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2 Collecting and analysing cognitive mapping data

Rob Kitchin

Introduction

In his pioneering studies, Kevin Lynch (1960) used the technique of sketch mapping in order to elucidate cognitive map knowledge of a city by its residents. In the forty years since, a wide range of techniques informed by various theoretical frameworks have been used by researchers to try to gain a clearer understanding of how we think about and behave in space. Rather than detail the mechanics of specific data generation and analysis techniques and their merits and limitations (for overviews see Newcombe, 1985; Montello, 1991; Kitchin and Jacobson, 1997; Kitchin and Blades, forthcoming), in this chapter a chronology of techniques is outlined, with key ideas and conceptual, methodological arguments detailed. The emphasis is to detail the progression of data generation and analysis since 1960, and to raise concerns and questions that have explicitly focused on these techniques, particularly within the disciplines of geography and psychology. In the final section of the chapter, how empirical cognitive mapping research might look in the future is speculated upon, along with a description of key concepts that need to be considered in future research. It should be noted that the chapter focuses specifically on the measurement and analysis of cognitive map knowledge, that is knowledge of spatial relations in the real world, and as such pure spatial cognition tests which focus on spatial understanding *per se* (e.g., paper-and-pen tests) are not discussed.

Past

Since Lynch's work, cognitive mapping research has been a multidisciplinary endeavour. This has led to a plurality of methodological approaches. Indeed, in the two decades following the publication of *The Image of the City*, there was a strong degree of innovation as researchers sought to answer questions that up until that time had received little empirical consideration. As a consequence, wide ranging data generation and analysis techniques were developed through researchers adapting traditional techniques to apply to new situations, borrowing ideas from related disciplines, and constructing new techniques to apply to particular contexts. Driving this innovation was the combination of ideas from different disciplines. For example, psychology provided techniques for the analysis of cognition and theoretical constructs for interpreting results; geography provided techniques that were ideally suited to measuring the spatial component of data and theoretical constructs relating to spatial relations in the real-world world.

Kitchin and Blades (forthcoming) classify the tests developed in this period into two main classes: uni-dimensional and two-dimensional tests. These sets of tasks were developed simultaneously, were often used interchangeably, and progressively became more sophisticated with time. Indeed, many of the original data generation techniques were relatively crude, but their improved successors are still used today.

Uni-dimensional tests seek to uncover one-dimensional aspects of cognitive map knowledge such as distance and direction. These dimensions are thought to be representative of spatial knowledge in general, but are particularly useful for measuring levels of route (procedural) knowledge. Kitchin and Blades (forthcoming) divide uni-dimensional tests into three sub-categories: distance tasks, direction tasks, and naturalistic tasks (which were developed later).

Distance tasks assess a subject's knowledge of the distance between locations. In his review, Montello (1991) identifies five groups of tests designed to measure cognitive distance estimates: ratio scaling, interval and ordinal scaling, mapping, reproduction and route choice. All were first formulated and used between the late 1960s and late 1970s.

Ratio scaling adapts traditional psychophysical scaling techniques to a distance context, with subjects estimating the distance to a location as a ratio of some other known distance, such as an arbitary scale (e.g., Allen *et al.*, 1978; Cadwallader, 1979) or the length of a ruler (e.g., Lowery, 1973; Briggs, 1973, 1976; Day, 1976; Phipps, 1979). *Interval* and *ordinal scaling* is similar to ratio scaling but differs in the level of measurement. Paired comparison requires a respondent to decide which one of a pair of distances is longer (e.g., Biel, 1982); ranking requires respondents to rank various distances in order along the dimension of length (e.g., Kosslyn *et al.*, 1974; Allen *et al.*, 1978); rating requires respondents to assign the distance between places to a set of predetermined classes that represent relative length (e.g., Baird *et al.*, 1979); partition scales require the respondent to assign distances to classes of equal-appearing intervals of length (e.g., Cadwallader, 1979). The third group of tests, *mapping*, requires several places to be represented simultaneously, at a scale smaller than the estimated environment. Distances are measured from this map for comparison with the actual distances. *Reproduction* requires respondents to provide distance estimates at the scale of the estimated distance. *Route choice* consists of inferring judgements of cognitive distance from the choice of route an individual makes when asked to take the shortest route between two locations.

In general, ratio scaling, mapping and reproduction distance data have been analysed using linear/non-linear regression. Here, the cognitive distance estimates are regressed onto the objective distance values and the relationship between the two observed. In addition, ratio scaling and reproduction estimates, along with interval or ordinal distance data, have been analysed using multi-dimensional scaling techniques (MDS). These techniques use distance data to explore the latent structure of knowledge by assessing the data's dimensionality. They do this by constructing a two-dimensional space from one-dimensional data using a series of algorithms. In essence, they construct a 'map' showing the relationship between a number of objects.

Direction tasks assess a subject's knowledge of the direction between two locations. It is generally assessed using a strategy of pointing. Pointing involves standing at, or imaging being at, a location and pointing to another location (e.g., Hardwick *et al.*, 1976). An alternative technique involves respondents being asked to draw a line across a compass which represents the direction to a place, when the central point represents the place the direction is being estimated from (e.g., Tversky, 1981). Direction estimates have been analysed by comparing the estimates to the actual directions, often through a simple subtraction process. In other cases, a technique of projective convergence has been used to construct a 'map' from estimates by calculating where estimates to the same location but from different sites intersect.

Two-dimensional data generating techniques produce data on a single plain, for example a map. Kitchin and Blades (forthcoming) identify three categories of two-dimensional data generating techniques: graphic tasks, completion tasks, and recognition tasks.

Graphic tasks consist of variants of sketch mapping. Subjects are given a sheet of paper and are asked to draw a map of a certain location (e.g., Lynch, 1960). Variants include providing respondents with a small portion of the map to provide a scale and reference (e.g., Pocock, 1973; Kozlowski and Bryant, 1977), and teaching subjects a sketch map language where specific symbols are used to denote particular features (Beck and Wood, 1976; Wood and Beck, 1976).

Completion tasks present subjects with a certain amount of data and require them to complete a task in relation to that data. Spatial cued response tests require subjects to place locations in relation to locations that are pre-placed (e.g., Ohta, 1979; Evans *et al.*, 1980). Reconstruction tests require subjects to locate places by constructing a model that represents their relative positions (e.g., Sherman *et al.*, 1979). Cloze procedure tests are highly cued spatial completion tests that require a subject to 'fill in' a missing space (an aspatial example of which would be, 'a dog barks but a cat _____?) (e.g., Robinson, 1974; Boyle and Robinson, 1979). Burroughs and Sadalla (1979) used a similar technique called sentence frames. Respondents were required to complete a set of these frames which took the typical format of: '_____ is close to _____' and '_____ is essentially next to _____.'

Recognition tasks measure how successful subjects are at identifying spatial relationships. Iconic tests require the respondent to correctly identify features on a map or aerial photograph (e.g., Blaut and Stea, 1971). Configuration tests require a subject to correctly identify which configuration, out of several, displays the correct spatial relations (e.g., Evans *et al.*, 1980; Evans and Pezdek, 1980). Verifiable statement tests require subjects to identify whether a textual description of a spatial relationship is true or false (e.g., Wilton, 1979).

Graphic tasks have been analysed using a variety of subjective classifications. Here, individual researchers, or more commonly members of a panel, judge the sketch maps using a set of pre-determined criteria, relating to content, style, structure, development, and accuracy. Analysis of completion tests varies according to test type. Spatial cued response and reconstruction data are often analysed using bi-dimensional regression, a two-dimensional equivalent of linear regression that quantifiably assesses scale, rotation and translation differences between the actual and estimated pattern of responses (e.g., Tobler, 1978). Cloze procedure and recognition tests are analysed by constructing an accuracy score which reveals as a percentage the number of correct placements or recognitions.

Whilst these tests were innovative and were used in a large volume of research they, and the theoretical frameworks which they were used to validate, were not accepted without criticism. In the first instance, the validity and utility of some techniques were questioned. In particular, the use of sketch mapping as a technique to determine the knowledge of spatial relations within an area was questioned with critics suggesting that sketch maps are difficult to subjectively score and code, are dependent upon drawing abilities and familiarity with cartography, have content and style influenced by size of paper used for sketching, suffer from associational dependence where later additions to the sketch will be influenced by the first few elements which are drawn, and often show less information than the respondent knows (Day, 1976; Boyle and Robinson, 1979; Downs, 1985; Saarinen, 1988).

This questioning of sketch mapping led to a reappraisal of other techniques. In part, some of the criticism identified that certain researchers, notably geographers, were borrowing techniques and ideas from psychology without a full appreciation of their merits and limitations (Cullen, 1976). This led to inappropriate tests being used to measure different aspects of spatial knowledge. Moreover, within each main category of tests, for example, distance measures, a plethora of specific tests were developed, many of which were derivatives of each other. This diversity of tests, each slightly different from tests used by other researchers, made comparison between studies difficult (Gold, 1992).

In the second instance, within the discipline of geography there was widespread questioning of the connections being made with (cognitive) psychology in the area of cognitive mapping studies as well as spatial preference, choice and decision-making relating to all aspects of daily life, e.g., shopping, residential location, travel patterns. Behavioural geography, as the burgeoning field of research was labelled, was criticized by structuralists and humanists who claimed that behavioural research was mechanistic, dehumanizing, ignored the broader social and cultural context in which decision-making operated, and over-emphasized empiricism and methodology at the expense of worthwhile issues and philosophical content (see Gold, 1992). Critics further warned of the dangers of psychologism, that is, the fallacy of explaining social phenomena purely in terms of the mental characteristics of individuals (see Walmsley and Lewis, 1993) and expressed concern over the lack of theory, poor research design and applied worth. These criticisms were particularly harsh as they were often made by researchers who had themselves engaged in behavioural geography studies (e.g., Bunting and Guelke, 1979).

The outcome of these debates was a theoretical shift of some behavioural geographers towards other positions and a subsequent division of analytical behaviouralists on the one side (who continue to engage in quantitative studies of cognitive mapping) and phenomological behaviouralists on the other side. The phenomenologists called for a shift in emphasis away from trying to measure and explain spatial knowledge to a focus on the life-world of individuals and their values, morals, and 'sense of place' (see Kitchin *et al.*, 1997).

This 'crisis of confidence' concerning the utility of theoretical and methodological frameworks used in the study of cognitive map knowledge was confined mainly to the discipline of geography. As such, whilst the number of studies by geographers noticeably declined at the end of the 1970s and the beginning of the 1980s, particularly in the UK, research continued in other disciplines, notably psychology. Accompanying the loss of momentum within geography was the emergence of a degree of insularity as cross-disciplinary links, which had been particularly prevalent between geography and psychology during the 1970s (see collections by Downs and Stea, 1973; Moore and Golledge, 1976), became less common (Kitchin *et al.*, 1997). This insularity meant that during the 1980s much of the focus of study concentrated on expanding theoretical understanding and providing a wider base of empirical evidence rather than on developing innovative, methodological frameworks – this often arises when two or more disciplines communicate and collaborate. As such, although our understanding of how people think about and behave in space improved, the methodological innovation that characterized work in the previous two decades waned. In addition, it seems that the utility and validity of techniques developed earlier were largely accepted as given (although see Bryant, 1984). As research in the 1990s has shown, however, methodological issues remain a key concern.

Present

In the 1990s, cognitive mapping research has undergone a resurgence. The field of research has once again become a growing area of interest in geography, and there has been a growth of interest in psychology and other areas of study such as computer science and information science. The insularity of the 1980s has been replaced with renewed interdisciplinary links (see Kitchin *et al.*, 1997; Freundschuh and Kitchin, forthcoming). There are several reasons for this renewed interest, but key has been the development of several kinds of spatial technologies (e.g., GIS, in-car navigation systems, personal guidance systems for visually impaired people) that need to be designed for use by non-spatial experts. Government-supported programmes, such as the US National Science Foundation's National Center for Geographic Information Analysis, have sponsored initiatives designed to bring multidisciplinary researchers from around the world together to share ideas, foster collaboration and set agendas for research.

A key focus within this revitalized field has been methodological considerations. Once again researchers have been seeking innovative ways to investigate cognitive map knowledge and to improve the validity and integrity of the techniques to generate and analyse data. The latter of these tasks has formed a substantial part of my own research agenda since 1991.

I have examined the ways in which conclusions drawn from a study are influenced by the method of data generation and analysis used. In Kitchin (1996) the results of a study which compared thirteen different tests designed to measure aspects of configurational knowledge are reported. Little consistency was found between the accuracy of respondents' spatial products in comparison to the objective standard (actual locations) and in comparison to their peers. For example, it was quite possible for respondents to do very well, both in comparison to an objective standard and their peers, when undertaking a spatial cued response test but do poorly when undertaking a recognition test. It was determined that these differences were mainly due to methodological biases introduced by the nature of the test. These biases consisted mainly of spatial and locational cueing. 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. Spatial cueing was found to produce more accurate spatial products by providing a spatial framework upon which respondents could 'hang' their knowledge. In contrast, locational cueing introduced random, residual error into the data sets because respondents

were required to locate places with which they had varying degrees of familiarity. To further compound these effects, because the locational cueing introduced large amounts of residual error, this error effectively masked the effects of spatial cueing (see Kitchin and Fotheringham, 1998). When these biases were removed the results for individuals across tests became closer both in terms of accuracy and in relation to peers. However task demands still produced some differences across tests and respondents.

Using the same data, the effects of aggregation upon research conclusions was also investigated. Data were analysed at the disaggregate level, and using collective and individual aggregation strategies (see Kitchin and Fotheringham, 1997). Collective aggregation entails aggregating each group's raw data sets together and creating a new 'average' data set. This 'average' data set is then analysed and the result used to represent a group. Individual aggregation entails analysing all of a group's individual data sets separately and then aggregating together all of the results and creating an 'average' group result. It was found that collective aggregation can lead to erroneous comparison of individual, spatial cognition because the strategy of aggregating raw data together to produce an average data set removes variation. This can lead to an 'inflated' set of results when the group data set is analysed. Similarly, individual aggregation removes the variation in the pattern of individual results. Disaggregation avoids this pitfall as all individual cases are still identified and the differences between individuals can be noted. For example, Figure 2.1 shows the collective (CA), individual (IA), and dis-, aggregate bi-dimensional regression r-squared results from a spatial cued response test. It is clear that the members of this group had a diversity in knowledge which the collective aggregate method clearly 'inflated' (CA: $r^2 = 0.72$; IA: $r^2 = 0.48$).

The results from this study indicated that test and analysis design are of critical importance, with different tests designed to measure the same knowledge producing significantly different results. As such, slight changes in the task demands of a test can lead to alternative conclusions about that respondent's spatial knowledge. Such findings have led to some concern about whether cognitive mapping data collection techniques are capable of generating data reflective of anything but the ability of the mapper to cope with the task set (Wood and Beck, 1976) or the mode of presentation (Spencer and Darvizeh, 1981). As Boyle and Robinson (1979) recognized, the methodology used to elicit knowledge enforces a medium of communication upon the respondent which may be complicated by the individual's interpretation of how this medium can be utilized:

> it is important that we recognize the artificiality of our demands and that we are aware of the probable lack of congruence between the narrow, corseted response which we require and the less formal, more flexible, and complex structures that people actually use.

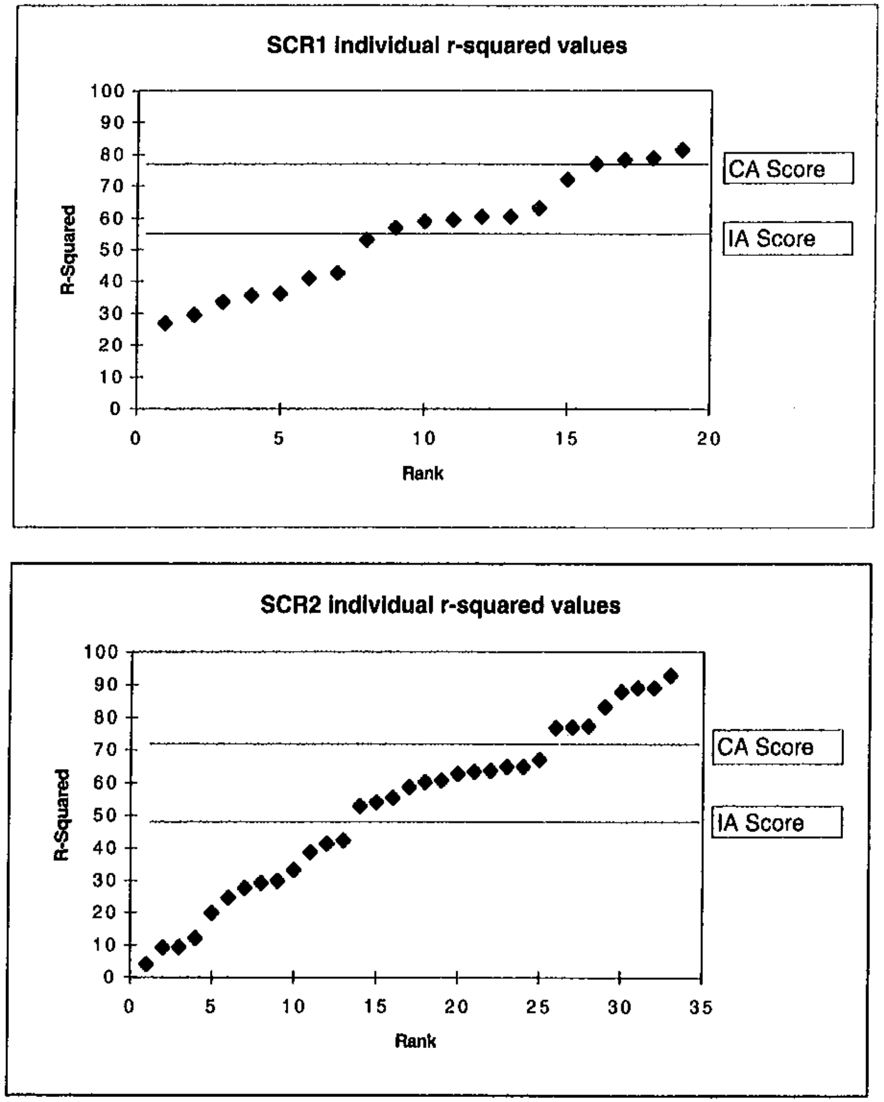

Figure 2.1 The effects of aggregation.

Indeed, the results indicate that researchers need to understand the ways in which the tests and strategies of analysis they use can introduce methodological and analytical bias into findings. These biases need to be carefully calculated so that their effects can be compensated for when interpreting results. In the case of aggregation, given the availability of computing power results should be analysed at an individual level, or a disaggregate level for

group comparisons, and should only be aggregated in specific instances, such as when computing place cognition (see Kitchin and Fotheringham, 1997).

There is evidence to suggest that these sorts of issues are being addressed as research design in the 1990s has developed significantly beyond 'simple' cognitive tasks that were often undertaken in isolation. Techniques have developed over time, with additional clauses introduced in an effort to improve the ability of particular techniques to measure specific aspects of cognitive map knowledge. In addition, the context in which these techniques have been used has become more sophisticated as experimental design has improved. Designs now usually consist of a battery of tests, designed to cross-validate findings. As noted, this strategy of multiple testing ensures a level of construct validity (whether the tests are measuring what they are supposed to) through an examination of convergent validity (tests designed to measure the same phenomenon produce the same results).

The ecological validity of laboratory settings has been questioned for a long time (see Bronfenbrenner, 1979). That is, it has been questioned whether the results achieved in a controlled laboratory have application in a real world that is more complex and variable. Increasingly experiments are taking place in real world settings rather than in a laboratory setting. This has particularly been the case with recent studies of how people with severe visual impairment learn a new route (e.g., Espinosa *et al.*, 1998; Jacobson *et al.*, forthcoming). Within these naturalistic studies, testing takes place at the scale of learning and within the actual environment the cognition of which is being assessed. Testing at this scale is thought to remove any laboratory-installed methodological biases and represent a 'truer' insight into cognition and its link to spatial behaviour. Here, instead of behaviour being inferred from knowledge, the level and nature of a person's cognitive map knowledge and abilities are inferred from both actual behaviour and evidence of knowledge gained through supporting tests.

In addition, there has been an increasing use of qualitative methodologies, both using a scientific and interpretative approach, to investigate spatial knowledge. Within a scientific approach, qualitative data is generated within very controlled tasks and usually analysed using quantitative methods. Tasks usually require respondents to describe a route or layout verbally (e.g., Taylor and Tversky, 1992). Interpretative approaches, rather than testing individuals' knowledge and abilities within controlled environments, suggest that just as much can be learnt about how people know and think about geographic space from talking to and observing individuals as they interact with an environment. Typically an ethnographic approach might be adopted. Here, the goal is to grasp the participant's point of view or relation to life and to realize their vision of their world. As such, subjects might be interviewed in depth or their behaviour within an environment observed in order to reveal their spatial understanding of an area. In my own work, I have combined aspects of the scientific and interpretative approach, using a system of semi talk-aloud protocols, semi-structured interviews and observation to investigate how people attempt to undertake a cognitive mapping test (Kitchin, 1997) and how visually impaired people spatially understand a locale (Kitchin, *et al.*, 1998). One particular strategy used was talk-aloud protocols where respondents described their actions or thoughts while performing a task, thus providing a running commentary.

Future

As we move into the new millennium, cognitive mapping research seems set to flourish given its wide range of potential applications and the healthy cross-disciplinary community that has developed. As witnessed at the end of the 1970s and early 1980s though, when a thriving community rapidly dissipated into insularity, cognitive mapping researchers need to work to ensure that the field of enquiry and links remains strong. I would argue that its methodological integrity is central to the success of cognitive mapping research. Without sound empirical evidence to support theoretical arguments and application in practical projects, cognitive mapping research is open to criticism. The future in relation to methodological aspects must (and if the progression is continued will) focus on a number of key design issues.

As detailed in the previous section, although data generation and analysis techniques and research design are becoming increasingly sophisticated, there is a need to continue to closely examine issues of data validity and integrity. This can principally be achieved through three strategies. The first is the use of multiple strategies of data generation and data analysis, using several techniques to gather and analyse data concerning the same or related issues. As my own work has shown, tests are susceptible to methodological bias and the use of multiple strategies allows the foibles of tests to be identified and compensated for. The second strategy is to generate and analyse data at a disaggregate level. Computing power now means that sophisticated analyses such as multi-dimensional scaling or the calculation of bi-dimensional regression results can be processed quickly and efficiently. Data can therefore be analysed at an individual and a group level. Again, as demonstrated in my own studies, the aggregation of individual data prior to analysis can remove variation and lead to group results that do not reflect individual performances. The third strategy is to use natural settings. As the research on spatial cognition and visual impairment is demonstrating, the results found in laboratory settings do not always apply to the real world (Jacobson *et al.*, forthcoming; Espinosa *et al.*, 1998). If we want to understand behaviour in real world settings then we need to test people's understanding and behaviour in these settings. A counter-argument might be that real world settings have too many intervening variables and are too open for effective testing. It is for precisely these reasons that testing needs to occur in natural environments, as it is these factors that people have to deal with in everyday spatial behaviour, not the controlled orderliness of the laboratory.

In addition, the utility of qualitative techniques to reveal spatial knowledge needs a more thorough examination. Recent studies, which have used scientific and interpretative approaches, suggest there is great potential. The scientific approaches have allowed an understanding of spatial language, a relatively under-studied area of spatial cognition, and, through the use of talk-aloud protocols, spatial cognition in action has been probed. Interpretative approaches allow us to try to understand the connections between spatial cognition and value systems through an examination of spatial behaviour. Here, there is a recognition that spatial behaviour is predicated on more than an understanding of spatial relations and how to get between locations.

There is also a need for the development of more sophisticated methodologies that can tease apart spatial knowledges to reveal processes of spatial thought. That is, rather than just reveal the levels of knowledge, reveal how such knowledge is structured and processed, how data learned through different media and at different scales is integrated and used in wayfinding practice. Although such work has started in earnest using traditional techniques much is still left to inference. Sophisticated battery tests linking spatial cognition tests, cognitive mapping tests, and behaviour in real world environments may be one approach; other approaches such as brain scans may also be of benefit.

Other forms of methodological development relate to the need for significantly more cross-cultural and cross-species research. Both types of study may reveal significant aspects of cognitive mapping and both provide methodological challenges. As some researchers, such as Jahoda (1979, 1980) have noted, cross-cultural studies often suffer because they conflate media experience with knowledge. For example, in societies with high rates of illiteracy, language-based tasks and pen-and-pencil tests will put those denied access to these media at a disadvantage (the same has been argued in relation to visual impairment – that the use of predominantly visual (or adapted) media will favour sighted subjects (e.g., Kitchin and Jacobson, 1997)). The challenge then is to find media that both groups are equally familiar with and then design suitable methodologies using these media that will adequately capture aspects of specific knowledge. In relation to cross-species research this question becomes more problematic, and it is likely that the only true comparator is actual behaviour and brain scans whilst particular activities are undertaken. The real danger is placing overly anthropomorphic assessments on spatial behaviour.

Moreover, there is a need to assess how applicable current methodologies are to measuring spatial knowledge derived from new spatial technologies such as GIS and virtual reality. There is an implicit assumption that knowledge gain through these media will mirror knowledge gained through traditional media, such as maps and the real world, and therefore can be validly measured in the same ways. Studies that have focused on spatial understanding of VR are finding that spatial knowledge development is significantly different, with spatial knowledge gained in VR inferior to those obtained from a map (Satalich, 1995; Tlauka and Wilson, 1996; Ruddle *et al.*, 1997) or the real world (Witmer *et al.*, 1996; Richardson *et al.*, in press). It may, however, be the case that spatial knowledge is not inferior but just different, with traditional tests unable to detect this difference. This is mere speculation, but nonetheless methodological integrity has to be determined in relation to new media.

Conclusion

In this chapter the development of methodologies to measure cognitive mapping has been detailed. Initially there was an explosion of different methods which, in part, was responsible for a crisis concerning the study of spatial cognition in the field in geography. This was because of the way tests were used, with little attention paid to their psychological context. The 1980s was a time of relative disciplinary insularity when innovation subsided and work concentrated on expanding theoretical understanding. The 1990s is characterized by renewed cross-disciplinary links, and testing has again become innovative and also increasingly sophisticated, addressing issues of methodological integrity. Testing procedures are now more likely to consist of batteries of tests, may include qualitative techniques, and may be set in natural environments. This is not to say that methodological procedures are perfect and a number of key questions for future research were identified. Indeed, future research needs to continue addressing issues of methodological integrity because without sound empirical evidence to support theoretical arguments the findings of studies are open to question.

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