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Factors influencing orientation within a nested virtual environment: External cues, active exploration and familiarity

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ABSTRACT

Three experiments using a spatial orientation task within a computer generated building examined the factors influencing maintenance of orientation to an external reference frame within a nested environment. Having explored a virtual building, participants were asked to point to an occluded external cue from 4 different rooms. Experiment 1 orientation errors were less in external rooms and previously visited internal rooms. To assess importance of guiding instructions, participants in Experiment 2 were shown a video of the building. Again orientation errors were less in previously visited rooms. Participants in Experiment 3 had no experience of the building. Participants shown the video were unable to maintain orientation in the internal visited room. Results suggest that maintaining orientation to an external frame of reference requires either access to an external cue or active exploration. Without previous familiarity passive exposure was not sufficient to maintain orientation within the building.

As we move through an environment, our egocentric relationship with the environment constantly changes. If an individual experiences, or perceives motion, they are required to reorient themselves via the use of constant static cues relative to their previous location. This process of reorientation is referred to as spatial updating (Rieser, 1989). For example if an individual is sitting facing a computer and turns to the right to answer the door, the computer is now on the individual's left. Evidence suggests that spatial updating is an automatic cognitive process (Farrell & Robertson, 1998; Rieser, 1989; Wang, 2004) which operates to ensure that an individual's egocentric reference matches their current alignment. Wan, Wang, and Crowell (2009) showed when stimuli are presented via a VR headset (display for each eye had a resolution of 800 (horizontal) 600 (vertical) pixels. The optical field of view for each eye being 26° diagonal) and when physically moved participants were still able to spatially update their position with reference to the VR environment. Within traditional real world environments, spatial updating acts to ensure that individuals retain knowledge of their local environment, do not collide with near objects as they move and enables the tracking of distant targets. Visual cues are not, however, required for automatic spatial updating, with blindfolded participants being highly accurate at spatial updating tasks (Farrell & Robertson, 1998). Evidence suggests that vestibular and proprioceptive information are central in enabling accurate spatial updating processes to occur (Lackner & DiZio, 2005). Lackner and DiZio (2005) argue that in situations where visual information is available, it acts to reinforce and support vestibular information, available from a variety of sources, including body position and ocular muscle positioning, rather than being the primary driver of this information.

Vestibular and other body movement cues are not, however, available when examining digital spaces, consequently tracking object locations within such spaces is potentially a greater challenge than within the real world. Indeed, Witmer, Bailey, Knerr, and Parsons (1996) demonstrated that the acquisition of survey knowledge and orientation accuracy is reduced within digital compared to real world environments. Individuals must rely on visual cues to track changes in digital environments (Hartley, Trinkler, & Burgess, 2004).

Riecke, Cunningham, and Bulthoff (2007) explored the sufficiency of visual cues for spatial updating when exploring within a virtual environment. Using a pointing paradigm, participants were seated within a motion platform, and witnessed a tour of a city. The study used a 2 × 2 mixed design, whereby participants either had or did not have access to physical motion cues provided by the platform, and either visual stimulus provided by a pre-recorded video tour of a city or matching optic flow patterns but no

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distinctive images and cues. Reicke et al. found that participants provided with the realistic tour of the environment were able to engage in automatic spatial updating, regardless of whether they had access to physical motion cues, suggesting that visual cues were sufficient for spatial updating. They found however that optic flow patterns were not sufficient to induce automatic spatial updating, regardless of the presence of motion cues.

Expanding on this work Riecke, Sigurdson, and Milne (2013) asked participants to perform point-to-origin tasks after visually simulated excursions along streets of varying curvature in a naturalistic virtual city. The majority of the participants were able to adjust for the curve of the streets and point correctly despite the fact they had been stationary. These findings suggest that participants were able to update their location even within an unreal environment. However, it should be noted that a minority of participants acted as if they had not turned and other research has noted that the neuro-activity associated with navigation in the real world and virtual environment can differ (Taube, Valerio & Yoder, 2013).

Spatial environments do not exist in isolation, but rather are part of larger spatial contexts (Wang & Brockmole, 2003a, 2003b). Real world examples of this include rooms within a building. Carlson, Holscher, Shipley, and Dalton (2010) have examined the factors which make navigating through a building more difficult. These environments are not independent of each other, movement within one aspect of the environment, for example the room within the building, changes an individual's spatial relationship with not just their immediate surroundings, items within the room, but also other elements in the larger environment, the outside space.

Wang and Brockmole (2003a) investigated spatial updating within nested environments, specifically, a room within a university campus. After learning the locations of key targets within both the room and the wider campus, participants were blindfolded and required to turn and face objects within either the room or the campus (turning stage). After the last trial of the turning stage all participants, whether asked to turn toward cues that were in or outside of the room, were left facing in the same direction. They were then required to point to objects both in and outside of the room. All participants were able to point accurately at the internal cues. If during the turning stage they had been asked to face external targets, then in the test stage they were able to point accurately toward the other external cues but if during the turning stage they had been asked to face toward internal cues they subsequently could not accurately point at the external cues. Wang and Brockmole took this as evidence that spatial updating with respect to the external landmarks was not automatic; it required specific attention to be paid to the external array while moving. Wang and Brockmole argue that this finding suggests that each sub-environment within nested environments is updated independently rather than simultaneously as part of a gestalt whole. The room and the campus were separate spatial reference frames.

Wang and Brockmole (2003b) found further evidence that participants had difficulty orienting to targets in a different frame of reference to their current local one. In a series of studies, participants were asked to find their way to a laboratory within Psychology department and then walk to location where they could point to a specified building on the campus. Only when they were outside of the building were the participants' able to point to the Student Union, and once outside, participants were unable to accurately point to the previously visited laboratory within the psychology building. As with the previous experiment, the authors took the results to suggest that spatial updating in respect to the external reference frame was disrupted by updating in reference to the internal reference frame.

Mou and Wang (2015) pointed out there was another way to remain orientated to an occluded target, Piloting (Gallistel & Matzel, 2013). If the spatial relationship is known between a visible cue and an occluded cue then it is possible to orientate to the occluded cue. Piloting could be used to describe how rats locate submerged platforms within a watermaze once the animals have learnt the platform's spatial relationship to the cues around the pool (Redhead, Roberts, Good & Pearce 1997) and similarly with human participants in a virtual environment (Redhead & Hamilton, 2007; Redhead, Hamilton, Parker, Chan & Allison, 2013). Contrary to Wang and Brockmole's findings, Mou and Wang (2015) demonstrated that while switching reference frames disrupted piloting, spatial updating was not disrupted. They suggested that path integration relies on participants' inertial cues (e.g., proprioceptive and vestibular cues) or optical flows to calculate the moving direction and speed. Unlike piloting, it does not rely on the spatial relations between visual landmarks (e.g., Gallistel & Matzel, 2013). Accordingly, path integration should not be affected by the less useful visual landmarks due to boundary crossing.

The current set of experiments used a computer generated building to examine the factors influencing maintenance of orientation with reference to an external array of cues within a nested environment. The experiments examine the relative use of the two strategies spatial updating and piloting, manipulating type of exploration and familiarity with the environment. The environment chosen for these experiments was a virtual model of the Psychology building, and campus of the University of Southampton. In Experiments 1 and 2, participants would be expected to be familiar with this location given they were all year 2 Psychology students and had received weekly lectures in the building. In Experiment 3 they were vistors on an open day so had no experience of the building. Participants were taken on a route around and inside the building (see Fig. 1a and b for diagram of the layout of the Psychology building and campus and the routes taken participants).

Participants were digitally placed into four different rooms. Napieralsk et al. (2014) used a similar teleportation procedure into positions and found participants were able to establish orientation. Room External Unvisited (EU) had not been previously visited (Fig. 2a). Room Internal Unvisited (IU) had not been visited and only had a view of the internal courtyard (Fig. 2b). Although there was no view of the external cues other rooms within the Psychology Building were visible for example the Computer room from which the location of the Main campus could be gauged. Room External Visited (EV) had been previously visited (Fig. 2c). Room Internal Visited (IV) had been previously visited but again only offered a view of the internal courtyard and computer room (Fig. 2d). In each of the rooms participants were asked to face toward one of the non-visible external cues and Orientation Error was recorded.

It would be predicted that having learnt the spatial relationship of the external cues a partial view of the external environment in the external rooms should allow participants to maintain orientation via a process of piloting in both external rooms but only via spatial updating in the external room which had been previously visited (EV). A view of only the computer room within the internal environment would disrupt piloting and, according to Wang and Brockmole (2003a), disrupt spatial updating with the external environment. However, participants having followed a path to the internal visited room (IV) Mou and Wang would predict participants would maintain orientation to the external reference frame via spatial updating. In Experiment 1, participants actively explored the computer model.