Virtual Reality as a Valuable Research Tool for Investigating Different Aspects of Spatial Cognition
(Abstract)

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The interdisciplinary research field of spatial cognition has benefited greatly from the use of advanced Virtual Reality (VR) technologies. Such tools have provided the ability to explicitly control specific experimental conditions, manipulate variables not possible in the real world, and provide a convincing, multimodal experience. Here we will first describe several of the VR facilities at the Max Planck Institute (MPI) for Biological Cybernetics that have been developed to optimize scientific investigations related to multi-modal self-motion perception and spatial cognition. Subsequently, we will present some recent empirical work contributing to these research areas.

While in the past, low-quality visual simulations of space were the most prominent types of VR (i.e., simple desktop displays), more advanced visualization systems are becoming increasingly more desirable. At the MPI we have utilized a variety of visualization tools ranging from immersive head-mounted displays (HMD), to large field-of-view, curved projection systems, to a high resolution tiled display. There is also an increasing need for high-quality, adaptable, large-scale, simulated environments. At the MPI we have created a virtual replica of downtown Tübingen throughout which observers can navigate. In collaboration with ETH Zurich, who have developed "CityEngine", a virtual city builder, we are now able to rapidly create virtual renditions of existing cities or customized environmental layouts. In order to naturally interact within such virtual environments (VEs), it is also increasingly more important to be able to physically move within these spaces. Under most natural conditions involving self-motion, body-based information is inherently present. Therefore, the recent developments of several sophisticated self-motion interfaces have allowed us to present and evaluate natural, multi-sensory navigational experiences in unprecedented ways. For instance, within a large (12 m × 12 m), free-walking space, a high-precision optical tracking system (paired with an HMD) updates one's position within a VE as they naturally navigate through walking or when passively transported (i.e., via a robotic wheelchair). Further, the MPI Motion Simulator is a 6-degree of freedom anthropomorphic robotic arm that can translate and rotate an observer

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in any number of ways (both open and closed-loop). Finally, a new, state-of-the-art omni-directional treadmill now offers observers the opportunity to experience unrestricted, limitless walking throughout large-scale VE's.

When moving through space, both, dynamic visual information (i.e., optic flow), and body-based information (i.e., proprioceptive/efference copy and vestibular) jointly specify the magnitude of a distance travelled. Relatively little is currently known about how these cues are integrated when simultaneously present. In a series of experiments, we investigated participants' ability to estimate travelled distances under a variety of sensory/motor conditions. Visual information presented via an HMD was combined with body-based cues that were provided either by walking in a fully-tracked, free-walking space, by walking on a large linear treadmill, or by being passively transported in a robotic wheelchair. Visually-specified distances were either congruent or incongruent with distances specified by body-based cues. Responses reflect a combined effect of both visual and body-based information, with an overall higher weighting of body-based cues during walking and a relatively equal weighting of inertial and visual cues during passive movement. The characteristics of self-motion perception have also been investigated using a novel continuous pointing method. This task simply requires participants to view a target and point continuously towards the target as they moved past it along a straight, forward trajectory. By using arm angle, we are able to measure perceived location and, hence, perceived self-velocity during the entire trajectory. We have compared the natural characteristics of continuous pointing during sighted walking with those during reduced sensory/motor cue conditions, including: blind-walking, passive transport, and imagined walking. The specific characteristics of self-motion perception during passive transport have also been further evaluated through the use of a robotic wheelchair and the MPI Motion Simulator.

Additional research programs have focused on understanding particular aspects of spatial memory when navigating through visually rich, complex environments. In one study that investigated route memory, participants navigated through virtual Tübingen while it was projected onto a 220° field-of-view, curved screen display. Participants learned two routes while they were simultaneously required to perform a visual, spatial, or verbal secondary task. In the subsequent wayfinding phase the participants were asked to locate and "virtually travel" along the two routes again (via joystick manipulation). During this wayfinding phase a number of dependent measures were recorded. The results indicate that encoding wayfinding knowledge interfered with the verbal and spatial secondary tasks. These interferences were even stronger than the interference of wayfinding knowledge with the visual secondary task. These findings are consistent with a dual-coding approach of wayfinding knowledge. This dual coding approach was further examined in our fully-tracked, free-walking space. In this case, participants walked a route through a virtual environment and again were required to remember the route. For 50% of the intersections they encountered, they were asked associate it with an arbitrary name they heard via headphones (e.g., "Goethe place"). For the other 50% of the intersections they were asked to remember the intersection by the local environmental features and not associate it with a name. In a successive route memory test participants were "beamed" to an intersection and had to indicate in which direction they originally traveled the route. Participants performed better at intersections without a name than they did for intersections associated with an arbitrary name. When repeating the experiment with meaningful names that accurately represented the environmental features (e.g., "Hay place"), the results turned around (i.e., naming a place no longer lead to worse performance). These results indicate that the benefits of language do not come for free.

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