direction of research will help to establish the mechanisms underlying this ability.

*See curriculum vitae for references