Analysis of distortions in a mental map using GPS and GIS

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Presented at SIRC 2004 – The 16th Annual Colloquium of the Spatial Information Research Centre
University of Otago, Dunedin, New Zealand
November 29th-30th 2004

ABSTRACT

Mental maps are a cartographic illustration of a person's internal representation of the spatial environment in which they live. They are often used to provide an insight into how different ethnic or social groups perceive their environment. A new method of measuring the distortions present in mental maps is developed and tested using a global positioning system (GPS) and a geographic information system (GIS). Results suggest distortions are apparent the further away subjects travel from their familiar environment and that there are consistent scales at which mental maps operate.

***Keywords and phrases*:** cognitive, student, scale

1.0 INTRODUCTION

Mental maps are cartographic representations of how people differ in their evaluation of places (Tuan, 1975). They have long been of interest to social geographers and psychologists as they can be used to analyse urban areas where there are social or ethnic groups exhibiting different characteristics. They can also provide an insight into the workings of spatial reasoning and how individuals perceive their geographic environment.

Cognitive maps are mental representations of external space and an individual's model of objective reality (Freundschuh, 1998; Golledge and Stimson, 1987, 1997; Hirtle, 1998; Portugali, 1996; Tolman, 1948; Tversky, 1981). A cognitive map cannot be considered to be a direct one-to-one internal representation of an external environment. Cognitive mapping is essentially a way of mentally structuring and interpreting sets of spatial information that exist in different environments which can include not only the observable physical environment, but also memories and images of environments experienced in the past (Golledge and Stimson, 1997). This type of mapping can also include the many varied social, cultural, political and economic environments that have influenced these past memories and the current experience. A mental map can be considered to be a 2–dimensional cartographic representation of an individual's cognitive map.

Previous research has shown that mental maps can be distorted, stretched and pulled with respect to the real place that they represent (Appleyard, 1970; Baird, Merrill, and Tannenbaum, 1979; Golledge and Spector, 1978; Golledge and Stimson, 1997; Gould and White, 1974; Hirtle, 1998; Magana, Romney, and Evans, 1981; Pocock, 1979; Tobler, 1976; Tuan, 1975; Tversky, 2003; Waterman and Gordon, 1984). Waterman and Gordon (1984) introduced a quantitative and relatively simple and rapid technique of measuring distortions in a mental map to show that older subjects drew the most accurate mental maps. They also showed the distortion is caused by an overestimate of distances close to the familiar place of residence and an underestimate of distances in less familiar remote areas.

In this paper, we report what we believe to be the first use of a global positioning system (GPS) in conjunction with a geographic information system (GIS) to measure distortion in mental maps and to establish if there are consistent scales at which mental maps operate. We also report on the mobility of a typical Otago University student.

In recent years GPS and GIS (GPS in particular) has become cheaper, more readily available and easier to use, not only for conducting research, but also to the general public. As a result of this, this present study can also be considered to be a test into whether or not both GPS and GIS can provide an effective and accurate method of conducting research not only into mental maps, but spatial human geography in general.

Two hypotheses are tested in this study: (1) there are consistent scales at which mental maps operate and (2) distortion on a mental map increases with distance from a subject's place of residence (i.e. their home).

2.0 METHOD

Data was collected from two sources: GPS data and the mental map drawn from memory by the subjects. Fifteen subjects (fourteen of whom were students attending the University of Otago, Dunedin, New Zealand) participated in the study. To maintain anonymity, each subject was allocated a unique ID number. The GPS data collection required each subject to carry around a Garmin GPS 72 for seven days. The GPS recorded their movement every 20 seconds as point coordinates and was stored in the GPS track log. This data was subsequently used to represent the subject's true spatial environment.

On completion of the seven-day period, subjects were asked to draw to the best of their ability a mental map on an A3 sheet of paper, of their movements for the previous seven days. Subjects were told to include routes travelled and specific landmarks visited. No other guidance was given, in order to minimise potential interference with the results. The mental maps were then scanned using a digital scanner, georeferenced against the GPS data and digitised into a series of Shapefiles, using ESRI *ArcGIS 9*.

The main assumption in the present study is that subject's have an intimate knowledge of their "home" environment ("home" being defined as the area in which they spend the majority of their time, typically where they eat, sleep and live). As a consequence of this assumption, four control points used when georeferencing were placed within close proximity of the subject's "home" location. The locations of control points were chosen in a way that had the least impact on the shape, topology and hence distortion of the mental map.

It is important to note that locations of control points were also selected so that they had small residual error values. In ESRI *ArcGIS 9*, the distance between the transformed point and the actual point is known as the residual error. The total error is computed by taking the root mean square (RMS) sum of all the residuals to compute the RMS error. This value describes how consistent the transformation is between the different control points.

Both the mental map and GPS data were reduced to a finite number of nodes. The digitised mental map was overlaid with the GPS data and points that could be identified on both maps were used as node locations. Each node was given a unique ID number, making sure that corresponding points had the same ID number on both the mental map and GPS datasets.

Three distortion values were calculated: absolute distortion, radial distortion and lateral angle distortion, as shown in Figures 1 - 3 and Equations 1- 3 respectively. The absolute distortion represents the distance between the equivalent GPS and mental map nodes (Figure 1).

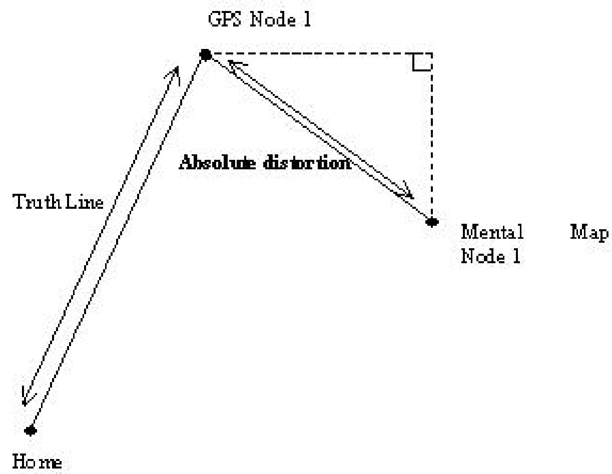

Figure 1: Use of Pythagoras theorem to calculate the absolute distortion

Absolute Distortion = $\sqrt{(MM_x - GPS_x)^2 + (MM_y - GPS_y)^2}$ ***Equation (1)***

where MM_x = *x coordinate of mental map node*

MM_y = *y coordinate of mental map node*

GPS_x = *x coordinate of GPS node*

GPS_y = *y coordinate of GPS node*

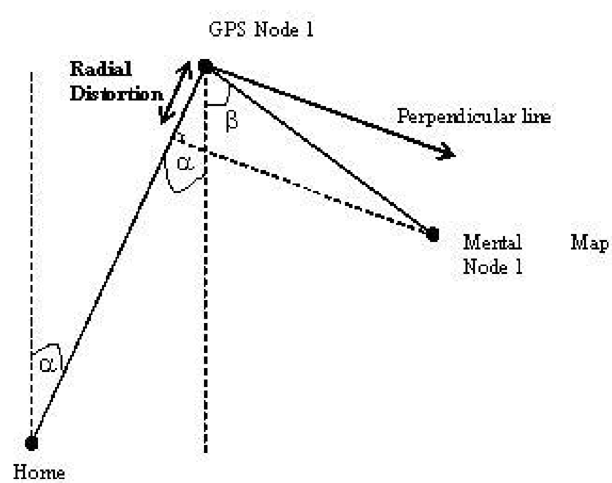

Figure 2: Demonstration of the position and calculations of the radial distortion

tan α = $\frac{Home_x - GPS_x}{Home_y - GPS_y}$

tan β = $\frac{MM_x - GPS_x}{MM_y - GPS_y}$

Radial Distortion = Absolute Distortion cos (Angle°) **Equation (2)**

The radial distortion represents the radial distance between the two nodes and the lateral distortion angle represents the angle between them, relative to "home". Figure 2 is an example of how the distance to a node could be underestimated, as the distance from the mental map node to "home" is less than the equivalent GPS node to "home" distance. Accordingly, the node was assigned a negative distortion value. If the mental map node was further than the GPS node from "home", it was assigned a positive distortion value. This approach was used to ensure that any distortions of each mental map node could be identified relative to the equivalent GPS node.

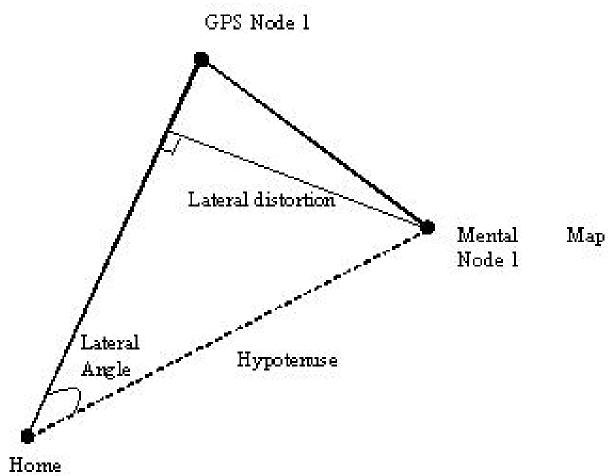

Figure 3: Example of the lateral distortion angle is and how it was calculated

Lateral Distortion = Absolute Distortion sin (Angle°)

Hypotenuse = $\sqrt{(MM_x - Home_x)^2 + (MM_y - Home_y)^2}$

Lateral Angle = sin $\left(\frac{LateralDistortion}{Hypotenuse}\right)$ **Equation (3)**

Figure 3 is an example of lateral distortion angle where the mental map node was in a clockwise direction relative to the Truth line. In this instance, the angle was allocated a positive value. If the mental map node was in an anti-clockwise direction, it was allocated a negative value.

The interpolation method of kriging was used to produce absolute, radial and lateral angle distortion surfaces for each mental map.

3.0 RESULTS

The shape and size of the mental maps drawn varied between subjects. Figure 4 is an example of the mental map drawn by subject 1341, along with the georeferenced and digitised version of this map is displayed in Figure 5.

Figure 4: Mental map drawn by subject 1341

The node files are also shown figure 5. Each node has a unique identification number. The triangle shaped nodes represent the predicted location of a point and the circle shaped nodes the true location. For example, the triangle node labeled "2" is where the subject thought the intersection of the road was, and the circle node labeled "2" is the true location of it, as specified by the raw GPS data.

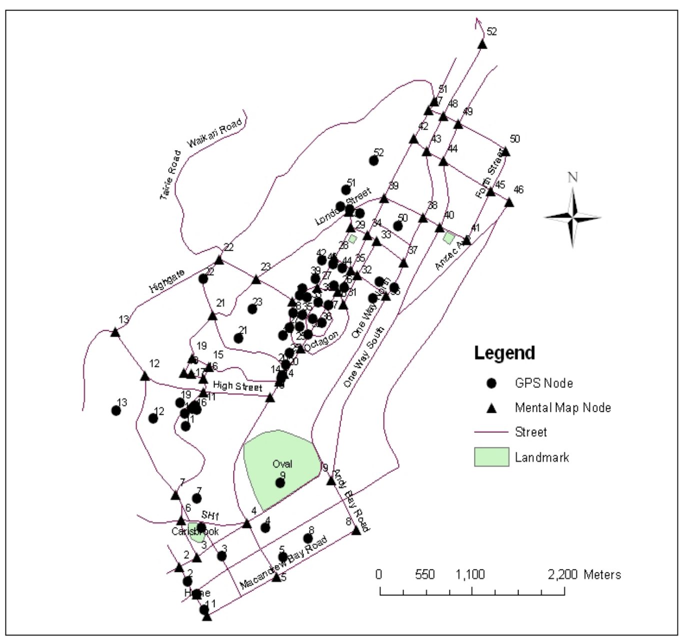

Figure 5: The digitised form of the mental map drawn in Figure 4, showing both the mental map and GPS nodes

The distortion map in Figure 6 represents the radial distortion present in the mental map drawn in Figure 4. The dark area in the middle represents where the subject underestimated distance and the area outside of this is where the subject overestimated distance. Home is located on the boundary of zero distortion.

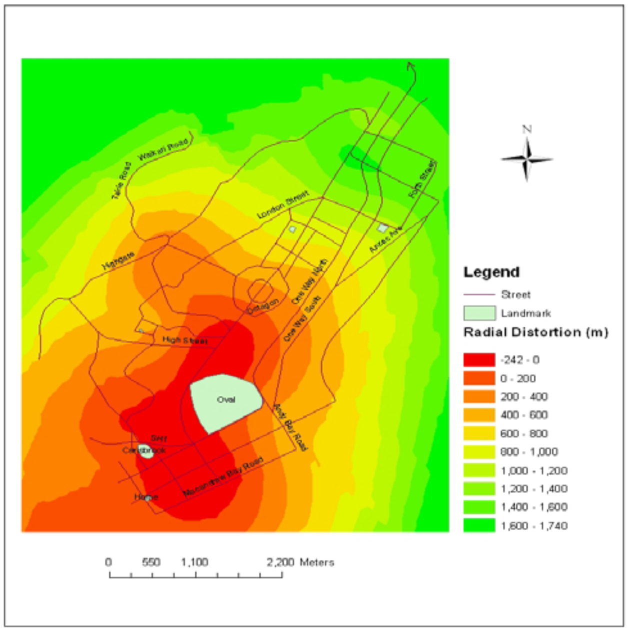

Figure 6: Radial distortion map arising from the mental map drawn by subject 1341

The absolute and lateral angle distortions were also interpolated to produce distortion surfaces. The absolute distortion did not have a direction, so all the distortion shown in Figure 7 for example, is positive. The absolute distortion in this map had a definite pattern, in that it increased in a radial direction the further the distance the subject was from Home.

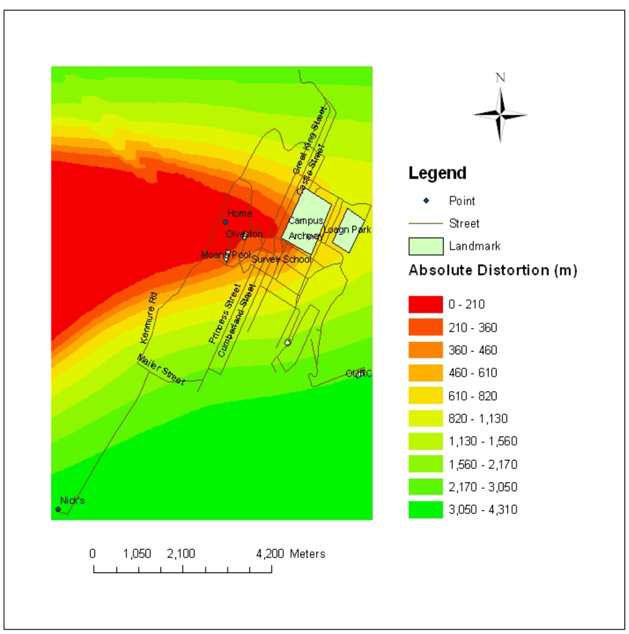

Figure 7: Absolute distortion map arising from the mental map drawn by subject 6748

The distortion surface in Figure 8 illustrates that the dark area in the lower right hand corner of the map contained positive lateral distortion angles. This means that the objects drawn in this section of the map were drawn in a clockwise direction, relative to the Truth line. The lighter area indicates the subject drew the objects in that area in an anticlockwise direction, also relative to the Truth line.

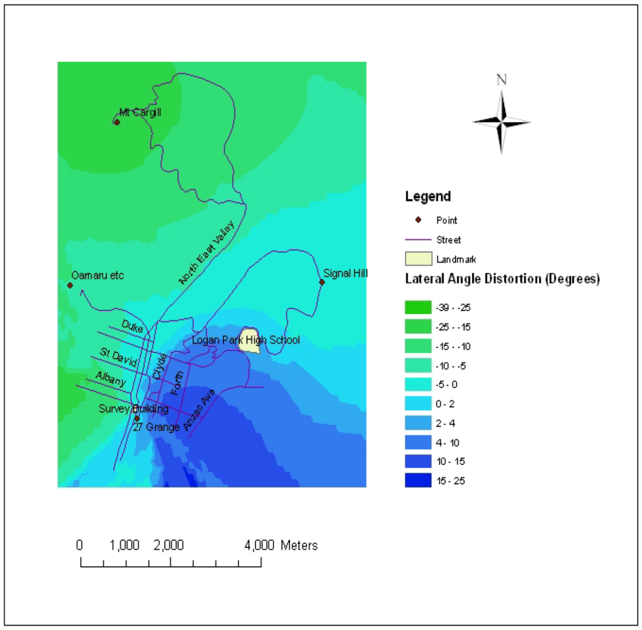

Figure 8: Lateral angle distortion map arising from the mental map drawn by subject 7786

The data presented in the Table, is a summary of the statistics for each subject and is representative of the maps drawn at the scale that covered the limits of Dunedin City. The median was used to avoid the influence of outliers. The radial distortion closest to zero was –7.83 for subject 2341.

Table - – Summary of the median distortion statistics for each subject

Subject ID	**Radial Median**	**Lateral Median**	**Aboslute Median**	**Radial R^2**
2341	-7.83	-7.17	350.04	0.003
5934	11.40	14.56	255.28	0.256
7786	34.19	-1.64	144.70	0.161
1492	65.90	-5.91	172.24	0.254
9688	99.69	-1.33	681.72	0.708
1623	99.82	-18.20	911.80	0.036
8343	246.73	2.35	305.34	0.419
4432	-249.13	2.49	510.20	0.590
5361	-320.34	-3.86	499.66	0.638
3341	363.54	-2.83	416.33	0.283
6748	550.22	9.23	707.34	0.537
1341	555.91	4.23	611.40	0.655
6529	-666.32	0.22	1722.55	0.990
1236	-755.68	-4.16	867.52	0.325
1819	-1494.23	-16.35	1790.90	0.084

4.0 DISCUSSION

The first hypothesis tested in this investigation was that there are consistent scales at which mental maps operate. Out of the 15 subjects that participated in this study, five drew three different maps, four drew two and the remaining six drawing drew only one map. In general there appeared to be three different scales at which the maps were drawn. The smallest scale maps were drawn at a scale that included roads, towns and cities (drawn by subjects who had travelled outside of Dunedin City). The middle scale maps were drawn at a scale that typically included streets and buildings. The largest scale maps were drawn in a manner that included objects that were at a city block level. These maps were drawn in areas that the subject had spent a large amount of time in, such as the University of Otago campus and the subject's neighbourhood. From these findings it is reasonable to say that the scale at which mental maps are drawn is partly influenced by so called geographic "objects". These objects typically being either man-made (e.g. Dunedin City, streets) or natural (South Island).

Subjects subconsciously attempted to keep the scale of a map constant. For example, they did not attempt to draw the route they travelled between two cities on the same map on which they drew their route from their Home to campus. As a result of this, the number of maps drawn by each subject appeared to be dependent upon the extent of their travels. Subjects who traversed a larger area drew more maps than those who covered less. The six subjects that drew one map only, drew them at either the city or neighbourhood scale. Three of the four subjects that drew two maps drew one map at the city scale and one map at the neighbourhood scale. Further to this, four of the five subjects who drew three maps drew one map each at the country, city and neighbourhood scales respectively. As a result of these findings, it is reasonable to accept the first hypothesis and state there is in fact a set of consistent scales at which mental maps operate.

The second hypothesis tested was that distortion increases with distance from a subject's Home. The distortion maps support this hypothesis. However, the magnitude and sign (negative or positive) of this distortion differs between subjects. When examining the maps drawn at the city scale, eight subjects initially overestimated distances closer to Home and then underestimated with increasing distance from Home. Five of the subjects did the opposite: they underestimated and then overestimated distance. The remaining two subjects either constantly overestimated or underestimated distance.

The distance at which the distortion changed from positive to negative (i.e. had zero distortion), or vice versa, ranged from 200 m to 2800 m with a median of 750 m. Therefore there would appear to be a "buffer" area around Home in which a subject's perception of distance changes and this distance varies among subjects. The ratio of this "buffer" distance to distance travelled was not constant across all subjects.

Waterman and Gordon (1984) concluded that distortion is caused by an overestimate of distances close to the place of residence and an underestimate of distances in more remote areas. Although this research focused on maps drawn at the country scale, their results are similar to those of the present study. Eight of the subjects initially underestimated distances and then overestimated them.

With regard to orientation as calculated by the lateral angle distortion, there is no obvious trend amongst any of the present subjects. The mental maps drawn by the subjects had both negative and positive lateral distortion angles. Although no definite trend was apparent, an interesting observation was made in relation to the orientation of maps when they were drawn, in that how the city scale maps were drawn was largely dependent upon the predominant direction of travel. For example, a subject who travelled south to get to campus drew their map with south at the top of the paper and north at the bottom. Subject who lived in South Dunedin and travelled north to get to campus drew north at the top of the paper. Further to this, a subject who travelled from Roslyn to campus, in a west-east direction, drew their map with west at the top of their map. Therefore it is reasonable to say the mental map at the city scale is a "person-orientated" map, rather than the conventional north orientated map. However, it is interesting to note that maps drawn at the country scale were drawn using the conventional method of having north at the top of the map.

From a geographical viewpoint, results support the theory discussed by Tuan (1977) that people have a sense of "place" associated with spatial areas to which they have a certain psychological attachment. Tuan suggested that when space feels thoroughly familiar to us, it has become "place". This statement is supported by the fact that subjects in this present study drew areas in which they had spent more time in greater detail. In the context of Tuan’s suggestions, the areas drawn in more detail, typically campus or the subject’s neighbourhood, have become “place” rather than “space” for the subjects.

5.0 CONCLUSIONS AND FUTURE RESEARCH

The present results suggest there are consistent scales at which mental maps operate, with subjects’ drawing maps at country, city and local scales. Distortion increases (both positively and negatively) with increased distance from a subject’s Home environment.

All but one of the subjects participating in this research was a student. After examining the extent of travels, it is appropriate to say that students have a mobile lifestyle, even during term time when they have lectures and other formal commitments. Within the time period of the data collection (i.e. seven days), five out of the fifteen subjects travelled outside Dunedin City to other parts of New Zealand. Therefore it is reasonable to conclude that students are mobile and lead a lifestyle in which they are prepared to travel around and visit different places.

The methodology used in the present study is unique, as GPS and GIS do not appear to have been used in previous studies of mental maps. The present project would appear to offer an improvement over this previous research, in that it resolves the problem of scale and lack of accuracy typically associated with the study of mental maps. In particular, it provides an example of how GPS and GIS can be used in spatially related sciences such as human geography. The use of GPS proved to be successful, in that it was easy to use and provided accurate datasets, with few technical difficulties. The GIS provided a platform in which the data could be stored, digitised, georeferenced and distortion surfaces interpolated. Therefore it is reasonable to say that the use of GIS was also successful as it provided a method of analysis and visualisation of the data.

As only fifteen subjects participated in this research, it is important to note that the conclusions reached can only be tentative. For more definitive and accurate conclusions to be established, future research should use a greater number of subjects.

Other factors that could be investigated in future research include the time lapse between the actual travel and when the map was drawn, which would test the effect of time on spatial memory recall. The impact of the length of the trips on the maps drawn could be investigated and the possibility of non-linear correlations between distortion and distance could also be explored. In addition, a more rigorous comparison with other methods that measure distortion in mental maps, such as multi-dimensional scaling and the Waterman and Gordon method, could be carried out.

The conclusions reached in this could be used for practical applications such as urban development planning. The conclusion that people’s perception is distorted beyond their familiar environments could be taken into account when people are describing or estimating distances, for example, when people are tramping or undertaking other outdoor activities.

ACKNOWLEDGEMENTS

Acknowledgement must be given to the Spatial Information Processing Theme (for providing funding for the study) and the technical staff in the Information Science Department, both at University of Otago, Dunedin, New Zealand. Thanks must also be given to the subjects who participated in the study and to Pip Forer, from University of Auckland, for providing some useful guidance.

REFERENCES

Appleyard, D. (1970) Styles and methods of structuring a city, *Environment and Behaviour, 2*, pp. 100-118.

Baird, J. C., Merrill, A. A. and Tannenbaum, J. (1979) Studies of the Cognitive Representation of Spatial Relations II, A Familiar Environment. *Journal of Experimental Psychology, 108*,pp. 92-98.

Freundschuh, S. M. (1998) The Relationship Between Geographic Scale, Distance, and Time as Expressed in Natural Discourse, In M. J. Egenhofer and R. G. Golledge (Eds.), *Spatial and Temporal Reasoning in Geographic Information Systems* (pp. 131-142). New York: Oxford University Press.

Golledge, R. G. and Spector, A. N. (1978) Comprehending the Urban Environment: Theory and Practice, *Geographical Analysis, 10*, pp. 403-426.

Golledge, R. G. and Stimson, R. J. (1987) *Analytical Behavioural Geography*, New York: Croom Helm.

Golledge, R. G. and Stimson, R. J. (1997) *Spatial Behaviour: A Geographic Perspective*, New York: The Guildford Press.

Gould, P. R. and White, R. R. (1974) *Mental Maps*: Penguin.

Hirtle, S. C. (1998) The Cognitive Atlas: Using GIS as a Metaphor for Memory, In M. J. Egenhofer and R. G. Golledge (Eds.), *Spatial and Temporal Reasoning in Geographic Information Systems* (pp. 263-274). New York: Oxford University Press.

Magana, J. R., Romney, A. K. and Evans, G. W. (1981) Scaling Techniques in the Analysis of Environmental Cognition Data, *Professional Geographer, 33*, pp. 294-301.

Pocock, D. C. D. (1979) The Contribution of Mental Maps in Perception Studies, *Geography, 64*, pp. 279-287.

Portugali, J. (1996) *The Construction of Cognitive Maps*, Boston: Kluwer Academic Publishers.

Tobler, W. R. (1976) The Geometry of Mental Maps, In R. G. Golledge and G. Rushton (Eds.), *"Spatial Choice and Spatial Behaviour" - Geographic Essays on the Analysis of Preferences and Perceptions* (pp. 69-81): Ohio State University Press.

Tolman, E. C. (1948) Cognitive maps in rats and men, *Psychological Review, 55*, pp. 189-208.

Tuan, Y. (1975) Images and Mental Maps, *Annals of the Association of American Geographers, 65*, pp. 205-213.

Tuan, Y. (1977) *Space and Place: the perspective of experience*, Minneapolis: University of Minnesota Press.

Tversky, B. (1981) Distortions in Memory for Maps, *Cognitive Psychology, 13*, pp. 407-433.

Tversky, B. (2003) Structures of Mental Spaces: How People Think About Space, *Environment and Behaviour, 35*, pp. 66-80.

Waterman, S. and Gordon, D. (1984) A Quantitave-Comparative Approach to Analysis of Distortion in Mental Maps, *Annals of the Association of American Geographers, 36*, pp. 326-337.