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The effects of spatial and locational cueing on the analysis of aggregate cognitive mapping data

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Abstract. The authors explore the effects of spatial and locational cueing upon the aggregated results of cognitive mapping data. Using four experimental data sets they demonstrate that locational cueing introduces random error into the analysis and that spatial cueing increases the relative and absolute accuracy of spatial products (external representations of spatial knowledge). These effects are consistent regardless of whether individual or place cognition is assessed. As such, location and spatial cueing compromise both construct and convergent validity, and the integrity of the conclusions from previous studies on cognitive mapping are brought into question. It is suggested that a multidata collection, multidata analysis approach should be adopted to highlight and compensate for these methodological weaknesses.

1 Introduction

Cognitive mapping involves the description of the way individuals store and process geographic information. To gain and examine such knowledge, researchers use carefully controlled experiments to measure factors such as distance and direction estimates, the relative and absolute location of places, and wayfinding ability. In general, geographers traditionally try to discover the amount of information known and the factors that affect what is learnt and remembered. Psychologists, on the other hand, tend to study the processes used in thinking about geographically based tasks and how our knowledge is stored (its structure) and in what form (for example, images or words) (Kitchin, 1994a).

Typically, cognitive mapping data are derived from individual responses and then analyzed in one of three ways: (1) the individual data sets are analyzed separately (disaggregation); (2) the individual data sets are averaged and then analyzed (collective aggregation); and (3) the individual data sets are analyzed and the results averaged (individual aggregation). The relative advantages and disadvantages of these aggregation strategies are discussed elsewhere (Kitchin and Fotheringham, 1997). In this paper we concentrate on exploring the effects of spatial and locational cueing on aggregated studies of cognitive mapping. Spatial cueing refers to the amount of spatial information provided to the respondent. For example, an exercise in which respondents are asked to locate towns and cities has high spatial cueing when many spatial cues, such as the coastline or a road network, are provided to the respondents. Locational cueing refers to the number of designated places a respondent has to locate in an exercise. High locational cueing occurs when a respondent is given a set of specific places to locate: low locational cueing occurs when the respondent has an unconstrained choice of which places to locate.

An understanding of the role of these methodological nuances is particularly important if we are to increase the construct and convergent validity of cognitive mapping research and thus increase the integrity of the conclusions drawn from the research. Construct validity is concerned with making methodology more reliable and experimentally sound so that the method measures what it is supposed to and the results are consistent over time. Convergent validity is concerned with the agreement of conclusions reached via different research methodologies. If two methodologies are designed to test the same hypotheses and they produce different answers then the convergent validity is weak. This brings the construct validity of the methodologies into consideration. Either one test is producing true results and the other is suspect or they are both suspect methodologies. Determining which method is correct is a difficult task, often involving the inclusion of another, or several, methodologies. Spatial and locational cueing provide useful means by which to investigate construct and convergent validity because the results of cognitive mapping exercises are often sensitive to the conditions under which the exercises are conducted.

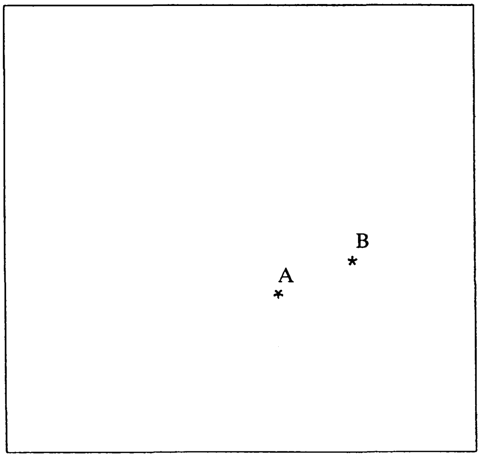
2 Strengthening construct and convergent validity

There are a number of factors which conspire to weaken the construct and convergent validity of cognitive mapping research. In particular, some researchers have noted that the nuances in the design of a methodology can have serious effects on the results from a study. For example, Pocock (1972) found that varying the size of the paper altered the sketch map responses of respondents. Cadwallader (1979) and Montello (1991) have discussed the design issues of methodologies to measure distance cognition. Cadwallader (1979) found that there were contextual factors operating, where the length and orientation of the scales, the cues used, and the order of the cues could affect the responses given. Montello (1991) concluded that researchers could potentially draw inaccurate judgments about individuals' ability to estimate distances as a result of the nature of the tests they had given their respondents. Phipps (1977) similarly found that the magnitude of the distance scales used affected the results gained. Ferguson and Hegarty (1994) suggest that the order of information requested can have a large effect upon the results gained, especially in text-based tasks where places mentioned first are most likely to become cognitive anchors. Similarly, Denis and Zimmer (1992) note that the style in which a passage is written could have serious effects on the resulting spatial products. It has been suggested that the conclusions drawn from configurational knowledge experiments can also be dependent on the methodology used (Bryant, 1984; Kitchin, 1996). Thirteen tests designed to measure respondents' cognitive map knowledge were found to produce differing results and in some cases alternative conclusions (Kitchin, 1996).

In the following discussion we illustrate that the method of data collection used in studies of spatial cognition may well have important implications for the results gained, leading to reduced integrity. At present very little is known about the specific mechanics of how methodological design affects the resulting outcomes. In this paper we provide an examination of the effects of methodological differences on spatial products by comparing the results gained from four tests of spatial cognition which vary only in the amount of spatial and locational cueing given to respondents.

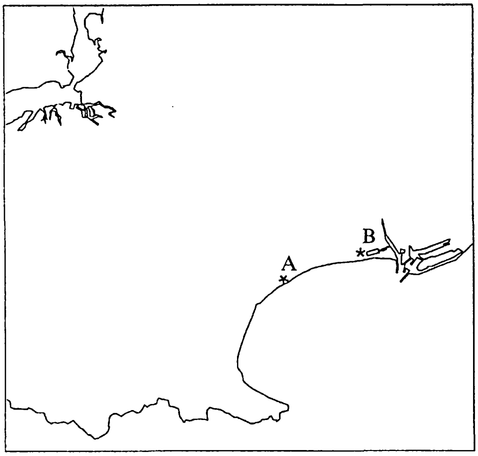
3 Experimental data

As part of a study assessing students' configurational knowledge of the Swansea region in the United Kingdom, 85 students were asked about the location of places within the region with use of four different spatial cued response (SCR) tests (figure 1). In the first (SCR1), 19 students were asked to locate any places they wished (low locational cueing) given only the locations of the Geography Department at the University of Wales, Swansea, and the Quadrant Bus Station to guide their placements (low spatial cueing).



Spatial cued response test 1 (SCR1, sample size $n = 19$): try and add to the base map by placing a point where you think other places and landmarks are in relation to the Geography Department (A) and the Quadrant Bus Station (B).
Spatial cued response test 2 (SCR2, $n = 19$): try and add to the base map by placing a point where you think the 25 listed places and landmarks are in relation to the Geography Department (A) and the Quadrant Bus Station (B) (a list was provided to each respondent).

(a)



Spatial cued response test 3 (SCR3, $n = 14$): try and add to the base map by placing a point where you think other places and landmarks are in relation to the Geography Department (A), the Quadrant Bus Station (B), and the coastline.
Spatial cued response test 4 (SCR4, $n = 33$): try and add to the base map by placing a point where you think the 25 listed places and landmarks are in relation to the Geography Department (A), the Quadrant Bus Station (B), and the coastline (a list was provided to each respondent).

(b)

Figure 1. Four spatial cued response tests: (a) no coastline shown, (b) coastline shown.

In the second (SCR2) 19 students were given the same map (low spatial cueing) but had to locate 25 named places (high locational cueing). In the third test (SCR3) 14 students were asked to complete the same task as SCR1 (low locational cueing) but were also given the coastline to guide their responses (high spatial cueing). In the fourth test (SCR4) 33 students completed the same task as SCR2 (high locational cueing) and were also provided with a coastline to guide their responses (high spatial cueing). In the two tests with high locational cueing (SCR2 and SCR4) where students had to locate 25 given places, each respondent was also asked to circle the places they felt they had guessed and rate their familiarity with the place on a scale of 0 – 5, with 0 representing total unfamiliarity and 5 representing high familiarity. Given that respondents were matched for educational ability and familiarity (all had only been resident in Swansea for 9 – 10 weeks) one might expect the responses to be most accurate in the third test (SCR3) where more spatial information was provided and where they could choose which places to locate. Correspondingly, the results from the second test (SCR2), where people were instructed which places to locate (regardless of whether they knew the location) and were provided with minimum spatial information, might be expected to produce the least accurate results.

To explore further any potential effects of familiarity caused by spatial and locational cueing the experimental data from tests SCR2 and SCR4, where the places to be located were given and where students were asked to rate their familiarity with each place, were analyzed at four different levels. The resulting subdatasets were differentiated in terms of the number of locations they contain. Subdataset A contains data on the cognitive locations of all 25 places. In subdataset B the locations of all places reported as 'guessed' by the respondents were eliminated. In subdataset C those places that scored a familiar rating less than 2 (unknown or low familiarity places) were excluded; and in subdataset D those places scoring a familiar rating less than 4 (unknown, low, and medium familiarity places) were excluded.

4 Methodology and results

Our intent in this paper is to explore the effects of spatial and locational cueing on both individual and place cognition using the four experimental datasets described above. Individual cognition relates to the opinion of one respondent as to the location of a place whereas place cognition is the consensus opinion of a group of respondents about the location of a place. In terms of methodology we follow our earlier work (Kitchin and Fotheringham, 1997) in which we reported that an individual aggregation strategy, whereby cognitive data from individuals are analyzed separately and the results averaged, is better for studying *individual cognition* and that a collective aggregation strategy, in which cognitive data about a place's location are averaged first then analyzed, is better for studying *place cognition.*

4.1 Individual cognition

Individual cognition is assessed here by the technique of bidimensional regression, which is essentially ordinary least squares (OLS) regression extended to two dimensions and can be used to measure the degree and direction of any association between two sets of coordinates (Tobler, 1965). In this case the two sets of coordinates correspond to objective (or real) space and to cognized space so that

$$\begin{pmatrix} u_j \\ v_j \end{pmatrix} = \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} + \begin{pmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{pmatrix} \begin{pmatrix} x_j \\ y_j \end{pmatrix} + \begin{pmatrix} e_j \\ f_j \end{pmatrix}, \tag{1}$$

where $\{u_j, v_j\}$ are the cognized coordinates of place j, $\{x_j, y_j\}$ are the actual coordinates, and e_j and f_j are the errors. The parameters a_1 and a_2 are analogous to the intercept term of OLS regression and perform the translation, and the scaling and the rotation are accomplished by the matrix of b_{ij} values (analogous to the slope coefficient in OLS regression). A rigid Euclidean rotation is maintained by constraining b_{12} to equal $-b_{21}$, and by constraining $b_{22} = b_{11}$ one ensures the scale on both the axes is adjusted by the same amount and thus the regression grid remains equilateral (Murphy, 1978).

The output from bidimensional regression analysis consists of a series of statistics which relate the cognitive environment to the real environment. The r^2 value represents the measure of association between the two configurations; the *scale* is an index that measures the scale change needed to produce the best fit, with a value less than one indicating that cognitive space needs to be contracted to fit the real-world space and a value greater than one indicating that the cognitive space needs to be expanded; the *angle* is the angle by which the coordinate axes must be rotated to produce the best fit, with a positive value indicating a counterclockwise rotation and a negative value indicating a clockwise rotation; a_1 is the horizontal translation, with a positive value indicating a west-to-east shift and a negative value indicating an east-to-west shift; a_2 is the vertical translation, with a positive value indicating a south-to-north shift and a negative value indicating a north-to-south shift (Lloyd, 1989).

Table 1. Bidimensional regression results of the four spatial cued response (SCR) datasets.

	SCR dataset			
	1	2	3	4
r^2	0.80	0.55	0.88	0.52
Scale	0.70	0.80	0.99	0.82
Angle	−16	−26	−2	−5
a_1	300	350	10	100
a_2	5	−100	−50	25

Note: for details of the four SCR tests, see figure 1; r^2, measure of association between the two configurations; scale, index to measure the scale change needed to provide the best fit; angle, angle by which the axes must be rotated to provide the best fit; a_1, horizontal translation; a_2, vertical translation.

These statistics are now discussed for each of the four experimental datasets described above (SCR1 – SCR4) and for the four subdatasets (A – D) of tests SCR2 and SCR4. All the results were generated using the CMAP package (Kitchin, 1994b). Table 1 provides the individual aggregated bidimensional regression values for each of the four experimental datasets (SCR1, SCR2, SCR3, SCR4). Figure 2 (over) portrays the results from subdatasets (A – D) of tests SCR2 and SCR4 in which differences between cognized and actual locations are analyzed at each subdataset level.

The results indicate the extent to which location and spatial cueing have an effect upon the bidimensional regression variables calculated. The effects of locational cueing are most evident in table 1 when comparing the r^2 values. It is clear that the r^2 values from tests SCR1 and SCR3, where respondents could choose which places to locate, are higher than those of SCR2 and SCR4, where respondents were constrained to locate all the places listed. Two sample t-tests of the individual r^2 values confirm that these differences are significant (table 2). These differences are presumably a result of individuals being asked to locate places with which they are unfamiliar, and this introduces random error into individual datasets. These errors are not removed by the strategy of aggregation as each dataset is analyzed individually and the results then aggregated. The effects of locational cueing are not as evident when comparing the scale, angle, a_1 and a_2 values as these variables are much more affected by spatial cueing. In this case, the spatial cueing effect of the coastline (SCR3 and SCR4) leads to reduced scaling, rotation, and translation effects. Here, the coastline acts as a major spatial reference. The differences in angle and a_1 are the result of respondents cognizing that the coastline was 'flatter' or 'shallower' than in reality, removing much of the curve of the bay in their spatial products, so that it gained a predominantly east – west orientation. As a result, respondents consistently cognized that Mumbles

Table 2. Two-sample t-tests comparing spatial cued response (SCR) tests SCR1 – SCR4.

	SCR1	SCR2	SCR3	SCR4
SCR1		5.47 (0.000)	−2.68 (0.013)	5.64 (0.000)
SCR2			7.76 (0.000)	0.46 (0.65)
SCR3				7.72 (0.000)
SCR4				

Note: for details of the four SCR tests, see figure 1.

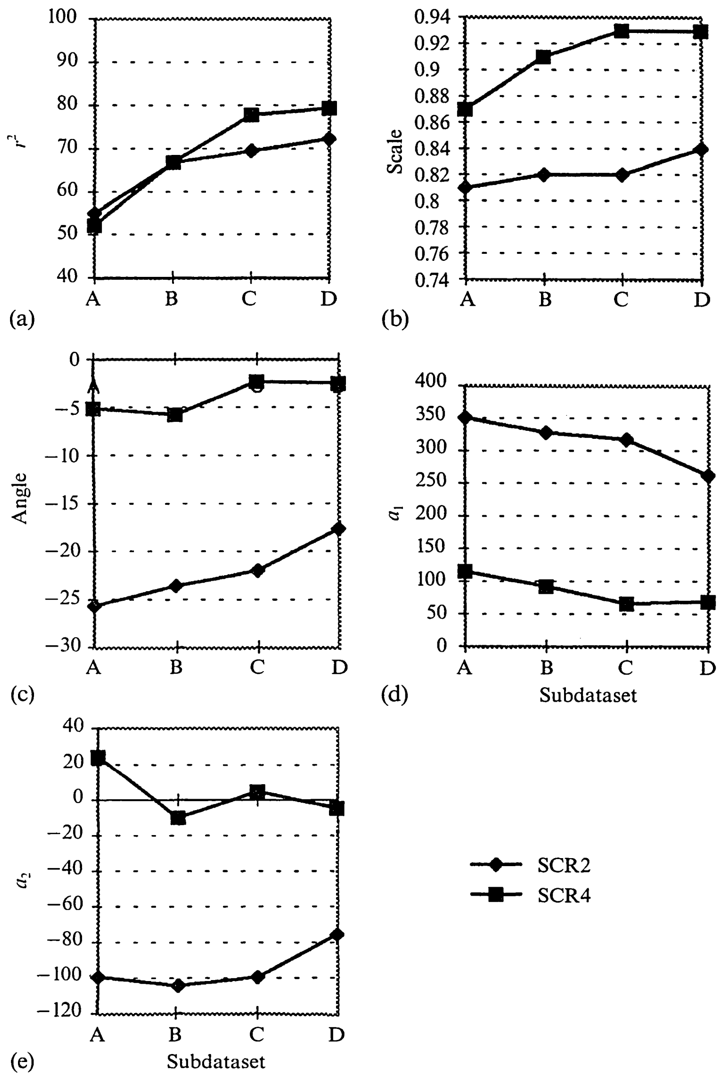


Figure 2. Bidimensional regression results for subsets A–D of SCR2 and SCR4 datasets: (a) measure of association between the two configurations, r^2; (b) scale index, measuring the scale change needed to provide the best fit; (c) angle, measuring the angle by which the axes must be rotated to provide the best fit; a_1, the horizontal translation; and (d) a_2, vertical translation, plotted against subdatasets A–D. Note: A, data on the cognitive locations of all places; B, data on all places reported as guessed; C, data on places which were unknown or of low familiarity; D, data on unknown places or of low to medium familiarity. For details of the spatial cued response (SCR) tests 2 and 4, see figure 1.

Pier was to the west of the University rather than directly south. This one error led to severe skewing and rotation across the spatial product.

The effect of locational cueing is demonstrated in figure 2 where the subdatasets (A–D) represent the removal of increasing amounts of error caused by respondents having to locate places with which they were unfamiliar. Subdataset A contains the results of all 25 places being located, whereas subdataset D contains only the results of places with which the respondents said they were 'very familiar'. As expected, the bidimensional regression results for both SCR2 and SCR4 exhibit an improvement in overall cognitive ability as familiarity increases. For example, the r^2 values for both SCR2 and SCR4 demonstrate a marked improvement across the four subdatasets, making the statistics for group D similar to the SCR1 and SCR3 results in which individuals located only places of their choosing. This improvement is mirrored in the other variables as the residual error is removed from individuals' spatial products.

Although the effects are evident between the scale, angle, and a_1 and a_2 variables, it is only with the removal of the residual error created by locational cueing across the four subdatasets that the effects of the spatial cueing on r^2 values is revealed. In the case of the r^2 value, it seems that the high residual error introduced by the locational cueing masks differences created by differential spatial cueing. When this residual error is removed through the removal of placements which were guesses and unfamiliar to the respondents, the effect of the spatial cueing is revealed. Given these results it is possible to suggest that locational cueing has increased the accuracy of the spatial products by 25% – 30%, and spatial cueing added another 5% – 10%. Therefore, it is clear that these tests, although similar in nature, can produce different results and conclusions. For example, the conclusions drawn from SCR2 and SCR3, where r^2 values differed by a third (0.34), would digress substantially.

4.2 Place cognition

Bidimensional regression provides statistical evidence concerning the relationship between two sets of coordinates. However, because it uses only the aggregated individual coordinates it does not detail the variance in how each individual place was located. To assess place cognition, magnitude shift and standard deviation ellipses can be calculated. The magnitude shift is the distance from the average cognitive location of each place $\{u_j, v_j\}$ to its equivalent real-world location $\{x_j, y_j\}$. A standard deviation ellipse represents the individual dispersion inherent in the grouped estimate of a particular location, with the shape of the ellipse representing the main axes of the dispersion (Golledge and Spector, 1978). By plotting the magnitude shift and standard deviation ellipses it is possible to observe the place cognition of an area, although it is often difficult to discern substantial differences in such plots when large numbers of ellipses are drawn. For this reason we have chosen to examine the differences in the magnitude shift and standard deviation ellipses statistically.

In figure 3 (over) the results of two-sample t-tests comparing the magnitude shift and ellipse size between the four datasets (SCR1 – SCR4) are illustrated. It is clear that location cueing has little effect upon magnitude shift (no significant difference between SCR1 and SCR2 or between SCR3 and SCR4). Spatial cueing, however, has a significant effect, with differences between SCR1 and SCR3 and between SCR2 and SCR4. This is expected as the coastline provides a significant anchor to placements, leading to relatively accurate consensual positioning. The location cueing has little effect because any residual errors are counterbalanced through the averaging process. However, location cueing has an effect on the ellipse size, with significant differences between SCR1 and SCR2 and between SCR3 and SCR4. Here, because there is no averaging process, there are no aggregation effects and the full effects of outlying residuals are realized in the form of increased ellipse size. The effects of spatial cueing are also evident with a significant difference between SCR1 and SCR3. The reason there is no significant difference between SCR2 and SCR4 is because the spatial cueing effect is masked by high residual error introduced by locational cueing. Once the locational cueing effects are reduced by means of the subdatasets, the effect of the spatial cueing becomes visible.

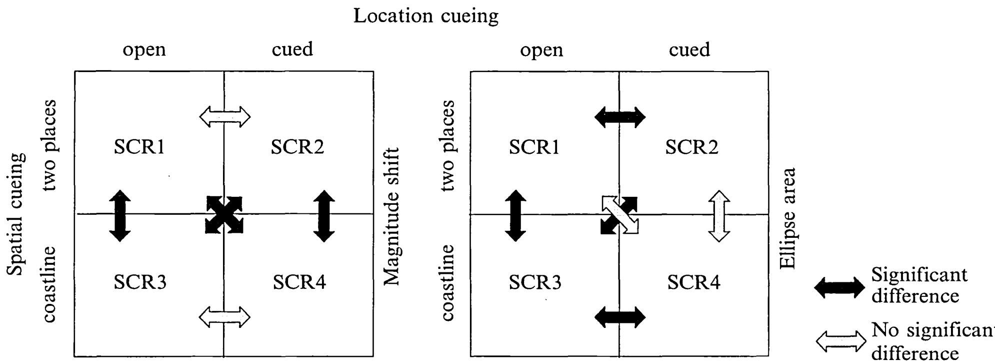


Figure 3. Two-sample t-test results for magnitude shift, and standard deviation ellipses, for the spatial cued response (SCR) datasets for SCR1 – SCR4. For details of tests, see figure 1.

5 Conclusions

In this paper we demonstrated that the nature of the methodology used to measure aspects of spatial cognition can have serious implications for construct and convergent validity. When analyzing the data from all four experimental datasets (SCR1 – SCR4) to investigate both individual and place cognition it is clear that the effects of location and spatial cueing are pronounced. Locational cueing introduces random, residual error into the datasets because respondents are required to locate places with which they have varying degrees of familiarity. Spatial cueing produces more accurate spatial products by providing a spatial framework upon which respondents can 'hang' their knowledge. To compound further these effects, because the locational cueing introduces large amounts of residual error, this error effectively masks the effects of spatial cueing. This means that in other studies where methodological frameworks which provide either spatial cues (inter alia Pearce, 1981; Pocock, 1973) or locational cues (interalia Beatty and Troster, 1987; McGuiness and Sparks, 1983) are used, the integrity of these studies is brought into question. For example, Ohta (1979) asked respondents to locate twelve landmarks in relation to a map showing the street pattern of a city. However, we know from our experiments that, although spatial cueing increases accuracy, locational cueing introduces large residuals, masking the effect of spatial cueing, and it is almost certain that cognitive mapping knowledge in this instance was underestimated. These cautions apply equally to studies that have investigated place cognition, such as those by Bryant (1984), Buttenfield (1986), Golledge and Spector (1978), and Lloyd (1989), which all use locational cues and varying amounts of spatial cueing.

Clearly, care needs to be taken to ensure that strong construct and convergent validity is present so that the integrity of the conclusions is not compromised. However, the strategy we have used to expose these weaknesses, namely a multidata-collection and multidata-analysis approach, can be used to increase the integrity of the conclusions drawn by highlighting where validity is compromised and revealing a more complete picture. By using such an approach, therefore, as well as highlighting methodological shortcomings, one will obtain results which can be accepted with more confidence through an inclusive process of cross-checking. We therefore recommend that such a multidata collection, multianalysis strategy be adopted by researchers seeking to understand cognitive mapping through statistical analysis.

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