Tasks, Strategies, and Cognitive Processes Associated With Navigational Map Reading: A Review Perspective*

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All geographers use and may create maps in their professional activities. While perceived by some as merely tools to present spatial information, maps are actually complicated communication mechanisms. Many geographers spend tremendous amounts of time learning about verbal and written communication (how to speak, listen, read critically, and write effectively). But to many, one of the basic tools of geographic communication, the map, is a general source of unknown. Many previous papers have focused on how to create effective maps; this paper focuses on how people read and use navigation maps. Everyone completes map-reading tasks, uses (often different) strategies, and processes information through cognitive processing. Geographers may benefit from understanding how they, as well as their map-viewing public, process the information contained on their maps. This paper addresses terms and issues addressed in navigational map reading, specifically including tasks and strategies as well as the governing cognitive processes. **Key Words: map reading, navigation, cognition, map-reading tasks, map-reading strategies.**

Introduction

Through a review of past literature, this paper will identify and describe several cognitive processes that may take place in a map reader's brain while managing the combined task (as well as subtasks) of map reading and navigation. In addition, the contexts (including cognitive processes, strategies, tasks) into which many cognitive issues may be studied are identified and discussed.

Whether in their teaching or research (and likely in their daily lives), all geographers use maps. Because maps are objects involved in nearly every aspect of geography, the researchers who use them should have at least a basic understanding of how they are processed and perceived by the map user (and the map user is not only the public served by the geographer, but also geographers themselves). Cartography is more than a technique, and maps are more than tools. Maps affect people; they are powerful data-display methods (Monmonier 1996; Wood 1992). In fact, as will be argued throughout this paper, different elements of the map (and likely, different types of maps) will invoke the use of different human cognitive processes, controlled by different sections of the human brain, and require the completion of different tasks, which are approached with different strategies. Consequently, the distinction between a topographic map and a population map is more than just the classification of the maps as reference and thematic, respectively; the way the maps are read and therefore perceived by the map user differs from map to map and from user to user.

Understanding what strategies people use, why different people use different strategies to complete the same task, and identifying what cognitive process are controlling those strategies provides the framework for a growing number of geographic research studies. In addition, the questions of why some people can read maps and navigate through an environment better than others holds an answer that has eluded researchers working in both cartography and psychology. Cognitive studies and spatial ability measures have been conducted for more than 100 years by psychologists and for more than 30 years by cartographers. However, while some studies provide insight into the cognitive processes and strategies associated with specific map-reading tasks, many of these tasks, strategies, and processes have yet to be identified and, possibly more importantly, understood. But this understanding must begin with identification; researchers should first identify the map-reading tasks, and then the more complex job

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of identifying the associated strategies, and then processes may begin. In short, we must know the object of study before it can be studied.

The Context

Research into cognitive processes in map reading has been conducted primarily in the fields of psychology and cartography. Researchers borrow theories and study results from one another's discipline, but with a few exceptions, most notably the work of Downs and Liben (1986, 1987, 1988, 1991, 1992, 1993, 1994, 1997) and Golledge's work with several psychologists (Klatzky et al. 1990; Loomis et al. 1993; Klatzky et al. 1998; Loomis et al. 1990; Garling and Golledge 2001), most of the cognitive research has been conducted either by psychologists or by cartographers but not by both in collaboration.

While studies found in the literature of the two disciplines address the same topic (map-reading ability), the actual foci of the studies are quite different. In psychological research, the primary focus is on human cognitive abilities. Less attention is given to the type (and sometimes even the quality) of the maps used in the studies. In other words, they often do not differentiate between different types of maps (Liben and Downs 1989), and "maps" are sometimes crude approximations of the street and road maps we generally use to find our way in the world.

Cartographers, on the other hand, focus on the map as well as the map reader but may lack a deep understanding of cognitive psychology and its theoretical constructs. With few exceptions, cartographic research has not been based on cognitive theories of spatial knowledge (Lloyd 1982; Blades and Spencer 1986; Liben and Downs 1989, Crampton 1992). Blades and Spencer argue that "if cognitive cartography is to establish a firm scientific foundation, it needs to be 'theory driven.' It is important that cartographers develop theories about the processes involved in understanding a map and that these theories lead to hypotheses that can be tested experimentally" (Blades and Spencer 1986, 7). In addition, the methods used in many cartographic experiments make validity measures difficult to obtain (Lloyd 1982). In fact, terms such as *test validity*, *test reliability*, or *construct validity* are rarely seen in cartographic literature.

Cognitive map-related testing has been conducted sporadically over the past hundred years. In psychology, the line of study that brings maps to mind most immediately is spatial abilities assessment. Galton developed the first spatial abilities assessment tests in 1883 (Anastasi and Urbina 1997). Since then, thousands of such tests have been developed and administered (Eliot and McFarlane-Smith 1983); many of these have no stimuli that we would label as geographic maps. The 1970s saw an increase in experimental psychology that focused on understanding the constructs assessed by intelligence and aptitude tests (Anastasi and Urbina 1997), some of which addressed map-reading ability. For example, Bronzaft, Dobrow, and O'Hanlon (1976) asked subjects to use a map of the New York City subway to navigate to a given destination; subjects' success was characterized as either "acceptable" or "not acceptable." Some researchers have used computer simulation to test the effectiveness and efficiency of route planning (Hayes-Roth and Hayes-Roth 1979; Streeter and Vitello 1986). Others addressed the influence of map orientation on route planning (Levine, Marchon, and Hanley 1984; Shepard and Hurwitz 1984).

The spatial testing conducted by psychologists focused primarily on understanding spatial cognition as part of the overall cognitive process. These tests helped to set the precedent for several cartographic cognitive studies that focus on understanding spatial cognition as part of the overall cartographic communication process, which has been a concern in the field for nearly half a century.

After a period of concept development that shifted cartography from questions of physical representation to questions of map effectiveness, cartographers asserted that research should focus not only on the needs of the map reader but also on their map-reading skills and abilities. In addition, cartographers recognized the importance of the map reader's interpretation of the map information as an integral component in the communication process (Kolacny 1969; Ratajski 1973; Morrison 1976). Kolacny (1969) argues the importance of understanding the map reader's cognitive process by suggesting that researchers should not just focus on the reader's map-use needs but also their skills and abilities. Ratajski (1973) discussed cognitive processes of the map reader more specifically by positing that a reader's memory affects map-reading and interpretation ability. Morrison (1976, 96) introduces even more specifics by suggesting that a map reader's interpretation of map information is influenced not only by the cognitive processes used during the interpretation of map information but also by "the information existing previously in the cognitive realm of the map reader."

Beginning in the 1950s, psychophysical studies focused on identifying map-reader contributions by evaluating their subjective impressions of various map-design elements (text, colors, symbols, and layout) (Cole 1981). Subject matter included magnitude estimation of graduated circles (Flannery 1971; Groop and Cole 1978), map symbol clustering (Jenks 1975), pattern complexity on choropleth maps (Olson 1975; Monmonier 1974) and gray scale effects (Kimerling 1975). Psychophysical studies provided results of interest for map design but provided little insight into how the reader processes the information.

As attention shifted to processing, cartographers began calling for more experiments that focused on identifying the cognitive processes associated with map reading (Olson 1979; Gilmartin 1981; Blades and Spencer 1986). This shift in focus broadened the scope of research as cartographers began to look at more components in the map-reading process. Although the scope of research broadened, most research into understanding the cognitive processes of map reading still is conducted primarily in psychology, which means that the focus of map-reading cognitive research continues to focus on *cognition* and not the *map*.

Differing Approaches to Cognitive Map Reading Studies

Recent cognitive map-reading experiments (the majority of which have been conducted by psychologists) may be divided into at least two categories: those that investigate strategies used by the map reader while performing specific map-related tasks and those that focus on cognitive processes used by map readers.

Map Reading Tasks

A map reader faces a navigational map-reading task any time that action must be taken. If faced with the challenge of navigating from one location to another with the use of a map, several tasks must be undertaken (and completed to some degree of effectiveness) in order to find a way to the navigation goal. These tasks will vary, and it is likely not all tasks associated with navigational map reading have been identified. But, some may include deciphering symbol meaning, route planning, self-locating, and text/image/geometry rotation. Some tasks may even include subtasks. In addition, the tasks (and their subtasks) may be completed by different map readers through the use of different strategies.

Map Reading Strategies

A map reading strategy is a specific method or tactic employed by a map user to complete navigational map-reading tasks. A distinct difference between strategies and processes is that everyone has and uses the same processes, but at varying levels of ability or effectiveness. However, the difference in an individual's ability levels in varying processes may dictate the strategies they use. Thus, everyone may use the same processes, but not everyone uses the same strategies.

A strategy may not be independent of a cognitive process, though. In fact, a person's cognitive processes may influence the strategies or methods used in reading a map. For example, a person whose visual memory is not as strong as his or her reasoning ability may not rely on memorizing the map as much as on analyzing it; a person possessing strong mental object rotation ability may not physically rotate the map during navigation. Therefore, differences in brain structure may lead to strategy differences. But learned behavior may also exert an influence on a person's approach to the tasks. A significant amount of research analyzing the spatial ability differences between males and females has been published (for a review of this literature see Montello et al. 1999). Many of the findings discussed in their review suggest that males and females differ in their ability to perform many spatial ability tasks. However, based on their own findings, Montello et al. (1999, 529) are careful to point out that it is incorrect to assume that "males in general have better spatial ability than females." They also propose that strategy differences may be observed during the completion of some spatial tasks. But the extent to which the differences are sex-related (based on real physiological differences such as hormones or brain structure) or gender-related (based on socialization and education) is not fully known.

Many researchers use a "think aloud" method for investigating map-reading strategies (Blades and Spencer 1986). They present subjects with a map and ask them to think aloud, or describe how they are learning the map. For example, Thorndyke and Stasz (1980) asked subjects to look at a map for a given amount of time and then reproduce the map from memory. While studying the map, subjects explained the strategies they used (memorizing one area at a time or memorizing hierarchy, for example). The researchers found that certain strategies resulted in more accurate map learning. Additionally, Gilhooly et al. (1988) and Crampton (1992) used the "think aloud" protocol to investigate strategy differences between expert and novice wayfinders by asking subjects to explain how they are learning the map.

Investigating strategies does not always involve the "think aloud" method, however. Kulhavy, Schwartz, and Shaha (1983) studied strategies people use to remember map information by presenting subjects with three versions of a single map and then asking them to perform a recall task, followed by a recognition task. The first map version contained features labeled with text only, the second version contained text in addition to mimetic symbols, and the final version contained text plus geometric symbols. Because subjects performed better on the task when faced with the text/mimetic symbols and the text/geometric symbols maps than they did on the text-only version, the researchers concluded that map viewers rely on visual memory to learn and retrieve map information.

Cognitive Processes

Researchers are beginning to investigate cognitive processes with as much or more frequency than they investigate strategies. The methods used in cognitive process experiments differ from those used in cognitive strategy experiments. Most often, the researcher has identified a specific cognitive process that may be used in map reading, and a subject's level of task performance is assessed relative to other subjects' performance on the same task. These methods usually result in researchers presenting a subject with a specific task, series of tasks, or series of questions, designed to reflect their ability level in a given cognitive process.

For example, several researchers have designed experiments to reflect the relative influence of object rotation on map-reading ability. These experiments investigate whether a person must perform a mental rotation when the map orientation and direction of travel are not aligned (Levine, Marchon, and Hanley 1984; Lloyd and Steinke 1984; Shepard and Hurwitz 1984; Aretz and Wickens 1992). The results of these studies indicate that object rotation is a cognitive process used during map reading and may influence a person's map-learning/reading speed and accuracy. This influence is especially profound with more complex maps because, as maps increase in complexity, the map reader is less able to mentally rotate the entire map and the rotation process is abandoned and replaced with an analytic process (Aretz and Wickens 1992). Additionally, researchers have studied the potential relationship between cognitive ability measures and map-reading ability. The results are consistent between studies and indicate that higher scores on general mental/cognitive ability tests correlate with higher scores in map reading ability tests (Thorndyke and Stasz 1980; Sholl and Egeth 1982; Lloyd and Steinke 1984; Streeter and Vitello 1986; Kovach, Surrette, and Aamodt 1988).

Many of the cognitive studies conducted by geographers are carried out under the general heading of "cognitive mapping." One of the earliest definitions of cognitive mapping was presented by Downs and Stea (1973, 9), who define it as "a process composed of a series of psychological transformations by which an individual acquires, codes, stores, recalls, and decodes information about the relative locations and attributes of phenomena in his everyday spatial environment." Studies such as the ones referenced thus far often focused on specific issues in an attempt to understand the *nature* of cognitive mapping.

Cognitive Processes Associated with Navigational Map Reading

Navigation is a necessary part of nearly everyone's life, and, as a result, most people will become familiar with at least one geographic area to the extent that they become capable of route planning and wayfinding. They will find their way through an environment using a variety of strategies and guides (such as verbal or written instructions, printed [tangible] maps, or memory based on previous exposure) to aid them. These guides and strategies aid in the development of cognitive maps, which are "any internal representation of a set of geographic locations that has been learned" (Lloyd 2000, 517). But, while memorial systems may differ from other influencing control processes as suggested by Kulhavy and Stock (1996), some processes may influence how well the spatial information is encoded; in addition, the manner in which the information is presented (through a cartographic map or through the physical environment, for example) may affect (and result in differing) information-processing abilities.

Cognitive Mapping

People will develop either survey or route knowledge, depending on *how* they learn the environment. Survey knowledge provides a user with a bird's-eye view of the geometry of the environment and is gathered through graphic representations (maps) or verbal representations (such as written or oral directions). Route knowledge results from the user "seeing" the environment from an on-the-ground perspective and is gathered by traveling in the environment without a map (exploring, or continuous exposure). Lloyd and Cammack (1995, 5) refer to these viewing vantages as internal perspective (survey knowledge from representations) versus external perspective (route knowledge from experience in the environment). They distinguish between external perspective as viewing an object from a "fixed vantage point" such as a map and internal perspective where the "viewer and the objects are part of the same space." Lloyd (1997) further suggests that the internal/external paradigm is not the only influence that perspective has on developing cognitive maps. When viewing a static map, the reader maintains a single perspective, relating geographic space along horizontal and vertical axes, as opposed to many perspectives experienced as one navigates through real geographic space. Research shows that knowledge gained by repeated exposure to an area (route knowledge), as opposed to exposure to representations (survey knowledge), results in more accurate development of a cognitive model of an area (Thorndyke and Hayes-Roth 1982). Additional research shows that increased exposure to an environment may lead a person eventually to develop survey knowledge, thereby enabling that person to visualize a more complete picture of the area (Golledge 1992). The process of creating a cognitive map through route knowledge gathered from the environment without the aid of a map is referred to as environmental mapping. The process of encoding a cognitive map from a cartographic map is called survey mapping.

Environmental Mapping

Learning an environment through the use of a map and learning an environment through repeated exposure are different tasks. While both may contribute to the development of cognitive maps, the cognitive process associated with the task of creating a cognitive map from the environment alone (without a printed map) will be referred to as *environmental mapping*. Through this process, a person "constructs patterns in the external environment and corresponding patterns in the mind . . . [where] objects and patterns in the external environment are being determined, marked, and internally represented as . . . the emerging cognitive map" (Stern and Portugali 1999, 107).

According to Lloyd (2000), cognitive maps are updated with repeated exposure to a spatial environment. "'Repeated exposure" may constitute many years of traveling the same route or merely a few quick scans of the objects on the sides of the road while driving. Eventually, through repeated exposure, cognitive maps will be brought to a steady state, meaning that the amount of new information brought to the map with each successive trip through the environment will diminish (Stern and Portugali 1999). The steady state refers not to achieving accuracy, but instead to achieving usefulness, that is, when a person can use the map to effectively navigate through the environment.

The process of environmental mapping may not immediately appear to have a direct effect on a person's map reading, but a person's ability to navigate, or to develop route knowledge "on the fly" may profoundly influence how well he or she can navigate with a map. Although this process occurs independently of the map, if individuals can quickly encode an accurate cognitive map, they may be able to develop a "sense of direction" or a sense of "where they are" on both their cognitive map as well as the tangible navigation map. They may have the ability to reorient themselves if confronted with a part of the environment from a different angle, and, after initial exposure to an area, they may need to refer to their map less often.

Although wayfinding (the task of navigating without the aid of a map) is not a specific focus in this paper, it may be pertinent to note here that environmental mapping may also influence wayfinding ability, where wayfinding is accomplished without the use of a map. If a person is able to create a functional cognitive map through environment mapping, wayfinding may be easier and more efficient. A person may be able to associate general world information (cardinal directions or the position of the sun) with direction of travel and may choose a street with which they are unfamiliar because they know it will lead them in the correct relative direction to the eventual travel goal (final travel destination) (Cornell and Heth 2001).

Survey Mapping

The process of creating a cognitive map based on information gathered from a printed (tangible) street map may be referred to as survey mapping, as survey knowledge is gathered from "bird's-eye view" street maps. While both environmental as well as survey mapping are processes that independently or together form cognitive maps, the formation process is different, depending on the type of stimuli (printed map versus environmental exploration).

In practice, most people probably form a single cognitive map during the task of navigating. Because cognitive maps are formed from different stimuli and are constantly updated, a person will begin his or her navigation task with a cognitive map developed from survey mapping or from environmental mapping. If the person has already gained some exposure to the environment in which she is conducting the navigational map use task, her cognitive map has already formed to some degree through the process of environmental mapping. As she consults the printed map, she will update the cognitive map through the process of survey mapping. However, if a person has no previous exposure to an area, the original cognitive map will be developed through survey mapping and as he begins to navigate, the cognitive map will be updated through environmental mapping. Eventually, both processes lead to the development of a single cognitive map.

Object Rotation

Many experiments conducted in the area of spatial ability focus on determining the effects of a single cognitive ability, as it is associated with a particular map-reading task. Some researchers have geared their studies to trying to determine the relevance of object rotation as a cognitive process (where mentally or physically rotating the map is the cognitive task) (Hintzman, O'Dell, and Arndt 1981; Steinke and Lloyd 1983; Lloyd and Steinke 1984; Aretz and Wickens 1992).

Aretz and Wickens (1992) designed experiments to determine whether mental rotations are required in map use and whether map complexity affects rotation efficiency. They showed subjects sets of two side-by-side maps and asked them to determine whether one of the maps was correctly rotated (as opposed to flipped or mirrored). Their results indicate both that rotation is a process affecting map reading and map complexity affects the efficiency of rotation. Shepard and Hurwitz (1984) asked subjects to use computer-simulated travel paths in order to determine the correct direction of travel on turns (left or right). The location of the turn was not always in an "up" location on the map (meaning that the direction of travel on a path when the turn is encountered is not "up"), and their results indicate that when the turn was not "up," response times increased. In fact, response times increased linearly as the angle of the travel path increased from "up." They concluded that subjects first had to mentally rotate the map to the "up" position before they could decide which direction to turn. Levine, Marchon, and Hanley (1984) investigated the affects of rotation on "You-Are-Here" maps. Similar to previously discussed results, they discovered that response time increased and task completion was less accurate when the maps were misaligned, or not in the forward-up position. The forward-up position is probably more effective even when the task performed involves geographical directions. Lloyd and Steinke (1984) asked subjects to view a series of maps that had been rotated and possibly flipped and determine whether the map was the "correct" or a "mirror" (flipped) version. Their results indicate that maps containing more information required longer response time when rotated from north up.

Mentally rotating a two-dimensional object appears to be an integral process associated with reading paper maps since most paper maps are not multioriented, meaning that a map will maintain only one direction toward the top of the map. Cartographic tradition dictates that north is most always oriented toward the top. Since map users are familiar with this protocol, "orientation bias" occurs when they are faced with a map that is not in north-up orientation. Studies (MacEachren 1992; Lloyd and Cammack 1995) show that maps may be learned so that they are orientation free, but the accuracy and amount of time taken to encode information from multiorientation is greater as compared to similar maps that are in north-up orientation. Real-life navigation will almost always require a map user to travel in a direction other than north (or whatever direction is oriented toward the top of the map). Therefore, when using a traditional north-up oriented map, readers must rotate the map mentally and maintain the actual map and its objects, including text and symbols, in its original orientation, or they must physically rotate the map and then mentally rotate the text, symbols, and other objects included on the map. Similar to the You-Are-Here map findings, studies have shown that map readers perform paper map-reading tasks more accurately and faster when the map is physically rotated so the direction of travel is oriented toward the top of the map (Aretz and Wickens 1992). That finding suggests that mental rotation of text and symbols is less difficult than mental rotation of map geometry. Navigation errors that result from incorrect object rotation are typically relative errors. These errors result when the frame of reference on a map is manipulated as a result of rotation, translation (when frame of reference is altered), or scaling of the map during the mental encoding process (Lloyd 1989). Navigation errors that occur as a result of object rotation ability may be alleviated with the use of in-car navigation system maps, which are constantly and automatically rotated.

Since most map readers will need to travel in a direction other than the one that is "up" on the map, they will most likely be faced with the task of object rotation. This task will not be encountered every time a person uses a navigation map but, when presented, may have a significant influence on a person's ability to benefit from the map.

Symbol Identification

Since the purpose of a map is to show a scaled representation of the real world, all maps contain symbols (Robinson et al. 1995; Dent 1999). Symbol identification is a task facing every map reader, and the ability to understand symbolization relies on the ability to differentiate between symbols and understand that they represent real three-dimensional environmental objects (Bluestein and Acredolo 1979). The complexity of the map affects the encoding of symbols and information into the spatial memory system (Winn and Sutherland 1989). The number of symbols a map reader can encode varies according to the individual spatial memorial system (Winn 1991).

Studies have shown that map readers of nearly any age (preschool to adults) seem to be able to decode the relatively simple symbols contained on most maps (Blaut and Stea 1971, 1974; Meyer 1973; Bluestein and Acredolo 1979; Ottosson 1988; Freundschuh 1990). Therefore, symbol identification may be a poor discriminator between better and worse map readers, but it is basic to one's ability to read and navigate effectively with a map and is faced *every time* a person reads a map.

Map/Environment Interaction

The task of navigating with a map requires the map reader to interact and relate the map and the environment with and between one another. Two processes (visualization and self-location) are identified and may govern specific tasks associated with map/environment interaction.

Visualization For persons required to navigate in unfamiliar territory, the survey knowledge obtained from a map provides the map reader with an aerial view allowing them to "see" what lies ahead. According to Crampton (1992), in order to visualize the area, the map reader must mentally transform the two-dimensional map into a three-dimensional form and "see" its characteristics and objects (morphology, streets, and buildings). This act of seeing with the mind's eye, or developing a mental representation as a result of seeing a visual image, will be referred to as *visualization*.

Visualization is a cognitive process and allows a person to identify patterns and impose order (MacEachren et al. 1992). This process allows map readers to "see themselves" on the map and place themselves in the real-world environment. In psychological literature, the term *visualization* is used to refer to a process in which a person can see in his mind how an object would appear after subjected to a single transformation or series of transformations. In this case, the term is used more specifically to refer to the process associated with the map-to-environment (or, more accurately, a representation-to-environment) interaction task, meaning that the map reader (or person hearing verbal directions or otherwise receiving spatial information) takes information from the representation and applies it to the environment by visualizing and predicting areas yet unseen and recognizing those areas once confronted. The process involves encoding spatial information acquired from the source (in this case, the navigation map) and comparing the encoded data to the environment to determine upcoming consequences (what the map reader will see in the environment as he travels one mile down the road).

Visualization can be thought of as continuous as opposed to discrete; it is a process conducted by map users while they are actively reading the map and navigating. While moving through an area (and a map), the user is constantly changing locations in the real world as well as on the map and must presumably continuously visualize what lies ahead in the environment.

As the term is used here, visualization as a cognitive process of map reading differs only in application from definitions of spatial visualization used previously (mostly in psychological research), where the term has been used to refer to "recognition, retention, and recall of two- or three-dimensional structures, in which change among the internal parts is depicted" (Golledge, Dougherty, and Bell 1995, 136). As these authors suggest, spatial visualization (as defined here) may be the most emphasized element in psychological spatial tests, but may be the least useful to geographers. A geographer's view of spatial ability would nearly always center on geographic location, and geographic space may be considerably different than geometric space (rotating cubes or axes). So, the visualization process itself may not necessarily differ substantially between the psychology and geography perspectives. But the elements to which the process applies, geometric space versus geographic or environmental location, does differ.

Self-Location Few researchers have addressed the issue of locating oneself on a map using the clues presented in the surrounding environment. Peruch and Pailhous (1986) asked subjects to find their viewpoints after being presented with geometric scenes, consisting of same-size, but different shape and color points (no lines or polygons included). Levine, Marchon and Hanley (1984) discussed the advantages of you-are-here maps, which are permanently affixed to the walls (shopping malls, specifically) aligned with the environment (as opposed to "misaligned"). However, the literature fails to address the degree to which a person's self-location ability may influence their navigational map use. In this context, the term *self-location* refers to a person's ability to effectively relate the clues on the map to the represented real world. Map readers solve the problem of determining their location on the map by recognizing real-world landmarks and relationships (clues), putting those clues together, and placing themselves on the map. A person executes this task when observing objects in the environment such as a grocery store, a gas station, and a library and using them to locate their correct relative position on the map. Sometimes, these features are not even on the map, but clues are pieced together from bits of previous knowledge (daily rush-hour traffic pattern as a clue to the location of downtown, street-numbering systems, commercial and residential density patterns, etc.). A person is able to deduce the correct location through logical reasoning.

Self-location is similar to visualization in that both require the reader to work between the two-dimensional map and the three-dimensional world. But, while visualization is associated with the map-to-environment task, requiring the map user to refer to the map during navigation and then to visualize or predict what lies ahead, self-location is associated with the environment-to-map task and is essentially a problem-solving act. Unlike visualization, which is presumably a continuous process occurring while the map reader is *in the process* of navigating, self-location is discrete and will take place at the start of navigation when locating oneself on the map, at the end of navigation, and in between at critical junctures such as when "double-checking" location or correcting erroneous decisions (getting lost).

Path Integration

Path integration is the process that allows a person to maintain a sense of direction or a sense of location within an environment (Loomis et al. 1999). Often, internal representations are developed according to how the information was encoded. Survey and route knowledge have been addressed above (survey mapping and environmental mapping, each of which may contribute to the development of a cognitive map). The representation that is developed from path integration is different from route knowledge developed during environmental mapping. In the case of environmental mapping, the cognitive map that is created represents a "route that has been traversed; as such, it contains information about the various path segments and turns as well as off-route landmarks that might be used in subsequent piloting" (Loomis et al. 1999, 132). However, the representation developed during path integration contains route information such as travel velocity or turns; a person identifies his or her location relative to the origin, and the representation is not used to navigate back to any position along the route. While the distinction may seem slight, route knowledge, or environmental mapping, results in the development of a cognitive map of an environment; path integration results in a sense of direction, or being able to move effectively in the environment, while maintaining a sense of the origin or homeward base. With a sense of direction, a person maintains "knowledge of the location and orientation of . . . [a person] . . . both with respect to facing direction (heading) and the location of significant nearby or distantly perceived (or memorized) features (landmarks)" (Golledge 1999, 33).

Path integration involves developing a frame of reference or origin. In order to accomplish this task, one must become familiar with spatial orientation, which requires a person to gauge a position relative (in terms of distance and direction) to other objects in the environment (Rieser 1999). According to Tversky (2001), frames of reference organize otherwise eclectic spaces into an organized space by locating other objects within their space based on at least two organizational frameworks, hierarchical organization and canonical axes. Hierarchical organization refers to reference frames in which smaller areas are contained within larger ones; for example, cities organized within states or buildings organized within neighborhoods. Hierarchical organization also includes interconnectivity knowledge; thoroughfares connect neighborhoods and secondary streets are used to connect starting and ending points with the same neighborhood (Cornell and Heth 2001). Canonical axes provide a framework in which reference frames are organized according to north-south or east-west axes of the world.

Experiments that are designed to assess path-integration ability usually involve leading a subject around or through a maze-like environment; in addition, the experiments often focus on the abilities of sighted as well as vision-impaired individuals. In some cases, subjects are led around the outside boundaries of an environment and then asked to travel through the environment to the origin (Klatzky et al. 1990; Loomis et al. 1993; Passini, Proulx, and Rainville 1990) or indicate the direction of the origin (Klatzky et al. 1998). In other related experiments, subjects are led to more than one location from a common origin and asked to identify the direction of multiple locations (Loomis et al. 1993).

Conclusions

Identifying the tasks, strategies, and control processes used by individuals undertaking the task of navigational map reading is imperative, since researchers seeking to understand how they affect task completion must identify the object of study before it can be studied. Once a process is identified, researchers may begin to understand how the process affects navigational map reading and, ultimately, develop a sound model of the complex processes controlling navigational map use. The importance of developing this understanding, and potentially, a navigational map-use processing model, is much more than expanding the theoretical basis of cartography (although important in it's own right).

If we may begin to understand how people use maps, we may begin to develop systematic and effective methods of teaching people how to use maps. Clearly, many people would benefit from such methods. But consider also the impact that this understanding could have on cartographic research that focuses on disabled map users. If we can identify specifically how people perform the task of navigational map reading, and especially if we can understand how and where that functioning takes place in the human mind, this understanding may be applied, at least to some degree, to all map users. For example, if a specific process is found to exert a profound influence on map-use ability and if we can identify the area of the brain that controls that process, we may be able to target a specific process or a specific area of the brain and focus or streamline some map teaching and learning for disabled users (both physically disabled, such as blind users, and mentally disabled).

Kitchin (1999, 233) argues that some researchers are rightly beginning to question the "ethical basis and validity of traditional expert models of research" to focus instead on studies that may lead to emancipating and empowering disabled map users. The importance of empowering disabled map users cannot be overstated. To that end, coupling any developed models or understanding of basic human processing that we now have, and will likely come to have in the future, with the new disability research approaches may aid researchers working in the area of disability studies.

We are an increasingly mobile society and while new technologies (such as personal mobile GPS units and in-car navigation systems) provide navigational assistance, map reading still is a task faced frequently by nearly everyone. As such, a person's ability to complete navigational map reading both efficiently and effectively may exert a profound influence on their mobility. ■

Literature Cited

Anastasi, A., and S. Urbina. 1997. *Psychological Testing*. Upper Saddle River, NJ: Prentice-Hall.

Aretz, A. J., and C. Wickens. 1992. The mental rotation of map displays. *Human Performance* 5 (4): 303–28.

Blades, M., and C. Spencer. 1986. The implications of psychological theory and methodology for cognitive cartography. *Cartographica* 23 (4): 1–13.

———. 1987. How do people use maps to navigate through the world? *Cartographica* 24 (3): 64–75.

Blaut, J. M., and D. Stea. 1971. Studies of geographic learning. *Annals of the Association of American Geographers* 61:387–93.

———. 1974. Mapping at the age of three. *The Journal of Geography* 73 (7): 5–9.

Bluestein, N., and L. Acredolo. 1979. Developmental changes in map-reading skills. *Child Development* 50:691–97.

Bronzaft, A., S. Dobrow, and T. O'Hanlon. 1976. Spatial orientation in a subway system. *Environment and Behavior* 8:575–94.

Cole, D. G. 1981. Recall vs. recognition and task specificity in cartographic psychophysical testing. *The American Cartographer* 8 (1): 55–66.

Cornell, E. H., and C. D. Heth. 2001. Route learning and wayfinding. In *Cognitive mapping: Past, present and future*, ed. R. Kitchin and S. Freundschuh, 66–83. London: Routledge.

Crampton, Jeremy. 1992. A cognitive analysis of wayfinding expertise. *Cartographica* 29 (3 and 4): 46–65.

Dent, B. 1999. *Cartography: Thematic map design*. Dubuque, IA: Wm. C. Brown Publishers.

Downs, R. M., and L. S. Liben. 1987. Children's understanding of maps. In *Cognitive processes and spatial orientation in animal and man. Volume 2: Neurophysiology and developmental aspects*, ed. P. Ellen and C. Thinus-Blanc, 202–19. Dordrecht, The Netherlands: Martinus Nijhoff.

———. 1988. Through a map darkly: Understanding maps as spatial representations. *Genetic Epistemologist* 16:11–18.

———. 1991. The development of expertise in geography: A cognitive-developmental approach to geographic education. *Annals of the Association of American Geographers* 81:304–27.

———. 1993. Mediating the environment: Communicating, appropriating, and developing graphic representations of place. In *Development in context: Acting and thinking in specific environments*, ed. R. H. Wozniak and K. Fischer, 155–81. Hillsdale, NJ: Lawrence Erlbaum Associates.

———. 1997. The final summation: The defense rests. *Annals of the Association of American Geographers* 87:178–80.

Downs, R., and Stea, D., eds. 1973. *Image and environment*. Chicago: Aldine.

Eliot, J., and I. M. McFarlane-Smith. 1983. *An international directory of spatial tests*. Oxford: NFER-Nelson Publishing Company.

Flannery, J. J. 1971. The relative effectiveness of some common graduated point symbols in the presentation of quantitative data. *The Canadian Cartographer* 8 (2): 96–109.

Freundschuh, S. 1990. Can young children use maps to navigate? *Cartographica* 27 (1): 54–66.

Garling, T., and R. Golledge. 2001. Cognitive mapping and spatial decision making. In *Cognitive* *mapping past, present and future*, ed. R. Kitchin and S. Freundschuh, 44–65. Routledge: London.

Gilhooly, K. J., M. Wood, P. R. Kinnear, and C. Green. 1988. Skill in map reading and memory for maps. *The Quarterly Journal of Experimental Psychology* 40A (1): 87–107.

Gilmartin, P. P. 1981. The interface of cognitive and psychophysical research in cartography. *Cartographica* 18 (3): 9–20.

Golledge, R. G. 1992. Place recognition and wayfinding: Making sense of space. *Geoforum* 23 (2): 199–214.

———. 1999. Human wayfinding and cognitive maps. In *Wayfinding behavior*, ed. J. Golledge. Baltimore: Johns Hopkins University Press.

Golledge, R. G., V. Dougherty, and S. Bell. 1995. Acquiring spatial knowledge: survey versus route-based knowledge in unfamiliar environments. *Annals of the Association of American Geographers* 85 (1): 134–58.

Groop, R. E., and D. G. Cole. 1978. Overlapping graduated circles: magnitude estimation and method of portrayal. *The Canadian Cartographer* 15 (2): 114–22.

Hayes-Roth, B., and F. Hayes-Roth. 1979. A cognitive model of planning. *CognitiveScience* 3:275–310.

Hintzman, D. L., C. S. O'Dell, and D. R. Arndt. 1981. Orientation in cognitive maps. *Cognitive Psychology* 13:149–206.

Jenks, G. R. 1975. The evaluation and prediction of visual clustering in maps symbolized with proportional circles. In J. C. Davis and M. J. McCullagh, eds. D*isplay and analysis of spatial data*, ed. J. C. Davis and M. J. McCullagh. New York: John Wiley & Sons.

Kimerling, A. J. 1975. A cartographic study of equal value gray scales for use with screened gray areas. *The American Cartographer* 2:119–27.

Kitchin, R. M. 1999. Ethics and morals in geographical studies of disability. In *Geography and Ethics: Journeys through a Moral Terrain*. ed. J. Proctor, and D. Smith. 223–36. London: Routledge.

Klatzky, R. L., J. M. Loomis, A. C. Beall, S. S. Chance, and R. G. Golledge. 1998. Spatial updating of self-position and orientation during real, imagined and virtual locomotion. *Psychological Science* 9 (4): 293–98.

Klatzky, R. L., J. M. Loomis, R. G. Golledge, J. G. Cicinelli, S. Doherty, and J. W. Pellegrino. 1990. Acquisition of route and survey knowledge in the absence of vision. *Journal of Motor Behavior* 22 (1): 19–43.

Kolacny, A. 1969. Cartographic information: A fundamental concept and term in modern cartography. *The Canadian Cartographer* 6:47–49.

Kovach, R. C. Jr., M. A. Surrette, and M. G. Aamodt. 1988. Following informal street maps: Effects of map design. *Environment and Behavior* 20 (6): 683–99.

Kulhavy, R. W., N. H. Schwartz, and S. H. Shaha. 1983. Spatial representation of maps. *American Journal of Psychology* 96 (3): 337–51.

Kulhavy, R. W., and W. A. Stock. 1996. How cognitive maps are learned and remembered. *Annals of the Association of American Geographers* 86:123–45.

Levine, M., I. Marchon, and G. Hanley. 1984. The placement and misplacement of you-are-here maps. *Environment and Behavior* 16 (2): 139–57.

Liben, L. S., and R. M. Downs. 1989. Understanding maps as symbols: The development of map concepts in children. In *Advances in child development and behavior*. H. W. Reese, ed. New York: Academic Press.

Lloyd, R. 1982. A look at images. *Annals of the Association of American Geographers* 72 (4): 532–548.

———. 1989. Cognitive maps: Encoding and decoding information. *Annals of the Association of American Geographers* 79 (1): 101–24.

———. 1997. *Spatial cognition: Geographic environments*. Dordrecht: Kluwer Academic Publishers.

———. 2000. Self-organized cognitive maps. *The Professional Geographer* 52 (3): 517–31.

Lloyd, R., and R. Cammack. 1995. Constructing cognitive maps with orientation biases. In *The construction of cognitive maps*, ed. M. Portugali. Dordrecht: Kluwer Academic Publishers.

Lloyd, R., and T. Steinke. 1984. Recognition of disoriented maps: The cognitive processes. *Cartographic Journal* 21:55–59.

Loomis, J. M., R. L. Klatzky, R. G. Golledge, J. G. Cicinelli, J. W. Pellegrino, and P. A. Fry. 1993. Nonvisual navigation by blind and sighted: Assessment of path integration ability. *Journal of Experimental Psychology: General* 122 (1): 73–91.

Loomis, J. M., R. L. Klatzky, R. G. Golledge, and J. W. Philbeck. 1990. Human navigation and path integration. In *Wayfinding behavior*, ed. R. G. Golledge. Baltimore: Johns Hopkins University Press.

MacEachren, A. M. 1992. Learning spatial information from maps: Can orientation-specificity be overcome? *The Professional Geographer* 44 (4): 431–43.

MacEachren, A. M., B. P. Buttenfield, J. B. Campbell, D. W. DiBiase, and M. Monmonier. 1992. Visualization. In *Geography's inner worlds: Pervasive themes in contemporary American geography*, ed. R. F. Abler, M. G. Marcus, and J. M. Olson. New Brunswick: Rutgers University Press.

Meyer, J. 1973. Map skills instruction and the child's developing cognitive abilities. *Journal of Geography* 72: 27–35.

Monmonier, M. 1974. Measures of pattern complexity for choropleth maps. *American Cartographer* 1 (2): 159–69.

———. 1996. *How to lie with maps*. Chicago: University of Chicago Press.

Montello, D. R. , K. L. Lovelace, R. G. Golledge, and C. M. Self. 1999. Sex-related differences and similarities in geographic and evnironmental spatial abilities. *Annals of the Association of American Geographers* 89:515–534.

Morrison, J. L. 1976. The science of cartography and its essential processes. *International Yearbook of Cartography* 16:84–97.

Olson, J. M. 1975. Autocorrelation and visual map complexity. *Annals of the Association of American Cartographers* 65 (2): 189–204.

———. 1979. Cognitive cartographic experimentation. *The Canadian Cartographer* 16 (1): 34–44.

Ottosson, T. 1988. What does it take to read a map? *Scientific Journal of Orienteering* 4:97–106.

Passini, R., G. Proulx, and C. Rainville. 1990. The spatio-cognitive abilities of the visually impaired population. *Environment and Behavior* 22:91–116.

Peruch, P., and J. Pailhous. 1986. How do we locate ourselves on a map?: A method for analyzing self-location processes. *Acta Psychologica* 61:71–88.

Ratajski, L. 1973. The research structure of theoretical cartography. *International Yearbook of Cartography* 13:217–27.

Rieser, J. J. 1999. Dynamic spatial orientation and the coupling of representation and action. In *Wayfinding behavior*, ed. R. G. Golledge. Baltimore: Johns Hopkins University Press.

Robinson, A. H., J. L. Morrison, P. C. Muehrcke, A. J. Kimerling, and S. C. Guptill. 1995. *Elements of cartography*. New York: John Wiley and Sons.

Shepard, R., and S. Hurwitz. 1984. Upward direction, mental rotation, and the discrimination of left and right turns in maps. *Cognition* 18:161–93.

Sholl, J. J., and H. E. Egeth. 1982. Cognitive correlations of map-reading ability. *Intelligence* 6:215–30.

Steinke, T., and R. Lloyd. 1983. Images of maps: A rotation experiment. *The Professional Geographer* 35:455–61.

Stern, E., and J. Portugali. 1999. Environmental cognition and decision making in urban navigation. In *Wayfinding behavior*, ed. R. G. Golledge. Baltimore: Johns Hopkins University Press.

Streeter, L. A., and D. Vitello. 1986. A profile of drivers' map-reading abilities. *Human Factors* 28:223–39.

Thorndyke, P., and B. Hayes-Roth. 1982. Differences in spatial knowledge acquired from maps and navigation. *Cognitive Psychology* 14:560–89.

Thorndyke, P., and C. Stasz. 1980. Individual differences in procedures for knowledge acquisition from maps. *Cognitive Psychology* 12:137–75.

Tversky, B. 2001. Levels and structure of spatial knowledge. In *Cognitive mapping: Past present and future*, ed. In R. Kitchin and S. Freundschuh. 24–43. London: Routledge.

Winn, W. D. 1991. Learning from maps and diagrams. *Educational Psychology Review* 3 (3): 211–47.

Winn, W. D., and S. W. Sutherland. 1989. Factors influencing the recall of elements in maps and diagrams and the strategies used to encode them. *Journal of Educational Psychology* 81 (1): 33–39.

Wood, D. 1992. *The power of maps*. New York: Guilford.

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