A Meta-Analysis on the Correlation Between Measurements of Spatial Tasks and Standardized Tests of Environmental Spatial Abilities

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Background and aims

Previous findings indicate that spatial abilities at different scales of space, e.g. small-scale and large-scale space (Montello and Golledge, 1999, Montello, 1993) are partially dissociated (Hegarty et al., 2006). Traditionally, the attempts to identify and assess these different sets of spatial abilities have focused mostly on small scale spaces, whereas significantly less work has focused on assessing large-scale or environmental spatial abilities. This is unfortunate because the existing psychometric tests for small scale spatial abilities account for only 5% of the variance in the ability to learn large-scale environments (Hegarty and Waller, 2005) and therefore represent poor predictors of environmental learning (Allen et al, 1996; Waller, 2000, 2005).

Given the limited work on developing standardized measures of environmental spatial abilities, such abilities have been investigated through people's performance on *non-standardized* spatial tasks in large scale outdoor spaces (McNamara et al, 2003). A multitude of such tasks have been designed and employed with the intention to measure environmental spatial abilities. However, progress with the development of standardized tests for large scale spatial abilities is currently hindered by a threefold challenge: (i) spatial tasks in large scale spaces are usually complex involving several spatial abilities rather than just one, (ii) several spatial tasks have been employed for assessing the same spatial ability, and (iii) spatial tasks in large scale spaces are strongly coupled with the environment in which they are investigated.

The goal of this meta-analysis is to investigate the relationships between environmental spatial abilities and their measurements, i.e. standardized tests or non-standardized spatial tasks, with the particular aim to identify those spatial tasks which have been successfully and consistently used to measure a particular environmental spatial ability. Our work has focused on identifying strong relationships between specific spatial tasks and environmental spatial abilities as a preliminary step in a larger research agenda aiming towards the development of standardized tests for measuring environmental spatial abilities.

Meta-Analysis

Literature Search and Coding Procedure

Forty nine papers have been initially selected among the papers published in the last 20 years (or less if the journal is newer) in the following peer-reviewed publications: Journal of Spatial Cognition and Computation, Presence: Teleoperators and Virtual Environments, Journal of Environmental Psychology, Intelligence Journal and Journal of Computer in Human Behavior. In addition, an extensive literature search was conducting using Google Scholar™, PsychINFO, ERIC, ScienceDirect and ACM Digital Library.

The criteria for a paper to be included in the meta-analysis consist of the provision of (i) information describing the measurement of environmental spatial abilities, and (ii) data on correlations between a pair of measurement of spatial abilities. Among the initially identified 49 papers, only 8 papers met the above criteria and could therefore be included in the meta-analysis. Although the remaining papers met the first criteria, they failed to provide correlational data.

Each selected paper reports complex experimental study with more than one condition. For the purpose of this analysis, each experimental study was broken down into several independent studies, i.e. one for each condition,, resulting in a set of 102 distinct studies. A standard system was used to code each of these studies, consisting of author, publication, year, spatial abilities, environment, spatial tasks and correlational data. Correlational data between pair of measurements of environmental spatial abilities and performance on spatial tasks were extracted and used for the computation of the size effect. We employed Cohen's (1988) interpretation of effect size: anything greater than 0.5 is large, between 0.5 and 0.3 is moderate, and between 0.3-0.1 is small.

Findings

The environmental spatial abilities captured by these studies include sense of direction, perspective topology, spatial updating, landmark recognition and route traversal. Each of them will be briefly outlined below: *Sense of direction* is the ability of maintaining awareness of one's orientation in large scale space; *Perspective topology* is the ability to acquire a two-dimensional representation and to recognize a bird's eye view of the environment; *Spatial updating* is the ability to keep track of the changing relationship between oneself and external object as one moves through the environment; *Landmark recognition* is the ability to relate to the landmarks along the routes. In addition, we also considered the small scale spatial abilities which account for variance in environmental learning such as mental rotation, perspective taking and spatial memory (Hegarty et al, 2006): *Perspective taking* is the ability to identify changes in the point of view of object or oneself with respect to the environment; *Spatial memory* is the ability to record information about one's environment and spatial orientation, and *Mental rotation* is the ability to manipulate visual patterns.

Findings

The results indicate significant effect size for 46% of studies, medium effect size for 33% of studies and low effect size for 20% of studies. This paper focuses on the description and interpretation of the data leading to high effect size (Table 1).

Table 1: High effect size of correlations between measurements of environmental spatial abilities

Abilities	Author/Year	Measured by Spatial Task or Standardized Test	Environment	Spatial Task/Test or Self-reported performance on spatial tasks	Effect Size
Sense of direction	Hegarty, 2006	SBSOD	Two floor building with 8 landmarks	Accuracy of direction estimates to unseen landmarks in a new environment learnt through direct experience	1.0361
	Prestopnik, 2000	Kozlowski & Bryant sense of direction scale	NA	Survey strategy (self report measure)	0.8729
				Familiarity (self report measure)	0.8471
	Waller,2004	Waller sense of direction scale	Building in a campus	Accuracy of direction estimates to unseen landmarks in a familiar environment	0.8216
	Hegarty, 2006	SBSOD	Two floor building with 8 landmarks	Accuracy of distance estimates to unseen landmarks in a new environment learnt through direct experience	0.7965
				Map sketching of a new environment learnt through direct experience	0.7717
				Accuracy of direction estimates to unseen landmarks in a new environment learnt through video	0.7231
				Accuracy of distance estimates to unseen landmarks in a new environment learnt through video	0.5385
Perspective Topology	Waller,2004	Time taken for recognizing the correct bird's eye view of a learnt virtual environment	NA	Campus familiarity	0.8471
			Building in a campus	Accuracy of direction estimates to unseen landmarks in a familiar environment	0.6521
		Accuracy in recognizing the correct bird's eye view of a learnt virtual environment		Accuracy of direction estimates to unseen landmarks in a familiar environment	0.6992

Abilities	Author/Year	Measured by Spatial Task or Standardized Test	Environment	Spatial Task/Test or Self-reported performance on spatial tasks	Effect Size
Spatial Updating	Waller,2004	Accuracy of direction estimation to unseen landmarks in learnt virtual environment	Building in a campus	Accuracy of direction estimates to unseen landmarks in a familiar environment	0.606
		Time taken for direction estimation to unseen landmarks in learnt virtual environment		Accuracy of direction estimates to unseen landmarks in a familiar environment	0.5608
Landmark recognition	Kirasic, 2001	Correct selection from 64 scenes of 12 scenes with the highest landmark value	NA	Accuracy of location indication of buildings from a previously studied map	0.8471
				Accuracy of patterns abstracted from a figure	0.629
				Accuracy of imagined appearance of playing cards after they are rotated	0.5608
				Accuracy of gestalt completion on drawings	0.5385
				Accuracy of distance ranking to a set of locations in a shopping place	0.5385
Perspective taking-	Kozhevnikov, 2006	Accuracy of direction estimation from imagined orientation	Two floor building with 2 landmark and 2 target building on a campus	Accuracy of tracing a covered route on the floor plan of a learnt environment	0.9526
				Finding a shortcut from the ending point to the starting point of the route, as number of route segments	0.629
				Accuracy of direction estimates to unseen landmarks in a learnt environment	0.606
Spatial Memory	Ondracek, 2001	Proportion of correctly placed colored chips on a blank figure, matching the colored dots on an amorphous figure no longer visible	Textual description of an environment, from survey, route, and vantage perspectives	Proportion of correct placements on a map of stickpins representing objects in an environment	0.7965
				Proportion of correct placements on a map of various locations in respect to the viewer's vantage point.	0.7668
Mental rotation	Kozhevnikov, 2006	Accuracy of identifying invariants in a pair of two-dimensional pictures of rotated three-dimensional geometric forms	Two floor building with 2 landmark and 2 target building on a campus	Accuracy of tracing a covered route on the floor plan of a learnt environment	0.6521
				Accuracy of direction estimates to unseen landmarks in a learnt environment	0.5164

Conclusion

Findings suggest that the most valid tools for assessing environmental spatial abilities are self report-based questionnaires. Indeed, over 30% of correlations of high size effect occur when environmental spatial abilities are captured through self report measurements of sense of direction. Moreover, the three scales of sense of direction correlate significantly with a large array of spatial tasks. Given the inherent subjectivity charactering self assessment, this is an interesting outcome partly explainable through the hierarchical organization of spatial abilities. Sense of direction is a complex environmental spatial ability encompassing several more basic abilities. We conjecture that the more complex an ability is, the stronger its measurements will correlate with a larger range of spatial tasks. While successful at handling complexity, measurements based on self report are limited in their ability to differentiate between the less complex abilities.

In contrast, WALKABOUT is a standardized test that offers objective measurements of two less complex spatial abilities such as perspective topology and spatial updating whose measurements correlate significantly with the ability to point to unseen locations in familiar environments (Waller, 2005). Although the size effect of such correlations is not as large as the one related to sense of direction, the test is still a successful unique attempt to fill the gap in understanding the cognitive components used in acquiring spatial knowledge of large-scale environments.

Because of the complexity of environmental spatial abilities, their relationship with spatial tasks is particularly difficult to disentangle. Findings indicate that measurements of different abilities correlate significantly with performance on the same tasks, and the same ability correlates significantly with performances on different tasks. Although one to one mapping between the measurement of a given ability and its criterion would be useful, it is more realistic to invest effort in developing novel spatial tasks which require a common set of spatial abilities but differ slightly among each other in aspects which require distinct input from different ability. Thus, succeeding in one such task and failing in another will offer an indirect method of assessing the spatial ability which is required by the first task but not by the second one.

Another interesting result is the complexity of the environments employed in these studies. Although holding high face validity, such complexity considerably challenges the investigation of spatial abilities. We conjuncture that the complexity of the environment is related with the complexity of the spatial tasks, and that by simplifying the environment the tasks could be better controlled and spatial abilities better investigated.

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