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Human Spatial Cognition: Memory, Navigation, and Environmental Learning

A Special Issue of *Psychological Research*
Berlin/Heidelberg/New York: Springer
2007

Contents

Editorial

Spatial learning and spatial behavior have been major topics of interest since the early days of psychology, and undoubtedly helped to establish experimental psychology on solid scientific foundations. Over the last 30 years or so, psychology has seen the emergence of "spatial cognition" as a new domain in its own right, intended to account for spatial behavior in terms of underlying mechanisms and the associated representations (e.g., Siegel & White, 1975). At the same time, the emphasis on the cognitive determinants of spatial behavior has led to their inclusion in more general theoretical accounts of human cognition, including its architecture and computational mechanisms. Not surprisingly, the increased interest of psychologists in spatial cognition has paralleled the development of behavioral geography, i.e., the part of human geography intended to explain how the behavior of individuals and populations within geographic space is determined by their cognitive representations (e.g., Downs & Stea, 1973; Moore & Golledge, 1976). Over the same period of time, the connections between psychology and other cognitive sciences, such as linguistics and computer science, have led scientists towards new frontiers in the study of the capacities of human and artificial cognitive systems. The representation of spatial knowledge has become a primary task for computer scientists, and a number of original works have set out to integrate theories, empirical studies, and formal models of spatial cognition (e.g., Freksa, Brauer, Habel, & Wender, 2000).

Two important influences on contemporary human spatial cognition research originate from studies of the spatial behavior of non-human species. The first of these is the elegant behavioral research carried out by ethologists and psychologists, which has characterized the exquisite capacities of many species for navigation and cognitive mapping, and has provided superb experimental paradigms for elucidating the mechanisms underlying these capacities (e.g., Cartwright & Collett, 1983; Mittelstaedt & Mittelstaedt, 1980; Thinus-Blanc, 1996; Tolman, 1948; Wehner & Wehner, 1986). The second important influence has been the discovery of place cells and head direction cells in the rat (O'Keefe & Dostrovsky, 1971; Taube, Muller, & Ranck, 1990). Besides revealing a surprising degree of sensory, motor, and memorial integration driving the activity of single neurons, the discovery of place and head direction cells has led to new theories about the mechanisms involved in navigation and cognitive mapping.

Human spatial cognition research has established important connections between cognitive psychology and cognitive neuroscience. In a number of joint projects, cognitive scientists and neuroscientists have worked together in an effort to account for the processes that subserve spatial cognition and to identify the neurobiological infrastructure underlying them (e.g., Amorim et al., 2000; Maguire et al., 2000; Mellet et al., 2000). Significant extensions have been developed in order to study how neurological and neuropsychological disorders affect space-related representations and behavior (e.g., Denis, Beschin, Logie, & Della Sala, 2002; Guariglia & Pizzamiglio, 2006).

A growing community of cognitive scientists is currently devoting research programs to spatial cognition. The questions at the heart of today's research include those related to how spatial knowledge is acquired, the format of such knowledge within human memory, how such spatial knowledge is transformed during real and imagined movements (e.g., May, 2004; Mou, McNamara, Valiquette, & Rump, 2004), and the status of the "cognitive map", be it a metaphor or a genuine cognitive entity (e.g., Golledge, 1999; Portugali, 1996). The contribution of verbal information to the construction of spatial representations is an issue that has been flourishing in the recent years, in particular in studies of the role of language in providing directions and conveying information about spatial environments (Bloom, Peterson, Nadel, & Garrett, 1996; Denis, 1997; Hickmann & Robert, 2006) and in studies concerned with whether spatial representations derived from language are functionally similar to those derived from spatial perception (e.g., Avraamides, Loomis, Klatzky, & Golledge, 2004).

Interestingly, some of these studies have been applied to the development of cognitive technologies, such as those intended to assist pedestrians or drivers in navigation and wayfinding tasks (e.g., Allen, 2006). Modern technology is also involved in the study of spatial cognition, through the virtual reality devices, which are now essential tools for behavioral and cognitive research (e.g., Hölscher, Schnee, Dahmen, Setia, & Mallot, 2005; Loomis, Blascovich, & Beall, 1999). Another significant advance in the understanding of spatial cognition has been the documentation of the contrast between the survey and route perspectives and their impact on the encoding and the memory of spatial information (Taylor & Tversky, 1992; Tversky, 2000). Lastly, there have been recent attempts to investigate the similarities and specificities of spatial cognition when it concerns either small-sized configurations, such as those used in psychometric measures of spatial abilities, or the large-scale environments that surround people and constitute navigable spaces (Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006).

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The objective of the editors of this issue was to gather studies that share the same concerns about the nature and function of the representations underlying spatial performance. The approach is predominantly empirical and behavioral, with some pointers towards the issue of the cerebral infrastructure of spatial cognition, although a full discussion of this topic would take more than a single issue of a journal. We have chosen to focus the entire issue on behavioral aspects of spatial cognition. In view of the wide range of sizes of the spaces to which human cognition applies, we concentrated on research addressing processes involved in the spatial cognition of navigable spaces. This does not mean that the articles below are all restricted to navigation strictly speaking, but that the cognitive processes under study all apply to navigable spaces.

The issue opens with two papers that address the question of the nature of the cues that people use when they are learning new environments or remembering locations within these environments. In a study based on the use of an immersive virtual environment, **Foo, Duchon, Warren, and Tarr** (2006) investigated the learning pattern according to which people are assumed to use cartographic-like representations built up from path integration first before switching to reliance on landmarks. Their experiment provides evidence that the learner's dependence on visual landmarks may develop earlier than previously postulated and may be maintained during learning. Their findings support the helpfulness of using a landmark-based strategy, which has the advantage of being computationally simpler than using path integration-based survey knowledge. **Lourenco and Huttenlocher** (2006) contrast the use of landmarks and of the geometric properties of an environment within which people are moving, as cues on which they rely in spatial learning. By using a variety of disorientation procedures, they challenge the view that young children rely primarily on geometrical information to reorient themselves in enclosed spaces and suggest that they actually code information about their own positions relative to the spatial environment.

The papers that follow explore the phenomenon of spatial updating as assessed by judging relative directions, in particular when these judgments are produced after rotating the scene or when the observer has moved around the scene. Typically, response times increase with the angular disparity between judged and encoded views of a scene. **Finlay, Motes, and Kozhevnikov** (2006) report their failure to find any evidence for automatic spatial updating in such situations. Similar increases of response times with angular disparity were found, regardless of whether the scene or the observer had moved. There was no evidence that the representation of the scene was automatically updated when an observer had moved around a scene. In the next article, **May** (2006) reports an investigation of how blindfolded people perform perspective switches on an environment by using their imagination. When participants pointed to objects in a familiar environment while imagining that they were adopting different spatial perspectives as a result of self-rotation, the typical increase in errors and response times was found. What is new is the finding that similar costs were involved in the pointing task whether it was performed in the actual learning place or in a remote testing room. This contrasts with the findings of previous studies that had suggested that the difficulties resulting from imaginal perspective switches are reduced when participants are tested outside the learning place. Lastly, **Valiquette, McNamara, and Labrecque** (2006) investigate the memory of the locations of objects seen in a room, depending on whether the views are or are not aligned with the frames of reference of the environment. The analysis of the judgments of relative direction reveals that spatial memory is biased towards orientations that are aligned with salient orthogonal environmental frames of reference. However, the study also provides fresh evidence that there are limits to the bias towards orthogonal axes in spatial memory.

The next articles focus on the contrast between visual cues and body-based senses, mainly proprioceptive information, in spatial memory. **Riecke, Cunningham, and Bülthoff** (2006) also use a pointing paradigm (in a virtual environment) to assess spatial updating after scene rotation and concomitant physical rotation of the observer. The main idea here consists of testing the efficacy of pure optic flow in spatial updating. The results show that visual cues are sufficient to induce automatic and obligatory spatial updating, irrespective of the physical motion passively applied to the observer. Pure optic flow is not sufficient to achieve effective automatic or obligatory spatial updating. The study by **Cornell and Bourassa** (2006) investigates the representations of the amount of turning accomplished by blindfolded participants invited to walk along curved paths in an outdoor environment. The rate of turning is known to be a determinant of memory of path segments and turns. The analysis of systematic errors in several tasks, such as direction pointing or path drawing, reveals that gradual turning is especially difficult to encode. In particular, kinesthetic cues are not sufficient to create an accurate representation of large radius curves. **Waller and Greenauer** (2006) have designed an experiment intended to contrast the effects of visual, proprioceptive, and inertial information on the acquisition of spatial representations in a large-scale environment. Relying on a variety of measures, such as pointing, distance estimation, and map drawing, they observed very few differences among groups of participants who had access to various combinations of such information. Proprioceptive information produced only a small effect, suggesting that pointing accuracy was better in people who had had access to that type of information.

The next two papers deal with spatial cognition as mediated by various types of symbolic devices. **Shelton and Pippitt** (2006) investigated the differences between navigation and map reading in environmental learning. They found that the contrast between these two modes of learning paralleled the contrast between a changing (route) perspective and a fixed (survey) orientation of the scene. An interesting addition here consisted of creating a hybrid condition, combining the survey perspective with multiple dynamic orientations on a map. An fMRI study suggested that the regions of the brain activated in this new condition include some that are activated by the ground-level (route) condition and others that are activated in the aerial (survey) condition. Language, a more abstract symbolic device, is introduced by **Giudice, Bakdash, and Legge** (2006) in a study which investigated the use of verbal information, with the special feature of providing dynamically-updated descriptions to help blindfolded participants move through a complex large-scale environment. The verbal messages are said to have been updated, as the information described was coupled to the participants' changing positions in the environment. The data for a target localization task provided information that updated verbal information facilitated route navigation and also supported free exploration of a novel environment. Interestingly, the pattern of spatial learning using verbal information proves to be very similar to that obtained using classic visual cues, indicating that the spatial representation based on verbal descriptions was functionally similar to that based on visual experience.

The last two papers also deal with map learning and verbal learning as media for creating mental representations of an environment and pay particular attention to the role of the working memory in the processes investigated. The study by **Coluccia, Bosco, and Brandimonte** (2006) addresses the role of visuo-spatial working memory in various forms of map processing. Map drawing is selectively impaired by a task that taps the spatial component of visuo-spatial working memory, which suggests that this component plays an essential role in learning from maps. A correlational approach provides evidence that performance in simultaneous visuo-spatial working memory tasks predicts the skills in map drawing. Map drawing and map learning are thus shown to be closely connected abilities. The research reported by **Gyselinck, De Beni, Pazzaglia, Meneghetti, and Mondoloni** (2006) examines the processing of a text that describes locations from a route perspective. A task tapping the spatial component of the working memory impaired performance when readers of the text were required to generate visual mental images of the situation being described. No such impairment was observed when the participants were invited to use a verbal strategy based on the repetition of information. In contrast, interference effects resulting from articulatory repetition were similar in the two instruction conditions. The study supports the view that the verbal and spatial components of working memory are independent subsystems specialized in the storage of distinct types of information.

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