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Behavioral Methods for Spatial Cognition Research

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The Seattle Public Library's Central Library building is an impressive glass and steel structure that opened to much fanfare in 2004. Although the building is undeniably striking and attracted glowing attention from architects and critics, not every report from members of the general public has been so positive. Many people have claimed that finding one's way around the building is exceptionally confusing and disorienting. Gabriel (he goes by Gabe) works for the prominent architectural firm in Holland that designed the building. His bosses have asked him to lead an investigation to figure out why their building is disorienting and what can be done about it. Gabe realizes he needs to look into the study of spatial cognition, which concerns how people comprehend and learn the spatial layouts of environments, in order to find their way efficiently while traveling around them and tell others how to find their way in them. Gabe's background in geography and architecture provides excellent preparation for studying spatial cognition in public buildings, because it has taught him about spatiality and about built environments. But he will also need behavioral research methods like those discussed in this chapter.

Spatial cognition is the multi-disciplinary study of perception, thinking, reasoning, and communication that is fundamentally about spatial properties and relations (henceforth, spatial properties) in the environment, whether by humans, non-human animals, or computational entities such as robots (Montello & Raubal, 2012). It therefore includes research from several sub-disciplines of psychology, geography and cartography, architecture and planning, anthropology, linguistics, education, biology, computer science, and more. With such a multi-disciplinary heritage, studying spatial cognition potentially involves a great variety of methodological approaches. In order to constrain this chapter and discuss some specific methods most directly relevant to Gabe's research interests, the focus of this chapter is delimited to the study of human spatial cognition with primary data collected via behavioral methods.

Primary data are data collected for the purpose of answering a researcher's specific research questions, using methods tailored to best address those questions, typically

Research Methods for Environmental Psychology, First Edition. Edited by Robert Gifford.

by that researcher herself or himself. The use of secondary data to study spatial cognition is not addressed; secondary data are collected for some purpose other than answering a researcher's specific research question and nearly always by someone other than that researcher. However, light could be shed on spatial cognition issues with carefully chosen secondary data, including archival data sources (such as administrative, demographic, or economic records) or physical traces (remnants of human activity such as wear marks on a lawn or the arrangement of chairs left after a meeting). Heth and Cornell (1998) studied the thinking and behavior of lost people using case records from search-and-rescue operations.

Behavioral methods involve recording behavior, including where people travel, where they look or point, and what they say or write. This review will broadly distinguish the observation of behavior from **explicit reports** (tests and surveys). Both non-verbal and verbal behavior can be observed (and coded and interpreted); prominent examples of non-verbal behavior in spatial cognition research include both locomotion and eye movement. Responses to explicit reports can also be distinguished as being non-verbal or verbal, with non-verbal responses comprising either scaling or sketch mapping. Scaling in spatial cognition research comes from either the psychometric or psychophysical traditions of research psychology.

In this chapter, research methods used exclusively to study spatial cognition in non-human animals are not discussed (e.g., Shettleworth & Sutton, 2005), although some behavioral methods are applied to both humans and non-humans. And some spatial cognition researchers are especially interested in computational modeling, perhaps to create navigating robots (e.g., Kuipers, 2000; Yeap & Jefferies, 1999). Computational modeling involves an extensive and very distinct set of methods for studying spatial cognition, of course, and are not considered further here. Finally, there is increasing interest in understanding the neuroscience of spatial cognition, and this also involves extensive and sophisticated methods beyond the scope of this chapter. Especially promising within the last couple decades or so has been the application of brain imaging, especially functional magnetic resonance imaging (fMRI), to understanding human spatial cognition (e.g., Maguire et al., 1998; Wolbers, Hegarty, Büchel, & Loomis, 2008).

As we saw above, scholars are sometimes interested in bridging the gap between basic and applied research. Some people think this is the gap between laboratory and field research, but in fact, basic research, with its focus on general explanations of phenomena for the sake of understanding itself, can be conducted in lab or field settings. Likewise, applied research, with its focus on understanding in order to achieve practical outcomes, can also be conducted in either setting. Laboratories are specialized environments for conducting data collection designed to facilitate physical control of potentially confounding or distracting variables. In the case of behavioral research with humans, such distractions include things like noise, salient objects in the visual field, or people walking by. So researchers should be familiar with methods appropriate in either lab or field settings. This will include existing environments like cities, campuses, and public buildings, and also **virtual environments (virtual realities or VR)** that simulate existing places with varying levels of detail and types of sensorimotor involvement (see Chapter 11 for more discussion of simulating environments for research).

Media for Experiencing Spatiality and Acquiring Spatial Beliefs

All phenomena in the domain of spatial cognition involve research participants' experience of spatial properties and their consequent acquisition of beliefs about the properties. Spatial properties include size, shape, location, distance, direction, connection, containment, and more. Spatial properties of environments can be experienced and acquired in a variety of ways, via one or more different media. Montello and Freundschuh (1995) identified four broad classes of such media (they called them "sources" of experience and knowledge). Spatial properties can be experienced and acquired through direct environmental experience while stationary or moving through the environment itself. The movement might be mechanically aided, such as by automobile, bicycle, or airplane. Spatial properties can also be experienced and acquired through indirect environmental experience, including through static pictorial representations (maps, pictures), dynamic pictorial representations (animations, movies), or natural language (spoken or written). A special case is when people experience and acquire spatiality in VR environments; depending on the type of VR system, this would be more like direct environmental experience or dynamic pictorial experience. Furthermore, people often experience and acquire spatiality via multiple media, such as when people both walk around a city and look at a map of it. Continuing research issues concern whether and how information from multiple media is combined or otherwise coordinated in experience and mind.

Montello and Freundschuh (1995) also discussed various factors that differentiate psychologically relevant ways people experience and acquire environmental spaces through different media. These include which sensorimotor systems are involved (vision, touch, walking, head turning, etc.), whether the medium incorporates static or dynamic information (in content or presentation), whether the medium provides sequential or simultaneous access to information, how abstract the medium's symbol system is, whether and how the medium involves translation of spatial (or temporal) scale, what viewing perspectives the medium allows or requires, and how much precision and detail the medium provides about spatial properties – it can be too much, too little, or appropriate.

Clearly, spatial cognition researchers need to think about the medium through which their participants have experienced and acquired spatial properties. This is true whether the researcher specifically exposes participants to the spatial properties or studies beliefs about the properties the participants bring to the study – properties the participants have experienced and acquired in their own way, some time before taking part in the study. Of course, a researcher gains empirical control over understanding the effects of different media if he or she controls participants' exposure to the spatial properties. Such control is not always possible, but when it is, the researcher will be in a better position to explain participants' spatial experience and learning. These choices about how to expose participants to environmental information then become a critical part of the choices researchers must make as part of their research methods.

Observation of Behavior

Since we are restricting our focus to behavioral methods in this chapter, it makes sense first to consider methods that simply involve observing spatially relevant behavior in environments (see Chapter 2 for more discussion of observational methods in environment-behavior research). Behavior is overt, potentially perceptible actions or activity by people. It is not thoughts, feelings, purposes, or motivations. That is, behavior is what we do, not why we do it or how we experience doing it. Nonetheless, behavior is nearly always goal-directed, and most environment-behavior researchers do not consider aimless movement to be behavior. For example, falling is not behavior but attempting to break your fall is.

When collecting data by observing behavior, the behaviors of individuals or groups are watched or listened to. Often, the behavior is somehow recorded. But these records are not, in themselves, data. The records must be coded to convert them into data, typically by segmenting them into relevant units and categorizing the units into meaningful classes (Boehm & Weinberg, 1997). This is a drawback of behavioral observation; coding is almost always hard and time consuming, and it is often difficult to do reliably, so that different coders segment and categorize the records in about the same way.

When using behavioral observation as a method, environment-behavior researchers can set up contrived situations or bring research participants into artificial settings in order to observe their behaviors. In contrast, they can focus on ongoing behavior as it naturally occurs in its actual settings. Historically, this approach was favored by researchers such as ethnographers, who study humans, and ethologists, who study non-human animals. It can provide the substantial benefit of creating data from behavior that does not change because it is becoming research data. That is, behavioral observation often produces data non-reactively. At least it does this when the observers or recording devices are hidden (observation of public behavior is considered ethically allowable). It may even be non-reactive when not hidden, as long as the people observed have become used to being observed and no longer "perform for the camera." Given enough time, even a participant observer may become an accepted part of a setting and not treated unusually by participants (participant observation may be a problematic data source for other reasons). Even when those being observed are fully aware they are participating in a study, certain behaviors such as eye movements may not be readily influenced by consciously held beliefs. That said, it bears emphasizing that, with any form of data collection, including the explicit reports discussed below, reactance – wherein participants change because they know they are being studied – is possible. But it only possibly occurs, not necessarily.

Observing non-verbal behavior

Observing locomotion. In the context of environment-behavior research, observed behavior will often be locomotion, moving one's body from place to place in a coordinated fashion (Montello, 2005). Coordinated means that people walk (e.g., crawl, hop, bicycle, drive) without colliding into barriers, driving off paths, or meandering randomly. A classic example of behavioral observation in environment-behavior research is the work of Hart (1979). He and his assistants observed a small group of children who lived close to each other in a small town. They observed and coded the behaviors of the children in the natural settings of their ongoing activities in and around their homes, intending to learn about the children's experience and understanding of their local surrounds. Behavioral observations were coded to address questions about the children's spatial activities and use of places, beliefs about places (including spatial properties), and their values and emotions concerning places.

An example of using behavioral observation to study spatial cognition with adults comes from an even earlier study by Yoshioka (1942). He and his assistants surreptitiously followed a large number of visitors, one by one, to the New York World's Fair, recording the locations and times of the exhibits they visited. They analyzed behavior patterns of the initial turning direction, the spatial relationship between each visitor's entrance and exit locations, and the spatial patterns of routes traveled. Although Yoshioka was interested in behavioral patterns in and of themselves, he also tried to explain the behaviors by inferences about internal mental states, including personality, motivation, and spatial knowledge. Valid or not, such inferences tend to be difficult to make with behavioral observations, pointing to one of their chief limitations as a method of studying spatial cognition. It can be difficult or impossible to determine the validity of inferences about mental states made from behaviors that do not directly express mental states; in contrast, explicit reports like surveys are thought to directly express mental states (below).

Observing eye movements. As implied above, observed behaviors are not restricted only to locomotion. An increasingly important technique involves observing and recording the behavior of participants' eyes as they look at something, whether a picture, text, or environmental scene. Researchers may be interested in tracking locations in the visual field where participants focus their gaze for some period of time, or in the spatial patterns of the eyes' scan paths to different parts of the visual field. Either way, researchers assume that the location where people are looking is the feature (object or event) in the world that is holding the person's attention. This logic ties the behavior of the eyes to inferences about mental states; also, patterns of eye movements are later correlated with responses to surveys or tests.

One of the earliest examples of eye-movement recording from environment-behavior research comes from Carr and Schissler (1969), who used fairly intrusive equipment that included a camera lens mounted to a contact lens to record participant eye movements while they rode as a passenger in a car. However, that research was an unusually early example of recording eye movements of traveling people, and it was only feasible for passengers who sat fairly still in a car; there was hardly any duplication of it for decades. The great majority of eye-movement research has examined non-locomoting participants, viewing static images or pictures. One of the potential benefits of studying spatial cognition with VR technology is that it reduces some of the technical difficulties of recording eye movements of locomoting individuals (Loomis, Blascovich, & Beall, 1999). One of the most exciting recent methodological advances for those studying environmental cognition is the development of workable technology for mobile eye-tracking, that can validly record eye movements even for pedestrians looking at their real surrounds (Kiefer, Straub, & Raubal, 2012).

Even with static images in a lab, however, analyzing eye-movement records is usually fairly complex; an enormous amount of data is typically recorded in a short time, and it must be processed in sometimes non-obvious ways in order to make sense of it. The technologies for recording eye movements typically involve costly equipment that can be troublesome to calibrate and touchy to maintain consistently. So far, these technologies do not allow surreptitious recording, so reactance is always possible. However, in many research contexts, participants will not be able to control their eye movements readily or may have no motivation for altering them (anecdotally, some researchers report that eye movements recorded on city streets reveal participants looking inordinately at attractive people walking by).

Observing verbal behavior

Although it was stated above that behaviors are overt actions by people, not directly the mental states that might explain the behaviors, we can still think of listening to or reading people's linguistic expressions as behavioral observation. Of course, the explicit reports considered below often involve verbal expression, and the distinction between verbal expressions as observable behaviors versus reports of beliefs is subtle. Nonetheless, there is an important difference that bears recognizing. When a researcher wants to study verbal expressions as the phenomenon of interest, with a focus (and coding) of what someone says or writes, this is behavioral observation. When a researcher considers the verbal expression to be the medium by which people express their beliefs about something, this is explicit reports in a verbal response format.

This becomes clearer when we consider examples of using records of verbal behavior as the basis for data. In the context of spatial cognition, research on giving verbal route directions is the most common example. Ward, Newcombe, and Overton (1986) coded the verbal directions female and male college students gave for routes determined from maps. Allen (1997) coded a corpus of verbal route descriptions, summarizing the types of features included in the descriptions and how they varied among individual describers. Allen (2003) also coded the non-linguistic gestures which so often accompany verbal route directions. Emmorey, Tversky, and Taylor (2000) have observed and coded sign language, which itself is technically a natural language, in order to examine how it uses spatial patterns to express spatial beliefs.

An intriguing recent use of written language as behavioral data for spatial cognition comes from Louwerse and Benesh (2012). They analyzed a large corpus of words and phrases found in J. R. R. Tolkien's famous novels *The Hobbit* and *The Lord of the Rings*, using automated coding techniques from computational linguistics. Their program carried out a statistical frequency comparison of references to city names in the novel, showing that the frequency of co-occurrence of city names (of fictional places) predicted the latitudes and longitudes of those cities quite accurately, because closer places were more often mentioned closely to each other in the novel. They report the fascinating finding that human research participants (new to the stories) who read the novels could estimate the spatial locations of the cities about as well as those who studied maps of the fictional places.

Case Study: How People Get Lost and Found in the Seattle Public Library

At the beginning of this chapter, we told the story of Gabe's new assignment at his architectural firm to design and conduct research on why people get disoriented in the Seattle Public Library and what can be done about that, if anything, from a design perspective (see Chapter 13 for more discussion of conducting evaluation research on built environments). In fact, human-environment researchers Laura Carlson, Amy Shelton, Ruth Conroy Dalton, Christoph Hölscher, and Saskia Kuliga have been conducting just this research project. After reading about the library building and the ideas that guided its design by the architectural firm in Holland (although Gabe is fictional, this firm is not), these researchers toured the building extensively. These preliminary steps supported the development of their studies incorporating an array of behavioral research methods. In particular, they have had research participants walk around the library, in some cases, with instructions to search for particular target locations (such as a particular room). The researchers collect and record observations of the participants' non-verbal behavior, especially where they walk (their locomotor routes), but also what they look at and who they talk to, if anybody. To efficiently collect this rich data set, the researchers developed an iPad app they call PeopleWatcher™ (Dalton, Conroy-Dalton, Hölscher, & Kuhnmünch, 2012). Records are entered via touchscreen, which supports real-time recording of navigationally relevant behaviors. For this project, the system's display included various buttons and blueprint images for each floor of the library; the system is also Wi-Fi and GPS enabled, and contains a digital compass, still and video camera, and audio recording capability. Thus, the researchers have been able to log precise and detailed information about the locations and times of all events/activities, including their participants' locomotion tracks and other behaviors and events, such as pausing, looking at signs, or asking for or being asked for directions. When they get confused or disoriented, the system can record what participants say about their thoughts or what they find confusing while moving about the library. In addition, the researchers coordinate these detailed logs with explicit-report measures, including psychometric spatial ability scales and sketch maps.

Explicit Reports: Tests and Surveys

Explicit reports are beliefs people express about things – about themselves or other people, about places or events, about activities or objects. They include beliefs people express about spatial properties in the environment. Of course, explicit reports also involve observing and recording human behavior – answering a survey question, whether orally or in writing, is a behavior. But explicit reports are considered to be a distinct type of data collection because data collected this way are determined by research participants' explicit beliefs about something, and they always involve explicit recognition by people that they are being studied by researchers. As we discuss below, the explicitness of explicit reports leads to some of their major strengths as well as their major limitations as a method (see Chapter 5 for more discussion of conducting surveys in environment-behavior research).

Explicit reports, including surveys, interviews, and tests, can ascertain many different types of beliefs: behaviors, knowledge, opinions, attitudes, expectations, intentions, experiences, and demographic characteristics. Explicit reports often request responses that cannot readily be judged as being right or wrong; the responses are personal opinions or preferences that cannot be compared to an objective standard of correctness, although they can be identified as common or unusual, related to other variables such as demographics, and so on. When explicit responses *can* be assessed for correctness, and that is of major interest to the researcher, we call the reports tests. Tests are used to study knowledge rather than opinion, in other words. Clearly, when studying spatial cognition, explicit reports often do constitute tests, as people's expressed beliefs about spatial properties can typically be compared to an objective standard, and such a comparison is frequently (not always) of central interest to the researcher.

Explicit-report instruments and the individual items (questions) that make them up are administered in various formats; likewise, responses are collected in various formats. Responses to explicit-report instruments in the domain of spatial cognition are very often – probably more often – expressed non-verbally rather than verbally, in numbers, gestures (such as pointing), graphics, or manipulable objects. Respondents commonly mark lines, draw pictures (including maps), sketch on or annotate maps, or construct physical models such as city layouts with blocks (Kitchin, 2000). But explicit reports are often administered verbally, and in even in spatial cognition, responses can be expressed verbally.

There are other aspects of how explicit reports are to be administered to consider. They can be self-administered or administered by the researcher. They can be administered individually or to groups of respondents. They can be administered in person (face to face), through the mail, over the telephone, or on the Internet (increasingly popular with researchers). Reports can be done with the help of computer programs that display questions and accept answers through the keyboard and mouse. Interviews may be audio or video recorded.

And there are still more choices for researchers to make about the design of explicit-report instruments and items besides administration and response format. Closed-ended items are those that give respondents a small, finite number of predetermined options from which to choose a response. Open-ended items do not; they allow respondents to give any response, of any length, that fits within the response format chosen. Standardized items are the same for each respondent, typically administered in the same way and in the same order for each respondent (they may be closed- or open-ended). Non-standardized items are often useful if one wants to ask follow-up questions that will vary depending on earlier answers respondents gave.

A variety of considerations determine the best way to administer and collect responses to explicit reports in a given study. These include the cost of administration, the number and nature of items to be administered, the rate of response one needs to get, whether one needs to do follow-up data collection, and the nature of respondents (such as their age and language skill). Particular interviewer artifacts may result from one's choices, perhaps from ways the appearance of a researcher could distort the honesty or validity of people's responses. Female respondents may under-report their spatial abilities to male research assistants, for example.

Explicit reports are straightforward and among the most flexible types of data collection in human spatial cognition research. If you want to know what people think, just ask them! But this apparent transparency is something of an illusion, and the limitations of explicit reports are substantial. They frequently depend on respondents' memories (such as for where they have traveled), but people sometimes forget or otherwise recall information in a distorted way, given that memory is elaborative and constructed (e.g., Hyman & Loftus, 1998). The emotionality of events can create stronger recall or stronger forgetting. Questions that require a great deal of aggregation ("how many times have you visited that neighborhood in your life"?) are more suspect than those with little aggregation. Truthfulness can be an issue, insofar as people sometimes intentionally give distorted answers in order to make themselves appear more impressive, to support the research or researcher, or to hurt the research or researcher. That is, people lie or practice deception with good or bad intent. Of course, explicit reports in verbal form can be compromised because some beliefs or feelings may be hard to put into words; non-verbal response formats are especially useful in spatial cognition research for this reason. Some beliefs and feelings may not be full accessible to consciousness, being subconscious or unconscious. A case in point, people often do not know how or why they do or do not believe certain things, their common willingness to offer personal lay theories about these things notwithstanding. Finally, most environment-behavior researchers study beliefs and feelings because of their relationship to action or behavior, but this relationship is not very strong in many cases. Behavior is often determined by habits, social or cultural norms, situational constraints and opportunities, and so on (Ajzen, 2001; Stern, 2000).

Scaling in spatial cognition

Scaling refers to a large and diverse set of explicit-report techniques in which respondents directly express their beliefs about quantitative properties of the environment, of objects or events, of themselves, or of others. Quantitative means that properties are not just classified but rated or estimated at a metric level of measurement – interval or ratio. Ordinal ranking is mostly treated in the next section, but it should be recognized that many authors consider rating scales to generate data that are only ordinal (others reasonably argue that such data may be treated as *approximately* metric), and even when using ranking tasks that clearly do generate only ordinal data, various analytic methods allow some metric information to be inferred or "extracted" from ordinal data (e.g., the non-metric MDS we consider below).

Scaling comes from two important methodological traditions within research psychology, **psychophysics** and **psychometrics**. Psychophysics refers to a set of techniques originating in the nineteenth century in which participants systematically estimate quantities of some property that the researcher then relates to the values of the objectively measured quantities (Gescheider, 1997). In spatial cognition, psychophysics has been used to study properties such as distance or size. Psychometrics, originating in the early twentieth century, refers to a set of techniques in which participants systematically estimate quantities of some property that do not correspond in any direct way to an objectively measurable quantity (Borsboom, 2005). In spatial cognition, these might be attitudes, abilities, preferences, or personality traits (see Chapter 6 for more discussion of measuring attitudes in environment-behavior research).

Psychometric scaling Psychometric rating scales come in a variety of specific forms. Semantic differentials have people rate the degree to which something is described better by one adjective or its opposite (hot–cold, near–far). A second type is a Likert scale, which has people rate the degree to which they agree or disagree with a particular statement. In the area of spatial cognition, Hegarty, Richardson, Montello, Lovelace, and Subbiah (2002) developed and validated a 15-item Likert scale (shown in Box 9.1) to assess people's beliefs about their own "sense-of-direction."

In general, rating scales typically have from 5 to 10 scale values (less with children), with an odd number of values if a middle value of neutrality makes sense for the question ("neither hot nor cold"). People often informally go well beyond this; it is common to hear people say something like, "rate this on a scale from one to a hundred."

Box 9.1 Santa Barbara Sense-of-Direction Scale.

Sex: F M Today's date:_______________
Age:_________

This questionnaire consists of several statements about your spatial and navigational abilities, preferences, and experiences. After each statement, you should circle a number to indicate your level of agreement with the statement. Circle "1" if you strongly agree that the statement applies to you, "7" if you strongly disagree, or some number in between if your agreement is intermediate. Circle "4" if you neither agree nor disagree.

strongly agree 1 2 3 4 5 6 7 strongly disagree

1. I am very good at giving directions.
2. I have a poor memory for where I left things.
3. I am very good at judging distances.
4. My "sense of direction" is very good.
5. I tend to think of my environment in terms of cardinal directions (N, S, E, W).
6. I very easily get lost in a new city.
7. I enjoy reading maps.
8. I have trouble understanding directions.
9. I am very good at reading maps.
10. I don't remember routes very well while riding as a passenger in a car.
11. I don't enjoy giving directions.
12. It's not important to me to know where I am.
13. I usually let someone else do the navigational planning for long trips.
14. I can usually remember a new route after I have traveled it only once.
15. I don't have a very good "mental map" of my environment.

Thinking about quantities on a 100-point scale is probably meaningful for most people in our culture, but it goes well beyond the valid discriminatory abilities of people. That is, it will produce spurious precision.

Psychophysical scaling Montello (1991) reviewed psychophysical scaling and other techniques for collecting estimates of quantities in spatial cognition (his focus was specifically on the cognition of environmental distances). Ratio estimation requires respondents to draw or mark lines or shapes to represent their belief about the amount of some quantity they have experienced, relative to a standard line or shape that represents a standard quantity. For example, "If this line represents the length of the first hallway you walked, draw a line to show the total length of the walk through the building." Jansen-Osmann and Wiedenbauer (2004) used ratio estimation to explore the "route-angularity effect" in spatial cognition, in which people think routes with more turns are longer than routes with fewer turns but of the same actual length (in fact, this and other research studies find the effect to be inconsistent, not found reliably). Battersby and Montello (2009) used ratio estimation to collect estimates of the areas of countries and other world regions, in order to investigate the possibility that exposure to non-equivalent map projections systematically distorts people's beliefs about land areas. Their respondents adjusted an icon of each region on a computer screen so its size was in appropriate ratio to the size of the standard area, the conterminous United States ("lower 48") (Figure 9.1).

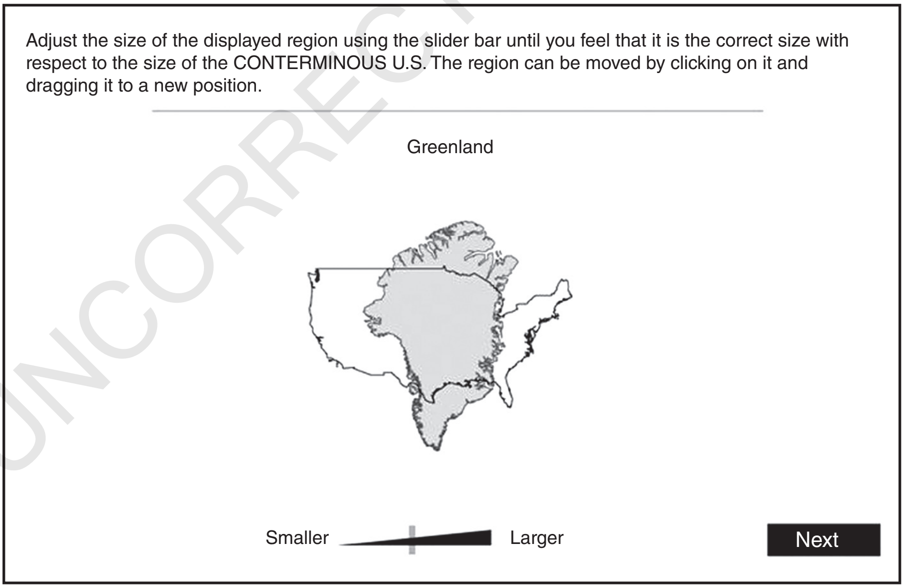

Figure 9.1 Psychophysical scaling technique of ratio estimation. The area of a landmass (Greenland, in this example) is adjusted until the participant believes it is in appropriate ratio to the standard area of the conterminous United States. Adapted from Figure 4 in Battersby and Montello, 2009; used with permission.

In contrast to ratio estimation, magnitude estimation collects responses directly in numerical form; it requires respondents to provide a number to represent their belief about the amount of some quantity they have experienced, relative to some standard quantity given a number. For example, "If the distance from the courthouse to the bus station is 100 units, give a number that equals the distance from the courthouse to the water park." In one of their studies, Battersby and Montello (2009) used magnitude estimation instead of ratio estimation to collect estimates of the areas of world regions. Their respondents gave numbers to represent the areas of world regions, given that the conterminous United States had an area of 1,000 units. In fact, many researchers simply ask respondents to estimate quantities like distances in units they are already familiar with, like miles or meters. One can appreciate this estimation in familiar units as being magnitude estimation with standard units acquired by participants before coming to the study.

Estimates of distances collected by scaling reveal participants' beliefs about distances between places in the environment taken two at a time. Such pairwise estimates are not mutually coordinated and do not directly reveal anything about the participant's conception of the layout of the entire environment. Pairwise distance estimates are often analyzed with a technique called **multi-dimensional scaling (MDS)** (Montello, 1991). For example, Golledge, Briggs, and Demko (1969) created two-dimensional configurations of cognitive maps of Columbus, Ohio, by applying MDS to pairwise estimates of distances in that city. In general, MDS algorithms take as input a matrix of distance estimates (in nonspatial contexts, this is often a matrix of similarity estimates) collected on a pairwise basis and reproduce it in a configuration space of one or more dimensions. The algorithm minimizes the difference, or stress, between the patterns of distances in the matrix and in the solution configuration. The solution can be of any spatial dimensionality, but one tries to minimize stress with a minimal number of dimensions. In environmental spatial cognition research, two-dimensional solutions typically work well (not perfectly).

Scaling techniques collect data efficiently and with apparent quantitative precision; the results can be statistically analyzed directly, without further coding. But psychophysical scaling that measures at the ratio level necessarily involves translating spatial scale (size) between the quantitative property being estimated and the quantitative response. The latter expresses the former at a reduced scale. This requires research participants to translate scale mentally, which is challenging for many people and can introduce additional error in the measurement process. Waller and Haun (2003) developed a version of MDS that reproduces subjective configurations based on direction estimates rather than distance.

Other non-verbal explicit reports in spatial cognition

Besides scaling techniques, researchers can have respondents estimate spatial properties using various other non-verbal methods. Participants may simply indicate the routes they travel in the environment, from which aspects of the person's beliefs about the routes can be inferred (Nasar, 1983); this is an explicit approach to obtaining data that could also be obtained via behavioral observation. Participants can rank order sequences of places along a route or order distances between places instead of rating them with a scaling task. In fact, Golledge et al. (1969) actually performed

MDS on *rankings* of distances between pairs of places, a simple task for participants in which they indicate which of two pairs are further apart; MDS can extract implicit metric spatial structure from such ordinal data.

Montello (1991) discusses the technique of reproduction, in which respondents directly walk or otherwise travel to a place indoors or outdoors, in order to estimate distances or locations. A major benefit of this technique, when it is feasible, is that it does not require any scale translation on the part of research participants. Some researchers also argue that having people travel to locations is a more naturalistic and functionally relevant task for assessing spatial knowledge than indirect tasks such as scaling, pointing, or mapping. Loomis et al. (1993) had respondents with or without visual impairments (wearing blindfolds in the latter case) estimate locations of places in a large room by walking directly to those places. More or less continuous records of these "tracks" were made, which could then be coded to create various specific variables, such as the distance from the walked endpoint to the correct target location (Figure 9.2).

Spatial cognition researchers frequently want to assess beliefs about directions rather than distance. The phenomenon of spatial orientation is, as its name suggests, most centrally about knowing which direction you need to travel to get to a destination (Montello, 2005). Participants can indicate directions by pointing directly with their hand, turning their body, or rotating the dial of a pointing device (Montello, Richardson, Hegarty, & Provenza, 1999). These **judgments of relative**

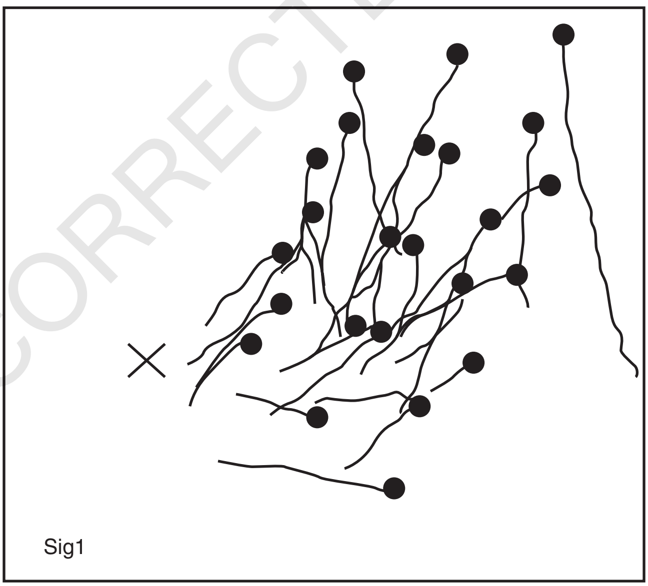

Figure 9.2 Technique of spatial reproduction represented by records of the tracks of a single sighted respondent that captures the respondent's walks to estimated locations in a large room. Circles show the respondent's starting locations on different trials (starting at different places), and X indicates the actual target place to which the respondent is attempting to walk. Adapted from Figure 5 in Loomis et al., 1993; used with permission.

direction (JRD) can be made from the perspective of a participant's current location and heading, or from an imagined location and heading, pointing to a target "as if" standing in a particular place or facing a particular direction. McNamara, Rump, and Werner (2003) used JRDs to study participants' cognitive maps of the layout of a city park, having them indicate directions from various imagined locations and headings.

The performance of different techniques for estimating directions is compared by Montello et al. (1999). These authors also discuss implications of analyzing the accuracy of directional estimates in terms of **absolute error**, which is the absolute value of estimates minus the correct value; **constant error**, which is the signed value of the mean estimate minus the correct value; or **variable error**, which is the variability of the estimates around their mean value. When working with constant and variable errors, it is correct to analyze directions with **circular (directional) statistics**. Unless the direction estimates for a given trial are fairly bunched around their mean value, it is quite misleading not to use circular statistics.

Sketch maps and related formats in spatial cognition

One of the most straightforward ways to find out what people think about the spatial layout of the environment is to ask them to "draw a map." Lynch (1960) is widely credited with introducing the technique of sketch mapping to spatial cognition and environment-behavior research (in fact, he also had respondents describe trips through the city, give verbal directions, and list distinctive places and features). Since then, probably hundreds of studies and countless additional informal data collections and demonstrations have asked people to sketch maps of places at various scales. The study by Jansen-Osmann and Wiedenbauer (2004) discussed above not only used ratio estimation to examine subjective distances but also had participants sketch maps. Baird, Merrill, and Tannenbaum (1979) had college students sketch maps of their campus, and compared them to MDS configurations generated from pairwise distance estimates. Saarinen collected sketch maps at the world scale over many years (e.g., Saarinen, Parton, & Billberg, 1996). He has observed that more familiar places tend to be drawn larger and with more detail, and one's home region is often centered in the sketch (although the influence of particular Western projections that center the Atlantic Ocean are common, too). Similar to map sketching, participants can be asked to construct physical models (Portugali, 1996).

As is so often true of open-ended methods (sometimes called "qualitative" methods), the ease and simplicity of collecting records is not matched by the ease and simplicity of coding and analyzing the records. This point was made above about behavioral coding. Analyzing sketch maps is something of a notorious problem in research. One piece of good advice is that you should figure out what kind of information you want to get from the sketch maps, based on what research questions you want to address. There is no omni-relevant way to analyze them. You can count features or measure spatial properties; you can assess them for accuracy by comparing them to a standard of what is correct; you can code the orientation of the map (what is at the top); you can code their drawing style (linear or survey); you can code the presence or absence of verbal labels; you can assess the relative scale of the map overall or in different parts; and more.

Once you decide what to code on the maps, another common difficulty is that certain variables can be hard to code, if not impossible, depending on how correctly, completely, and clearly the maps were drawn. How can one measure the accuracy of distances if it is not known which road that refers to? How can one tell if that landmark is located correctly, if one can't tell which landmark you thought that was, or you provide a label that is not correct? These thorny issues can be somewhat ameliorated by providing more structure to participants than just a blank page or screen (Kitchin, 2000). You could provide path networks like roads, macro-features such as mountains or water bodies, or indications of the proper scale to draw the map. You could provide a list of features to be located on the map, allowing you to focus on the location of placed features, not whether they are included in the first place. If features on the map can be matched with corresponding features in the world (or on another map), techniques like **bidimensional regression** (Friedman & Kohler, 2003) can quantitatively compare the degree of correspondence (relative accuracy) of the two layouts, giving the amount of rotation, translation, and scaling needed to make them correspond as much as they can.

Verbal explicit reports

As we discussed above, explicit reports are often collected as verbal responses. This method is sometimes used in spatial cognition research, although less than in most areas of research in the social and behavioral sciences, areas that probably use verbal responses most often to collect data. For instance, a marketing researcher might ask you to describe in words what you think about a particular product or a sociologist might ask you to say what you think about people of different racial groups. One can further distinguish verbal expressions themselves as the behavior of interest (behavioral observation) from verbal reports as the medium by which people express their explicit beliefs about something.

Taylor and Tversky and their colleagues (e.g., Taylor & Tversky, 1995) have reported several studies of spatial cognition assessed by people's oral and written responses. They have used verbal responses to study spatial perspectives and other aspects of the reference systems by which people store and recall spatial beliefs stored in memory. In a unique and very interesting study, Bahrick (1983) assessed people's cognitive maps for a small city and college campus after retrieval intervals of as many as several decades. He did this by testing not only current and recent students at the college but also alumni, some of whom had graduated over 40 years earlier and had rarely or never been back to the city. He collected data on their cognitive maps, including the accuracy of their spatial knowledge, by having them recall names of city and campus buildings, spatially ordering them along dimensions of east–west and north–south. He also gave them a structured map-sketching task, providing an outline map of the city with streets and buildings indicated but not labeled; participants were asked to name the streets and buildings.

Hirtle and Jonides (1985) collected verbal recalls of landmark structures (mostly buildings) on a college campus as a clever way to reveal their participants' memory organizations for the campus layout. By having the participants repeatedly recall the names of the campus landmarks, seeding each recall sequence with a different starting landmark, they could apply cluster analysis to reveal persistent tendencies for their participants to recall mentally related landmarks close together in the recall sequence. The researchers could then examine properties of the clustered landmark to show that spatial proximity, for instance, or functional relatedness provided the basis for memory associations.

An important verbal method for collecting data on people's spatial thinking is protocol analysis. Protocol analysis requires people to "think aloud" when they are reasoning about some problem. Their verbal responses are recorded and coded, and in spatial cognition research, behavioral measures such as pointing or looking are frequently recorded as well. For instance, Passini (1992) reported protocol analyses of people wayfinding to a destination inside a public building, having his participants talk about what they were looking at and thinking about while trying to find a destination.

Summary and Conclusions

This chapter contains a discussion of behavioral methods for conducting research studies in spatial cognition. Spatial cognition researchers study perception, thinking, reasoning, and communication that is fundamentally about spatial properties in the environment. This review has focused on the study of human spatial cognition with primary data collected via behavioral methods, probably the most common methods for collecting data by environment-behavior researchers. The review distinguishes behavioral methods based on observation from those based on explicit reports, including tests, surveys, and interviews. Both behavioral observation and explicit reports can be based on either verbal or non-verbal behavior (or a combination). Verbal behavior can be spoken or written, and may include gestures and other para-verbal behavior. Non-verbal behaviors studied in spatial cognition include locomotion, eye movements, psychophysical and psychometric scaling, and map sketching.

The review suggests that environment-behavior researchers have choices to make when designing studies. These choices should be dictated by a reckoning of the benefits different methods offer, and the costs they extract. Different methods tell us more or less about particular behaviors, particular beliefs, particular preferences, and so on. They come with different costs, whether of time, effort, money, or comfort.

Before we end, it is appropriate to remember that environment-behavior researchers basically study the interactions of humans and environments (some would say "transactions," to suggest an integrated, indivisible system of human–environment). That points to the important truth that we cannot understand human–environment by focusing only on human behavior and mind. We must also understand the environment, including its physical and socio-cultural aspects. That is especially fitting to remember for researchers who have training not only in cognitive disciplines such as psychology but also in environmental disciplines such as geography and architecture.

In the context of spatial cognition research, that includes understanding how the layout and appearance of built and natural environments influence spatial learning and wayfinding. A detailed analysis of the environment can help. Factors such as visibility, differentiation of appearance, and layout complexity and shape have been recognized as important (Carlson, Hölscher, Shipley, & Dalton, 2010;

Kelly, McNamara, Bodenheimer, Carr, & Rieser, 2008; Weisman, 1981). Analyzing vistas – the extents of people's lines-of-sight from different places and in different directions – is increasingly recognized as relevant; these have traditionally been called "viewsheds" when outdoors and "isovists" when indoors. A fruitful approach to understanding the complexity of path networks, whether hallways or roads, is provided by the techniques of space syntax analysis (Kim & Penn, 2004).

The social and cultural environment is important, too. Observing people verbally interacting with each other would be a useful way to address the understudied problem of spatial reasoning in groups (Hutchins, 1995). Cultural and regional conventions influence the design of built spaces, of road signs, of guidebooks, and of maps (Koshiro, 2003; Lawton, 2001). Spatial cognition may differ even more fundamentally across cultures as a function of differences in the way spatial languages use reference systems (Levinson, 2003).

Glossary

Absolute error Error in an estimated quantity such as distance, direction, or area, calculated by taking the absolute value of the difference between the estimated value and the correct value. Averaged over estimation trials, it assesses total error of estimation, including both systematic bias and unsystematic variability.

Bidimensional regression Statistical technique for analyzing two-dimensional data, such as estimated locations in a spatial layout. Allows quantitative comparison of the degree of correspondence (relative accuracy) of two layouts (two estimated layouts, or one estimated and one actual layout), giving the amount of rotation, translation, and scaling needed to make them correspond as much as possible.

Circular (directional) statistics Appropriate statistical techniques for analyzing data such as directional estimates that vary across part or all of 360 angular degrees. However, absolute directional errors are linear and do not require circular statistics.

Constant error Error in an estimated quantity such as distance, direction, or area, calculated by taking the signed (directional) difference between the estimated value and the correct value. Averaged over estimation trials, it assesses systematic error of estimation, indicating any bias in one direction or another (e.g., direction estimates in the clockwise direction).

Explicit reports Type of data collection in which people's intentional expression of their beliefs about themselves, other people, places, events, activities, or objects are recorded. Surveys assess beliefs that are not or cannot be scored primarily for accuracy (i.e., not compared to a standard of correctness); tests assess beliefs that are scored primarily for accuracy.

Judgments of relative direction (JRD) Estimates of directions in the environment made from the perspective of a participant's current location and heading, or from an imagined location and heading, pointing to a target "as if" standing in a particular place or facing a particular direction.

Multi-dimensional scaling (MDS) Computational algorithm that generates a spatial configuration of any number of dimensions (most often two-dimensional in environmental spatial cognition research) given as input a matrix of pairwise estimates of distance, similarity, or another property. The algorithm creates a configuration solution by minimizing the difference, or stress, between the patterns of values in the input matrix and in the solution configuration.

Scaling (psychometric) Set of techniques in which participants systematically estimate quantities of some property that do not correspond in any direct way to objectively measurable quantities; includes rating scales. In spatial cognition, psychometrics can be used to study attitudes, abilities, preferences, or personality traits.

Scaling (psychophysical) Set of techniques in which participants systematically estimate quantities of some property that the researcher then relates to the values of the objectively measured quantities; includes ratio and magnitude estimation. In spatial cognition, psychophysics can be used to study properties such as subjective distance or size.

Variable error Error in an estimated quantity such as distance, direction, or area, calculated by taking the absolute value of the difference between the estimated value on one trial and the mean estimate across trials. Averaged over estimation trials, it assesses unsystematic error of estimation, indicating variability or resolution of estimation.

Virtual environments (virtual realities or VR) Interactive, real-time, three-dimensional graphical computer displays that simulate the experience of moving through real environments, actual or imagined. They display varying levels of detail and invoke different types of sensorimotor involvement, but prototypically present a first-person perspective, appear fairly realistic, and change appropriately in response to user movements (i.e., they incorporate at least partial active control).

References

Ajzen, I. (2001). Nature and operation of attitudes. *Annual Review of Psychology, 52*, 27–58.

Allen, G. L. (1997). From knowledge to words to wayfinding: Issues in the production and comprehension of route directions. In S. C. Hirtle & A. U. Frank (Eds.), *Spatial information theory: A theoretical basis for GIS* (pp. 363–372). Berlin, Germany: Springer.

Allen, G. L. (2003). Gestures accompanying verbal route directions: Do they point to a new avenue for examining spatial representations? *Spatial Cognition and Computation, 3*, 259–268.

Bahrick, H. P. (1983). The cognitive map of a city: Fifty years of learning and memory. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. *17*, pp. 125–163). New York, NY: Academic Press.

Baird, J. C., Merrill, A. A., & Tannenbaum, J. (1979). Cognitive representation of spatial relations: II. A familiar environment. *Journal of Experimental Psychology: General, 108*, 92–98.

Battersby, S. E., & Montello, D. R. (2009). Area estimation of world regions and the projection of the global-scale cognitive map. *Annals of the Association of American Geographers, 99*, 273–291.

Boehm, A. E., & Weinberg, R. A. (1997). *The classroom observer: Developing observation skills in early childhood settings* (3rd ed.). New York, NY: Teachers College Press.

Borsboom, D. (2005). *Measuring the mind: Conceptual issues in contemporary psychometrics.* Cambridge, UK: Cambridge University Press.

Carlson, L. A., Hölscher, C., Shipley, T. F., & Dalton, R. C. (2010). Getting lost in buildings. *Current Directions in Psychological Science, 19*, 284–289.

Carr, S., & Schissler, D. (1969). The city as a trip: Perceptual selection and memory in the view from the road. *Environment and Behavior, 1*, 7–36.
Dalton, N. S., Conroy-Dalton, R., Hölscher, C., & Kuhnmünch, G. (2012). An iPad app for recording movement paths and associated spatial behaviors. In C. Stachniss, K. Schill, & D. Uttal (Eds.), *Spatial cognition VIII* (LNAI 7463, pp. 431–450). Berlin, Germany: Springer-Verlag.
Emmorey, K., Tversky, B., & Taylor, H. A. (2000). Using space to describe space: Perspective in speech, sign, and gesture. *Spatial Cognition and Computation, 2*, 157–180.
Friedman, A., & Kohler, B. (2003). Bidimensional regression: Assessing the configural similarity and accuracy of cognitive maps and other two-dimensional data sets. *Psychological Methods, 8*, 468–491.
Gescheider, G. A. (1997). *Psychophysics: The fundamentals* (3rd ed.). Mahwah, NJ: Erlbaum.
Golledge, R. G., Briggs, R. & Demko, D. (1969). The configuration of distances in intraurban space. *Proceedings of the Association of American Geographers, 1*, 60–65.
Hart, R. (1979). *Children's experience of place*. New York, NY: Irvington.
Hegarty, M., Richardson, A. E., Montello, D. R., Lovelace, K., & Subbiah, I. (2002). Development of a self-report measure of environmental spatial ability. *Intelligence, 30*, 425–447.
Heth, C. D., & Cornell, E. H. (1998). Characteristics of travel by persons lost in Albertan wilderness areas. *Journal of Environmental Psychology, 18*, 223–235.
Hirtle, S. C., & Jonides, J. (1985). Evidence of hierarchies in cognitive maps. *Memory & Cognition, 13*, 208–217.
Hutchins, E. (1995). *Cognition in the wild*. Cambridge, MA: MIT Press.
Hyman, I. E., & Loftus, E. F. (1998). Errors in autobiographical memory. *Clinical Psychology Review, 18*, 933–947.
Jansen-Osmann, P., & Wiedenbauer, G. (2004). The influence of turns on distance cognition: New experimental approaches to clarify the route-angularity effect. *Environment and Behavior, 36*, 790–813.
Kelly, J. W., McNamara, T. P., Bodenheimer, B., Carr, T. H., & Rieser, J. J. (2008). The shape of human navigation: How environmental geometry is used in the maintenance of spatial orientation. *Cognition, 109*, 281–286.
Kiefer, P., Straub, F., & Raubal, M. (2012). Location-aware mobile eye-tracking for the explanation of wayfinding behavior. *15th AGILE International Conference on Geographic Information Science (AGILE 2012)*, Avignon, France.
Kim, Y. O., & Penn, A. (2004). Linking the spatial syntax of cognitive maps to the spatial syntax of the environment. *Environment and Behavior, 36*, 483–504.
Kitchin, R. (2000). Collecting and analysing cognitive mapping data. In R. Kitchin & S. Freundschuh (Eds.), *Cognitive mapping: Past, present and future* (pp. 9–23). London, UK: Routledge.
Koshiro, S. (2003). A comparative study of the spatial descriptions in tourist guidebooks. *Geographical Review of Japan, 76*, 249–269.
Kuipers, B. (2000). The spatial semantic hierarchy. *Artificial Intelligence, 119*, 191–233.
Lawton, C. A. (2001). Gender and regional differences in spatial referents used in direction giving. *Sex Roles, 44*, 321–337.
Levinson, S. C. (2003). *Space in language and cognition: Explorations in cognitive diversity.* Cambridge, UK-: Cambridge University Press.
Loomis, J. M., Blascovich, J. J., & Beall, A. C. (1999). Immersive virtual environment technology as a basic research tool in psychology. *Behavior Research Methods, Instruments, & Computers, 31*, 557–564.
Loomis, J. M., Klatzky, R. L., Golledge, R. G., Cicinelli, J. G., Pellegrino, J. W., & Fry, P. A. (1993). Nonvisual navigation by blind and sighted: Assessment of path integration ability. *Journal of Experimental Psychology: General, 122*, 73–91.

Louwerse, M. M., & Benesh, N. (2012). Representing spatial structure through maps and language: Lord of the Rings encodes the spatial structure of Middle Earth. *Cognitive Science, 36*(8), 1556–1569.

Lynch, K. (1960). *The image of the city*. Cambridge, MA: MIT Press.

Maguire, E. A., Burgess, N., Donnett, J. G., Frackowiak, R. S. J., Frith, C. D., & O'Keefe, J. (1998). Knowing where and getting there: A human navigation network. *Science, 280* (May 8), 921–924.

McNamara, T. P., Rump, B., & Werner, S. (2003). Egocentric and geocentric frames of reference in memory of large-scale space. *Psychonomic Bulletin & Review, 10*, 589–595.

Montello, D. R. (1991). The measurement of cognitive distance: Methods and construct validity. *Journal of Environmental Psychology, 11*, 101–122.

Montello, D. R. (2005). Navigation. In P. Shah & A. Miyake (Eds.), *The Cambridge handbook of visuospatial thinking* (pp. 257–294). Cambridge, UK: Cambridge University Press.

Montello, D. R., & Freundschuh, S. M. (1995). Sources of spatial knowledge and their implications for GIS: An introduction. *Geographical Systems, 2*, 169–176.

Montello, D. R., & Raubal, M. (2012). Functions and applications of spatial cognition. In D. Waller & L. Nadel (Eds.), *Handbook of spatial cognition* (pp. 249–264). Washington, DC: American Psychological Association.

Montello, D. R., Richardson, A. E., Hegarty, M., & Provenza, M. (1999). A comparison of methods for estimating directions in egocentric space. *Perception, 28*, 981–1000.

Nasar, J. L. (1983). Environmental factors, perceived distance and spatial behavior. *Environment and Planning B, 10*, 275–281.

Passini, R. (1992). *Wayfinding in architecture* (2nd ed.). New York, NY: Van Nostrand Reinhold.

Portugali, J. (1996). Inter-representation networks. In J. Portugali (Ed.), *The construction of cognitive maps* (pp. 11–43). Dordrecht, The Netherlands: Kluwer.

Saarinen, T. F., Parton, M., & Billberg, R. (1996). Relative size of continents on world sketch maps. *Cartographica, 33*, 37–47.

Shettleworth, S. J., & Sutton, J. E. (2005). Multiple systems for spatial learning: Dead reckoning and beacon homing in rats. *Journal of Experimental Psychology: Animal Behavior Processes, 31*, 125–141.

Stern, P. C. (2000). Toward a coherent theory of environmentally significant behavior. *Journal of Social Issues, 56*, 407–424.

Taylor, H. A., & Tversky, B. (1995). Assessing spatial representation using text. *Geographical Systems, 2*, 235–254.

Waller, D., & Haun, D. B. M. (2003). Scaling techniques for modeling directional knowledge. *Behavior Research Methods, Instruments, & Computers, 35*, 285–293.

Ward, S. L., Newcombe, N., & Overton, W. F. (1986). Turn left at the church, or three miles north: A study of direction giving and sex differences. *Environment and Behavior, 18*, 192–213.

Weisman, J. (1981). Evaluating architectural legibility: Way-finding in the built environment. *Environment and Behavior, 13*, 189–204.

Wolbers, T., Hegarty, M., Büchel, C., & Loomis, J. M. (2008). Spatial updating: How the brain keeps track of changing object locations during observer motion. *Nature Neuroscience, 11*, 1223–1230.

Yeap, W. K., & Jefferies, M. E. (1999). Computing a representation of the local environment. *Artificial Intelligence, 107*, 265–301.

Yoshioka, J. G. (1942). A direction-orientation study with visitors at the New York World's Fair. *Journal of General Psychology, 27*, 3–33.

Suggested Readings

Ericsson, K. A., & Simon, H. A. (1993). *Protocol analysis: Verbal reports as data* (Rev. ed.). Cambridge, MA: MIT Press.

Foreman, N., & Gillett, R. (Eds.) (1997). *Handbook of spatial research paradigms and methodologies* (Vol. *1*: Spatial cognition in the child and adult). East Sussex, UK: Psychology Press.

Fowler, F. J. (2009). *Survey research methods* (4th ed.). Thousand Oaks, CA: Sage.

Gentry, T. A., & Wakefield, J. A. (1991). Methods for measuring spatial cognition. In D. M. Mark & A. U. Frank (Eds.), *Cognitive and linguistic aspects of geographic space* (pp. 185–217). Dordrecht, The Netherlands: Kluwer.

Gerber, R., & Kwan, T. (1994). A phenomenographical approach to the study of pre-adolescents' use of maps in a wayfinding exercise in a suburban environment. *Journal of Environmental Psychology, 14*, 265–280.

Golledge, R. G. (1976). Methods and methodological issues in environmental cognition research. In G. T. Moore & R. G. Golledge (Eds.), *Environmental knowing* (pp. 300–313). Stroudsburg, PA: Dowden, Hutchinson & Ross.

Krippendorff, K. (2009). *Content analysis: An introduction to its methodology* (2nd ed.). Thousand Oaks, CA: Sage.

Newcombe, N. (1985). Methods for the study of spatial cognition. In R. Cohen (Ed.), *The development of spatial cognition* (pp. 277–330). Hillsdale, NJ: Erlbaum.

Rosenthal, R., & Rosnow, R. L. (2007). *Essentials of behavioral research: Methods and data analysis* (3rd ed.). Boston, MA: McGraw-Hill.

Webb, E. J., Campbell, D. T., Schwartz, R. D., & Sechrest, L. (2000). *Unobtrusive measures* (Rev. ed.). Thousand Oaks, CA: Sage.

Zeisel, J. (2006). *Inquiry by design: Environment/behavior/neuroscience in architecture, interiors, landscape, and planning* (2nd ed.). New York, NY: W.W. Norton.