Navigational Map Reading: Predicting Performance and Identifying Relative Influence of Map-Related Abilities

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Most of us know people who "cannot read a map" and others who seem to navigate intuitively. Such discrepancy in ability is puzzling, given that most people navigate to and between locations many times every day. In many cases the locations are those that are destinations we visit regularly (school, work, home, store), but people are also frequently faced with the task of navigating to a new location, whether it is a store not previously visited or a vacation destination. Why do such differences exist and can we identify some of the human traits or abilities that lead to such differences? This article presents results from empirical research designed to investigate these differences. Three research questions were asked: (1) Can a reliable and valid navigational map reading test instrument be designed? (2) To what extent does the instrument predict navigational map reading? and (3) What is the relative influence of individual map-related abilities on overall navigational map reading? A Navigational Map Reading Ability Test (NMRAT) was designed to measure five map-related abilities, and a Real World Map Navigation Exercise (RWMNE) was developed to assess the validity of the NMRAT. Forty-four subjects completed both the test and the exercise. Results demonstrate that, overall, the NMRAT is both reliable and valid as an indicator of navigational map reading ability. Results also show that the five map-related abilities exert different influence on the overall task of map navigation. *Key words: abilities, map reading, navigation.*

Presented with the task of using a map to aid in navigation between locations in the environment, different people will likely complete the task using different strategies and cognitive processes, and with different degrees of success. In fact, some may not be able to complete the task at all and others may navigate with ease after only an initial cursory glance at the map. Some will physically rotate their map throughout the course; others will not. Some will stop to get their bearings or check their map, others will press on without stopping and without checking their map. Why? Why can some people complete the navigational map reading task to greater degrees of effectiveness and efficiency than can others? Clearly some people are better map navigators than are others. But, what are the individual abilities that affect such a difference?

The research presented in this article investigated navigational map reading abilities and addressed three primary questions: (1) Can a reliable and valid navigational map reading test instrument be designed? (2) To what extent does the instrument predict navigational map reading? (3) What is the relative influence of individual map-related abilities on overall navigational map reading? The presentation of the results will include discussion of the design (including reliability and validity assessments) of the navigational map reading testing instrument, referred to as the Navigational Map Reading Ability Test (NMRAT). Results also reveal the relative influence that individual map-related abilities (measured with the NMRAT) exert on map navigation.

This research focuses specifically on measuring the relative influence that select spatial abilities exert on a person's performance when navigating *to an unknown location with a printed map*. Navigational map reading is a complex task composed of relatively simpler cognitive subtasks (though simpler relative to the larger task, many of these subtasks are in fact complex themselves). Navigation "involves the planning of travel through the environment, updating position and orientation during travel, and, in the event of becoming lost, reorienting and reestablishing travel toward the destination" (Loomis et al. 1999, 125). The *type* of navigation performed may be even further defined. Allen (1999) offers a three-category scheme of navigation: (1) travel to reach a familiar destination, (2) exploratory travel, returning to a familiar location, (3) travel to a new (previously unknown) location.

The type of navigation conducted may dictate the format of the navigational aid. Travel to a familiar location (such as the daily commute to work or school) likely does not involve the use of either a printed map or verbal directions. Exploratory travel may or may not

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involve the use of such aids. However travel to a new, specific, location often involves the use of navigation aids, which may include a printed map, verbal or written directions, or, increasingly, in-car navigation systems. The research presented here was designed to investigate navigation to a new location with a map. The printed map is of paramount importance here and it should be noted that the focus is *not* on wayfinding without a map.

Context

Most research that involves the exploration of human cognition in any way is thorny from the onset due to the complexity of and the unknowns about the human brain. Every moment of human existence involves the human brain and cognition, and every action, from blowing a bubble to seeking solutions to differential equations, requires a use of the brain in various ways. As a result, cognition researchers are often careful about identifying the specific area in which their research is focused (i.e., tasks, strategies, processes, intelligence, personality, memory, emotions, perception, abilities, etc.).

Tasks, Strategies, and Processes

This research investigated primarily those cognitive abilities associated with navigational map tasks. When most humans engage in actions, they will complete a task (or tasks). They will perform these tasks using chosen strategies, the choice of which may involve little conscious thought or may be a labored decision-making process. Individuals' cognitive processes affect strategy choice and the ability (measured in efficiency and/or effectiveness) to complete a task.

Map-Related Tasks. A map-related task is a charge a person is given during the map reading process. Tasks vary by map purpose; for example, tasks associated with reading a thematic map for the purpose of extracting and analyzing spatial data patterns will differ from tasks completed during navigational map reading. Examples of map-related tasks include identifying symbols, route planning, and locating oneself on a street map. Subjects participating in cognitive cartographic experiments are often asked to complete tasks such as sketching a map environment (Golledge, Dougherty, and Bell 1995), distinguishing between rotated map images (Aretz and Wickens 1992), identifying target boundaries (Brennan and Lloyd 1993), or estimating direction (MacEachren 1992).

Map-Reading Strategies. Map reading strategies are plans, tactics, or methods used by individual map-readers during the map reading process (Lobben 2004). These strategies differ from tasks in that different map-readers may utilize different strategies to accomplish the same task. For example, if asked to perform a task such as drawing a representation of an environment, one person may relate all locations based on *linear distance* (miles, feet, meters, kilometers, etc.), another person may relate locations based using an estimate of distance based on *travel time*. In this case, the task is the same, estimating distance, but the strategies used are different: linear distance versus travel time.

Cognitive Processes. Cognitive processes are more complicated, both in theory and in research practice. Cognitive processes are control agents that govern which strategies people utilize in the performance of specific tasks (Anastasi and Urbina 1997). Although everyone performs the same cognitive processes, a person's ability levels in specific processes may dictate the strategies used to complete a task (Lobben 2004).

In research practice, experiments that focus on cognitive processes of map reading/use can be complex in design and execution. Whether the research question addresses identifying process, assessing ability levels, or determining influence on strategies and tasks, gathering research data becomes problematic. For example, if a researcher questions whether map-readers utilize the strategy of physically or mentally rotating their maps during route planning or navigation, the researcher can observe whether a subject rotates the map or not. However, to determine the influence that mental map rotation ability has on the strategy used during the navigation task, a map-reader's ability to mentally rotate map images must be assessed, compared to the strategies employed, and, ideally, analyzed against overall map reading ability to determine the process's influence on the task.

Another method that researchers are applying to investigate cognitive processes that may be connected with navigational map reading is functional Magnetic Resonance Imaging (fMRI). Such investigation requires a subject to complete tasks while undergoing a fMRI scan. Most of this research is conducted by psychologists and the tasks are not likely to include map graphics, nor are the researchers claiming a link between their studies and navigational map reading. But geographers may identify links between much of the fMRI research and navigational map reading. Examples of processes investigated include geometric object rotation (M. S. Cohen et al. 1996; Gauthier et al. 2002; Podzebenko, Egan, and Watson 2005), visual search (Gitelman et al. 2002), spatial attention (Gitelman et al. 1999), and navigation in virtual reality (Maguire et al. 1998; Hartley et al. 2003; Rosenbaum et al. 2004). Though less common, geographers have also begun to use fMRI to investigate cognitive processes associated with map reading (Lawrence 2005; Olson, Lobben, and Huang 2005).

Spatial Abilities

Certainly the success of cognitive task completion is based, at least in part, on ability. Such a statement may not be extraordinarily meaningful, however, because definition of the term "ability" differs between and within disciplines. Ability can be broad, such as verbal or motor ability, or specific, such as riding a bicycle (Howe 1998). Moreover, when the extent to which ability is mitigated by achievement or aptitude is considered, the waters are muddied (Anastasi and Urbina 1997; R. J. Cohen and Swerdlik 2005). In all likelihood, a person's ability to perform various map-related tasks is affected by both achievement (training/experience) and aptitude (innate brain function/other physical affects).

Along the ability continuum, spatial ability is rather broad, so broad in fact that measures of spatial ability sometimes equate with measures of intelligence (McGrew and Flanagan 1998). Spatial ability is also often a component in models of intelligence. Gardner's Theory of Multiple Intelligences includes spatial ability/intelligence as one of the seven intelligences; the others are logical-mathematical, linguistic, musical, bodily-kinesthetic, intrapersonal, and interpersonal (McGrew and Flanagan 1998). The fluid-crystallized (Gf-Gc) theory suggests that intelligence is composed of Gf, or fluid intelligence (inborn), and Gc, or crystallized intelligence (education, culture, training, and knowledge). This theory includes many separate intelligences, among which GV, or visual intelligence, accounts for most spatial ability (Carroll 1993; Horn and Noll 1997; McGrew and Flanagan 1998). Carroll's Three-Stratum Theory of Cognitives identifies levels of abilities from very general (Stratum III) to more specific (Stratum I); spatial abilities are included in Broad Visual Perception, a Stratum II ability (Carroll 1996).

Inasmuch as definitions of ability differ, the construct of *spatial* ability changes with perspective, which is often based on differences between disciplines. Research falling under the large umbrella of spatial abilities is cross-cutting between at least two disciplines: geography and psychology. But definitions, applications, and approaches differ between the disciplines.

The sheer volume of spatial ability literature produced by psychologists reveals the importance of the spatial ability construct to their discipline. In a broad sense, psychologists identify spatial ability as "the ability to generate, retain, retrieve, and transform well-structured visual images" (Lohman 1996, 98). But psychologists commonly associate spatial ability with manipulation of two- and three-dimensional objects such as geometric forms and cube diagrams (Golledge, Dougherty, and Bell 1995). In fact, for many researchers "rotated three-dimensional images is the gold standard for measuring spatial cognition in humans" (Driscoll et al. 2004, 326). Additional spatial tasks investigated by psychologists include visual working memory, spatial attention, and spatial scanning.

The spatial abilities and tasks studied by psychologists are not dismissed by geographers; in fact, spatial visualization and spatial orientation are abilities that are important to geographers (Golledge and Stimson 1997; Montello et al. 1999), though the common tasks of rotating two- and three-dimensional geometric objects may not be as useful (Golledge, Dougherty, and Bell 1995). A geographic perspective on spatial abilities includes the ability to make spatial relations—that is, to maintain relationships between objects in geographic space (Self and Golledge 1994; Golledge, Dougherty, and Bell 1995; Golledge and Stimson 1997). In addition, geographers are interested in investigating spatial ability and its relationship to environmental tasks such as reading a map, navigation (Montello et al. 1999), environmental perception, and mental map formation and use. Within this vein, Golledge and Stimson (1997, 156) identified as *geographic* spatial abilities the abilities to think geometrically; form images of complex spatial relations; recognize spatial patterns of phenomena; perceive three-dimensional structures in two dimensions and vice versa; interpret macrospatial relations; give and comprehend directional and distance estimates as required in navigation and path integration activities used in wayfinding; understand network structures; perform transformations of space and time; uncover spatial associations within and between regions or cultures; form images of spatial arrangements from verbal reports or writing; form images and organize spatial material hierarchically; orient oneself with respect to local, relational, or global frames of reference; perform rotation or other transformational tasks; re-create accurately a representation of scenes viewed from different perspectives or points of view; and compose, overlay, or decompose distributions, patterns, and arrangements of phenomena at different scales, densities, and dispersions.

Certainly geographers should ground their work in the theoretical advances made by psychologists in the area of spatial abilities, but it is also valid for geographic researchers to suggest and investigate additional spatial abilities and develop instruments that may be more appropriately applied to geographic tasks, such as navigational map reading.

Spatial Abilities Associated with Navigational Map Reading

The experiment designed in this research focused on assessing the relative influence several spatial abilities exert on the task of navigational map reading. Five abilities were chosen as the objects of study: *map rotation*, *place-recognition*, *self-location*, *route memory*, and *environmental mapping*, though many more abilities may be associated with map navigation. In this research the extent to which a person can memorize a route is investigated for its effect on navigational map reading, but such a "map in the head" ability is likely not the only way people encode, retrieve, and use environmental information. Therefore, it is important to note that the abilities investigated in this research represent a sampling of map navigation abilities.

Not just mirroring the term "spatial ability," the term *ability* has been purposefully selected for this research. It should be noted that there has been a recent change in the terms associated with psychological assessment. Where once it was understood that aptitude tests "measure the effect of learning under relatively uncontrolled and unknown conditions, whereas achievement tests measure the effects of learning that occurred under partially known and controlled conditions" (Anastasi and Urbina 1997, 475), that distinction has become less clear in test designs and applications. Both terms have referred to individual learning, with aptitude tests reflecting the cumulative learning across a lifetime and achievement tests measuring accomplishment as a result of a relatively controlled learning experience such as a college course, but increasingly it is the case that some tests classified as "achievement" tests may actually reflect broad educational experiences and some "aptitude" tests rely on fairly controlled prior learning. Regardless of its categorization, any cognitive test provides some type of ability measure and, therefore, the term *ability* often is being used in place of the terms aptitude and achievement (Anastasi and Urbina 1997; R. J. Cohen and Swerdlik 2005).

Map Rotation. Usually when people engage in navigational map reading they are faced with the task of rotation, but the type of rotation completed may differ, depending on strategy use, which in turn may depend on rotation ability (Lobben 2004). Consider the following example: a map is oriented north-up; a person begins at a location in the south and must travel to the northwest. He first travels along a north-south oriented road and is therefore moving "up" the map. At some point he will need to make a turn to the west, which on this map will be to the left. Following that turn, he will choose one of two rotation strategies: either physically rotate the map, now west-up, and mentally rotate much of the text, or mentally rotate the street network. The difference between the two strategies is whether the person chooses to rotate the text or the geometry, respectively. Either way, he must complete a rotation task.

Map rotation is one of the most common map-related abilities investigated by geographic researchers. Its popularity may be influenced by the focus of psychologists on mental rotation, as well as the fact that map rotation is one of the few cognitive abilities that can, to some extent, be witnessed by a researcher (we can see and record when a person rotates a map).

In cognitive cartographic research, map rotation refers to the process of *mentally* rotating a map. A number of studies have focused on object (map) rotation, and researchers have looked at how map rotation affects subjects' response times during orientation tasks (Levine, Marchon, and Hanley 1984; Aretz and Wickens 1992) as well as their ability to distinguish between rotated-only and rotated-and-flipped maps (Lloyd and Steinke 1984; Olson, Lobben, and Huang 2005). Also studied have been the effects of map complexity on mental map rotation ability (Lloyd and Steinke 1984) and alignment effects (Levine, Marchon, and Hanley 1984; MacEachren 1992; Lloyd and Cammack 1996).

The extent to which rotation ability, complexity, or alignment affects the real-world task of navigational map reading is still unclear. In particular, research has not focused on whether a person's map rotation ability determines his map-use strategy (will he physically rotate the map during navigation or mentally rotate map objects while keeping the physical map aligned as originally designed?) nor whether a person's ability and chosen strategy affect his overall navigational map reading ability.

Place Recognition. The place-recognition construct relates to the cognitive process of visualization—not visualization in the sense of being able to rotate geometric objects, rather the "human ability to develop mental representations" (MacEachren et al. 1992) and use those representations during the course of navigating with a map. More specifically, the process is similar to that described by Ottosson (1988) wherein the map navigator not only encodes a mental map of the anticipated route but uses it to predict and then recognize the route and objects encountered during the process of navigating. The navigator maintains the representation of the route and relates that representation to the real-world environment. Because maintaining the representation can be either through constant referral to the printed map or referral to a person's memory of that map, it is possible that route-memory (discussed below) could also affect place-recognition performance. Place-recognition, in this research, necessarily includes using a tangible representation of the environment (in this case, a printed map) to navigate a determined or prescribed route. The task differs from wayfinding, generally, in that wayfinding may or may not include a map and may or may not be restricted to a specified route (Cornell and Heth 2000).

Self-Location. Though Levine, Marchon, and Hanley (1984) were mostly investigating the effect of alignment on their "you-are-here" maps, their location-underlying construct is similar to what is referred to here as self-location ability, the ability to locate oneself on a map. In nearly every navigational map reading task, especially the manner in which the task was used in this study, the subject has to relate his or her location in the environment to the corresponding location on the map, and vice versa. To accomplish this task, the person could observe objects in the environment (intersections, bridges, buildings) and identify corresponding patterns of objects in the map in order to determine correct location on the map.

Route Memory. The ability to remember from a map the route and objects along the route is referred to as route memory. Researchers have argued that spatial memory affects how well a person learns information obtained from a map (Levine, Jankovic, and Palij 1982; Kulhavy, Schwartz, and Shaha 1983; Peterson 1985; Lloyd and Steinke 1986). If true, then the ability to encode a tangible street map into a usable cognitive map with retrievable information may affect navigational map reading performance.

The cognitive map is encoded in at least two ways, each of which is defined according to the form in which the spatial data are presented to the map-reader. Sources include a tangible medium (aerial photograph, a virtual or interactive map, or a printed two-dimensional map), verbal instructions, or exploration of the environment itself (Lloyd 1997, 2000a). But even when a cognitive map is encoded from a printed map, tasks may differ, which may result in different encoding strategies and processes. Because the research presented here focuses on navigation using a map for a prescribed navigational task, map route memory, specifically, is investigated.

Wayfinding. Wayfinding is a complex task and has been discussed and defined in different ways. Here, wayfinding is considered to be the ability not only to accurately encode and remember an environment through direct experience in it (no map or other representation), but also to use that knowledge to make spatial judgments about the geographic area, individual parts of the area, and relationships between locations that may be known and unknown.

Wayfinding ability may affect in at least two ways a person's navigational map reading ability, or their ability to navigate between target locations in at least two ways. First is whether, after consulting a map to determine the start/end points, the person is able to use the survey knowledge acquired from the map to navigate more effectively (with accuracy) and efficiently (quickly). In other words, is the person able to maintain trajectory or bearing and resolve distance traveled and distance yet to be traveled (abilities that are often commonly referred to as a sense-of-direction). Second is whether the person is able to call on their wayfinding ability to return to the correct route should they deviate from it during navigation. Further illustrating, and borrowing from Cornell, Heth, and Alberts (1994), this term suggests that even when people cannot remember specific landmarks, they may be able to re-create an approximation of the route and surrounding environment and either return to the identified route or construct (without the use of the map) another equally effective and efficient route to complete their navigation task.

Instruments

Two instruments were created for use in the experiment, the Navigational Map Reading Ability Test (NMRAT) and the Real World Map Navigation Exercise (RWMNE).

The NMRAT

Traditional spatial ability tests used in psychological measurement may be used as indicators of general spatial ability, however these tests have not proved useful in predicting navigational map reading, and most such tests lack map-related graphics. More important, as suggested by Lloyd (2000, 97), "if cartographers are to develop a theory of map reading, they need to develop a perspective that allows them to . . . observe processes that directly connect map readers with their maps." Because one objective of this research was to investigate navigational map reading ability and some of the more specific abilities involved in that dynamic process, it was necessary to construct the NMRAT.

Most of the NMRAT instrument was designed as a sit-down test that can be group-administered. Although group tests do impose creativity restrictions and lack flexibility for examinee's answers, the advantages of group testing—the minimal role of the facilitator, simultaneous administration, and objective scoring—provide support for selecting the group testing method. In addition, since the proposed test was designed to evaluate only one ability or class of abilities (map-reading) instead of general intelligence, there is less need to provide freedom and flexibility for examinee's answers (Anastasi and Urbina 1997; R. J. Cohen and Swerdlik 2005).

The computer test was composed primarily of graphics about which the subject was asked to draw conclusions. Since subjects were told they were participating in a map-reading ability study, using map-related graphics also enhanced the test's face validity (i.e., the subjects' assessment of test validity: whether the subjects think the test measures what it is designed to measure), which may affect test-taking motivation and performance (Chan et al. 1997).

NMRAT Test Structure. The first four sections of the NMRAT were created primarily with Macromedia Director and Freehand. An introductory section explained the general structure and purpose of the test and gave an estimate of the participation time in this part of the testing procedure. The ability tasks were represented in separate sections, each of which began with an explanation of the task. Following the explanation, the subject was offered the opportunity to review the instructions or to proceed with some practice questions. The practice questions resembled the questions subjects would complete in the scored questions in that section.

Map Rotation

In the map rotation section, subjects were presented with pairs of side-by-side maps. In some cases, the map on the right had been flipped and rotated, in other cases it had been rotated only. The objective was to determine whether the map on the right had been flipped and rotated or only rotated. This protocol is similar to those used in standardized tests of spatial ability, such as the Vandenberg Mental Rotations Test and the Card Rotations Test, tests that have been widely used and are generally accepted as effective means to gauge spatial ability. Those tests, however, do not contain map graphics, nor do they purport to predict *map* rotation ability, and an acceptable amount of research has not been presented to show a significant relationship between geometric spatial rotation and map rotation ability.

Place Recognition

The place-recognition section required subjects to predict the objects they would encounter while traveling along a route indicated on a map. Subjects were shown a map containing anthropogenic and natural environmental objects. An arrow drawn on the map indicated the start location and direction of travel. Subjects studied the map and the indicated trajectory. Then, from a series of environmental objects depicted in photos, they identified which object they would encounter first if traveling along the prescribed route.

Self-Location

In the self-location section, subjects were presented with a map and a panoramic photograph of some location in the environment. Using the photo as reference, subjects determined their location on the map as well as the direction they were facing (assuming the same site line they saw in the photo). Subjects chose the arrow that represented that direction and dragged it to the correct location on the map.

Route Memory

In the route memory section, subjects were presented with a series of maps (presented individually), each of which highlighted a travel route. Subjects were told to study each map until they had memorized the route (they were able to control the amount of time spent studying each map). When they were ready, they advanced to another screen that contained a list of written directions corresponding to the route. The objective was to first determine the correct order of these directions as they would travel along the route, then drag numbers to the appropriate component of the directions, indicating the correct order.

Wayfinding Exercise

The wayfinding exercise test was designed to determine a person's ability to encode a map from environmental exposure only, and then navigate and perform three wayfinding tasks (without the aid of a printed map). This section is part of the NMRAT, even though the exercise was not created by nor administered through computer. Instead, the exercise was conducted in a university building, which is large and relatively complex with many hallways.

Three markers, labeled 1, 2, and 3, were affixed to the wall in three separate locations on the third floor of the building. Individually, the subjects were led to the locations of the markers in numerical order. Subjects were then taken to the second floor, were told that the layout of the two floors was identical, and were asked to identify the location of each marker by placing identical 1, 2, 3 markers as observed on the previous floor. A facilitator followed behind each subject during the test, allowing the subject to set the pace for the task and also allowing the facilitator to evaluate the subject unobtrusively.

The Real World Map Navigation Exercise

The Real World Map Navigation Exercise (RWMNE) was designed to assess the construct and criterion validity of the NMRAT. The environment for the exercise was established within two adjoining buildings, which maintain a vast and complicated hallway network, as well as seamless interior joins between the two buildings. A mock street network was created inside the building test environment. Street signs were affixed to hallway walls at every hallway intersection. Athough the building network does not replicate typical outdoor environments such as urban or suburban street networks, conducting testing in this environment provided more experimental control. Testing was conducted after normal university hours, during evenings and weekends. Aside from the subject and researcher, no other people were present for any of the testing sessions.

An accompanying map was created of the environment after three actual street maps (ADC's Visitor's Map of Washington, D.C.; Rand McNally's map of Atlanta; and the American Automobile Association's map of Portland) were first analyzed to determine the average number of map symbols per city block on a real map, so the same number would be maintained on the building map. In addition to the labeled "streets," the final map (Figure 1) created for the exercise contained only two sets of symbols representing exits and lobby/common areas.

Subjects referred to the map during the exercise, which included two locating tasks and four navigation tasks. The locating tasks were conducted to determine subjects' self-location ability. For these two locating tasks, the subject was guided to specified locations, then given the map and asked to use a pen to draw a small "x" on the map corresponding to their location in the building. Subjects were then asked to navigate to four locations in sequence, beginning with location 1, with the other destinations provided after successfully navigation to the previous site. Subjects could consult the printed map, which was kept by the researcher and handed to the subject upon request. By so doing, the amount of time a subject spent studying the map could be measured.

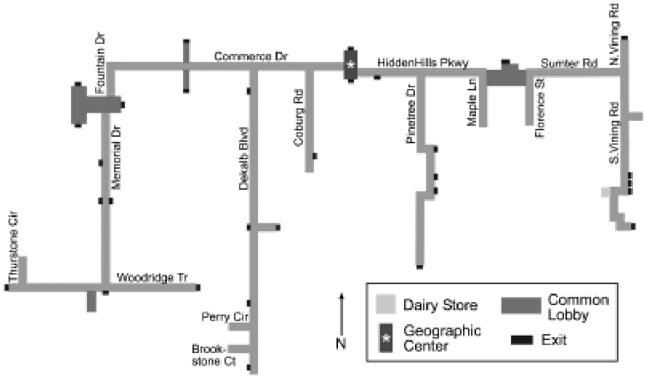

Figure 1. Map used in the Real World Map Navigation Exercise (RWMNE).

A score sheet was used to evaluate subject performance during the exercise. Each task was scored independently and data were gathered for four criteria: the number of times the subject rotated the map (based on 90-degree rotation), the number and duration of stops, the number of hesitancies (times when subject slowed stride but did not stop), and the amount of time spent reading the map.

Procedure

Focus Group Evaluation and Pilot Testing

Focus groups can be useful in the pilot stages of an experiment or to evaluate participant perspectives (Suchan and Brewer 2000), as well as useful in evaluating cartographic products (Monmonier and Gluck 1994; Duh, Lobben, and Philpotts 1998; Olson et al. 1998). Therefore, before the computer-administered NMRAT was administered, a focus group evaluation of the test was conducted to elicit feedback about the design of the NMRAT. In this case, the focus group was conducted solely to respond to clarity of test instructions, face validity of the instrument, and design of the interface. Because the computer-based NMRAT is an interactive test, feedback was sought about the design of button placement and design, color usage, aesthetics, text legibility, and screen layout. Following the focus group, some design changes were made. The entire experiment was

Table 1. Summary statistics of NMRAT scores

	Route memory	Map rotation	Place recognition	Self-location
Number of cases	44	44	44	44
Minimum (ms)	2863	4223	3002	7841
Maximum (ms)	71550	68426	26498	61445
Mean (ms)	32020	24088	10855	28545
Standard deviation	16295	16340	4889	15288

Note: NMRAT = Navigational Map Reading Ability Test.

then pilot-tested using five subjects. Minor changes were made and formal testing proceeded.

The Formal Experiment

A written script was used to make verbal instructions to subjects during the experiment. After subjects signed a consent form, they completed the NMRAT, followed by the RWMNE. The entire process took approximately 1 hour per subject.

A total of forty-five subjects participated and forty-four useable results were obtained. Subjects ranged in age from twenty-one to sixty-eight years; twenty-four were female and twenty were male; twenty-nine subjects came from the university student community (undergraduate and graduate students) and fifteen came from outside the university and held occupations such as retiree, city planner, and civil engineer. The volunteers were obtained through advertisement flyers posted in community areas including recreation centers, gyms, laundromats, and grocery stores in addition to verbal advertisement in introductory college classes. Each participant received $15 and a coupon for a serving of ice cream at the campus Dairy Store, which is located in the testing building.

Subject Performance

Separate scores were recorded for each part of the NMRAT. In design and scoring, the NMRAT is considered a speed test; as such, only response times are considered in the scoring. Two general categories of tests, the speed test and the power test, differ in two important ways. In the speed test, the questions are uniform in difficulty (and often uniformly easy), whereas questions in the power test increases in difficulty until they become nearly impossible to answer toward the end of the test. Also, in the speed test either the number of questions that can be answered in a given time or the amount of time taken to answer questions is recorded; in the power test, unlimited time is given (Anastasi and Urbina 1997; R. J. Cohen and Swerdlik 2005).

For the NMRAT, response time (rather than the total number of questions answered) was recorded in milliseconds and provided subjects' scores for each section. Of the 1,716 questions (thirty-nine questions asked of each of the forty-four subjects) only 7 percent were answered incorrectly, with no pattern of difficulty for any specific question, indicating that the test was rather uniformly easy (consistent with most speed tests). Summary statistics for each section of the NMRAT are shown in Table 1. The differences in response times across test sections do not necessarily indicate difficulty differences between tasks. Rather, some of the tasks were more time-consuming in design. For example, to complete each self-location task, subjects had to toggle (often several times) between two screens, one showing the map and one showing the photo. As a result, it may be inappropriate to compare means across sections of the NMRAT.

Data from the RWMNE were recorded on an evaluation sheet, and included whether the four assigned locations were found; the number of map rotations; the number and duration of stops for each location; and the amount of time spent studying the map. All subjects successfully navigated to every location; however variation was observed in map rotations, which ranged from 0 to 14 with a mean of 2.6; the duration of stops each subject made, which ranged from 0 to 77 seconds with a mean of 18; and the amount of time subjects spent studying the map, which ranged from 25 to 215 seconds (mean of 65).

The score for the two self-locating tasks was based on correctness of the hall, side of hall, distance from the actual location, and time spent completing the task. Slightly more than half of the subjects (twenty-four) identified the correct location in the first locating task, and thirty-six correctly located themselves in the second task. For completion of the first task the subjects' time ranged from 6 to 128 seconds, with a mean of 55.7 seconds; for the second task time ranged from 3 to 37 seconds, with a mean of 11.3 seconds.

An overall score, indicating subjects' success navigating to all locations, was also calculated. Data were recorded using several criteria in the RWMNE exercise, but only stops and map study time were included in the formula devised to determine the overall score. Because all subjects successfully navigated to every location, accuracy was not a factor. To factor out individual differences in stride pace, instead of using a time for the entire exercise, the sum of the amount of time spent studying the map and the duration (in seconds) of stops was added for the final RWMNE score (the self-location task scores were not included in the RWMNE score).

Test Evaluation (Assessing the Reliability and Validity)

Recall that the first research question associated with this project was whether a reliable and valid navigational map reading test instrument can be designed. Many assessment instruments administered in research involving human subjects should be tested for reliability and validity as they both affect the confidence level at which results may be reported as well as the meaningfulness and strength of conclusions. Researchers may utilize several methods for testing the reliability and validity of their measurement devices, depending on potential error of the test and how the test scores will be used.

Test Reliability

Test reliability refers to the consistency of scores that may be obtained by a person when tested on different occasions. In other words, test reliability is determined by how consistently a test measures a given trait or ability. Several analyses for test reliability may be conducted; researchers select a reliability method depending on what they identify as the potential sources of error. For the NMRAT, a split-half analysis was conducted. Split-half, which is an appropriate method to assess reliability of speeded test instruments, calculates reliability by comparing the consistency of two scores from equivalent halves of a single-administered test (Anastasi and Urbina 1997; R. J. Cohen and Swerdlik 2005). The calculated value (a correlation) identifies the reliability of the test; the closer to 1, the better the reliability. The results of the analyses, shown in Table 2, indicate that all four sections of the computer-administered NMRAT are highly reliable. The Wayfinding assessment (the non-computer-administered test) shows only marginally acceptable reliability.

Table 2. NMRAT split-half reliability (by section)

Test section	Split-half correlation
Map rotation	0.925
Place-recognition	0.945
Self-location	0.969
Route memory	0.989
Wayfinding	0.617

Note: NMRAT = Navigational Map Reading Ability Test.

Test Validity

Test validity refers to how well the test captures the construct it was designed to measure, where a construct can be concepts such as personality, intelligence, or spatial ability. Both construct validity (the extent to which a test measures the theoretical construct) and criterion validity (the extent to which a test accurately predicts a variable's outcome) were measured. For this research, the construct validity suggests how well the test sections capture the map use constructs they were designed to measure; the criterion validity indicates the extent to which the map-reading ability test measures (both as a whole and in individual sections) and predicts a person's ability to perform the map navigation task.

The NMRAT was designed to predict how well a person navigates with a map in a real environment, and the RWMNE provides an indicator of the actual map navigation ability. In the linear regression analyses, the RWMNE (as a whole or in parts, depending on the specific analysis) functions as the dependent variable, and the NMRAT (as a whole or in parts) functions as the independent variable(s).

Construct Validity

Several potential cognitive abilities of map reading have been proposed and discussed. When research involves the creation of a test that is administered to human subjects for the purpose of yielding analyzable results, in many cases it is patently incorrect for the researcher to merely assume that the created test measures the mental constructs it was designed to measure. In this research an analysis of construct validity was conducted to determine whether the five sections of the NMRAT adequately measure the five constructs (map rotation, place-recognition, self-location, route memory, and environmental mapping). Because navigation with a map is a complex task presumably affected by the five cognitive abilities under investigation, the construct validity analyses require the individual test sections to be compared to parts of the navigation exercise that are hypothesized to be influenced by each ability.

Unlike the criterion validity analysis, which applies regressions of the *total scores* of each of the five parts of the map reading ability test against the *total scores* from the *entire* map reading/navigation exercise, the construct validity is determined by analyzing the relationships between each of the five parts of the NMRAT and the scores from *individual parts* of the RWMNE. For example, a construct validity analysis would determine the extent to which the map rotation test section measures a person's ability to mentally rotate maps while navigating.

Table 3. Linear regression with number of rotations from RWMNE (dependent) and map rotations from NMRAT (independent)

Dep Var: ROTATIONS *N*: 44 Multiple *R*: 0.722 Multiple R^2: 0.521
Adjusted multiple R^2: 0.509 Standard error of estimate: 3.013

Effect	Coefficient	Std Error	Std Coef	Tolerance	*t*	*P*(2tail)
CONSTANT	3.006	0.603	0.000	.	4.987	0.000
MAPROT	0.000	0.000	0.722	1.000	6.756	0.000

Note: RWMNE = Real World Map Navigation Exercise; NMRAT = Navigational Map Reading Ability Test; MAPROT = Map rotation.

Map rotation. At the start of the experiment, the hypothesis was that a person who could mentally rotate maps would not need to physically rotate the map during the RWMNE. The validity of the map rotation construct involved comparing how often a subject rotated the map during the RWMNE (functioning as the dependent variable) with the subject's score from the map rotation section of the NMRAT (functioning as the independent variable). The results (Table 3; Figure 2) indicate a significant relationship between the two variables. While a standardized coefficient of 0.722 and a multiple R^2 of 0.521 may be considered unacceptably low in some physical sciences, in ability (or many human cognition) experiments such as this, that result represents a relatively strong relationship.

All test sections were regressed against rotations to determine whether any other section of the NMRAT may influence ROTATIONS. Only one independent variable, place-recognition, is a significant predictor of map rotation ability—though with a low standardized coefficient (0.273) and squared multiple *r* (0.074), the relationship is of little practical significance (Table 4).

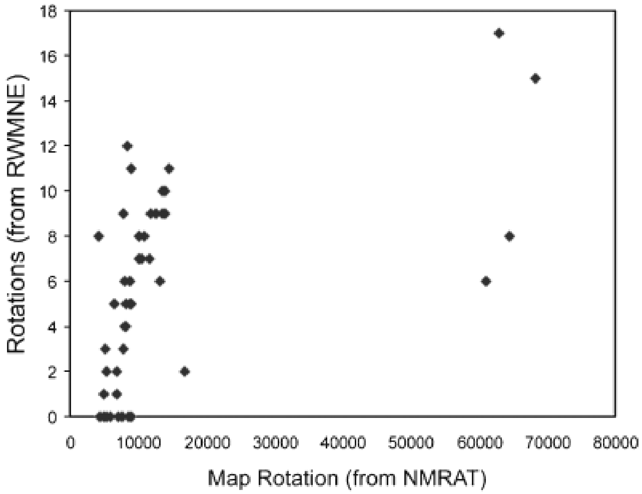

Figure 2. Scatterplot with Rotations (from RWMNE) and Map Rotation (from NMRAT). RWMNE = Real World Map Navigation Exercise; NMRAT = Navigational Map Reading Ability Test.

Outliers

The model and scatterplot (Table 3; Figure 2) also shows that four observations exerted large leverage. If outliers are removed, the model (Table 5) (scatterplot Figure 3) still indicates a significant (and stronger) relationship. Following Tukey's test for outliers, adding three-times the midspread to the upper hinge, the four observations are clearly outliers (graphically illustrated in the box-whisker graph, Figure 4). As a result, the observations were scrutinized in order to identify a possible explanation for their outlying location. Each outlying score represents the total score for a subject's map rotation performance. The response pattern for each of these four subjects was studied and no time spikes are present in the responses, indicating that computer malfunction or subject distraction on one or two answers is likely not the cause for the high scores.

One other consideration is that the outliers may represent performance differences that are commonly associated with ability testing. The outliers may be legitimate members of the data set or they could be a result of unidentified error. But the performance of these same four subjects was then compared in all NMRAT sections and each of the four subjects received outlying scores on all of the other sections. Such a pattern of poor performance could still be considered legitimate evaluation. However, it is more likely that subjects were disinterested, generally confused about the task, or maintained an aversion to testing.

All analyses were conducted with both the presence and absence of these outliers. Interestingly, the absence or presence of these outliers did not significantly affect results in *any* of the statistical analysis. But because the same outliers are consistently above the outer limits in all test sections, they were removed.

Map Rotation Performance and Sex-Related Similarities

One reliably consistent result of mental rotation experiments has been the performance differences between males and females (with better performance by males). The research presented here included a map rotation

Table 4. Linear regression with ROTATIONS from RWMNE (dependent) and place-recognition from NMRAT (independent)

Dep Var:ROTATIONS	*N*: 44	Multiple *R*: 0.273	Multiple R^2: 0.074
Adjusted multiple R^2: 0.052		Standard error of estimate: 4.187	

Effect	Coefficient	Std Error	Std Coef	Tolerance	*t*	*P*(2Tail)
CONSTANT	3.079	1.552	0.000	.	1.984	0.054
RTMEM	0.000	0.000	0.273	1.000	1.836	0.073

Note: RWMNE = Real World Map Navigation Exercise; NMRAT = Navigational Map Reading Ability Test; RTMEM = route memory.

exercise; in addition, census data collected from subjects included identification as male or female. A simple difference in means test was performed to identify whether mean differences exist between male and female performance on the map rotation tasks. Results revealed no statistically significant difference between group performance (Table 6). Such results seem to contradict previous research (as well as generally held beliefs) regarding male superiority in mental rotation exercises. Perhaps differences are a result of stimuli differences or test administration.

In traditional experiments, mental rotation ability has been measured using paper-and-pencil tests such as the Vandenberg test, which shows subjects cube objects and asks them to identify from several options the cubes that are the same as the original, but rotated. As researchers have begun to administer rotation tests in computer environments, some results indicate no statistically significant differences in performance between males and females. Parsons et al. (2004) administered spatial rotation tasks to forty-four subjects, where some of the tasks included traditional paper/pencil rotation questions in addition to rotation tasks completed in a virtual environment. Their results confirm sex-related differences in the traditional form of the test, but not in the virtual environment rotation task. Rilea, Roskos-Ewoldsen, and Boles (2004) administered computer versions of traditional spatial tests, including administering mental rotation tasks bilaterally to identify potential influence of the right brain hemisphere on task performance. In the rotation task, which used stick-figure stimuli, no sex-related performance differences were evident. Roberts and Bell (2003) created a computerized version of the gingerbread man mental rotations task and found no performance differences between males and females. Piburn et al. (2002) found no sex differences in performance on a computer-administered rotation test. They administered both paper/pencil as well as computerized versions of same spatial ability tests, including mental rotation of block diagrams. Similar to the results of Parsons et al. (2004), Piburn et al. (2002) found the expected sex differences in the paper/pencil version but not in the computer-administered tests.

Place Recognition. During the RWMNE, the number of times a subject stopped to "get their bearings" was recorded (these were stops that did *not* include map consultation). The hypothesis was that if a person could look at a map and visualize the environment, then they would recognize the actual real-world environment when confronted with it during the navigation exercise and would not have to stop to get their bearings. The place-recognition section of the NMRAT was designed to capture this ability. To assess the construct validity, the place-recognition section of the NMRAT (indicated by PLRECOG in the model) functioned as the independent variable and was regressed against duration of stops recorded in the RWMNE (indicated by STOPS in the model). The results (Table 7) reveal high *t*-statistic and low *p*-value, indicating that the model is highly significant (above the 0.01 level). Moreover, high multiple R^2 of 0.544 indicates that the place-recognition inde-

Table 5. Linear regression with ROTATIONS from RWMNE (dependent) and map rotations from NMRAT (independent)—leverages removed

Dep Var: ROTATIONS	*N*: 40	Multiple *R*: 0.905	Multiple R^2: 0.820
Adjusted multiple R^2: 0.815		Standard error of estimate: 1.520	

Effect	Coefficient	Std Error	Std Coef	Tolerance	*t*	*P*(2Tail)
CONSTANT	–4.280	0.737	0.000	.	5.807	0.000
MAPROT	0.001	0.000	0.905	1.000	13.140	0.000

Note: RWMNE = Real World Map Navigation Exercise; NMRAT = Navigational Map Reading Ability Test; MAPROT = Map rotation.

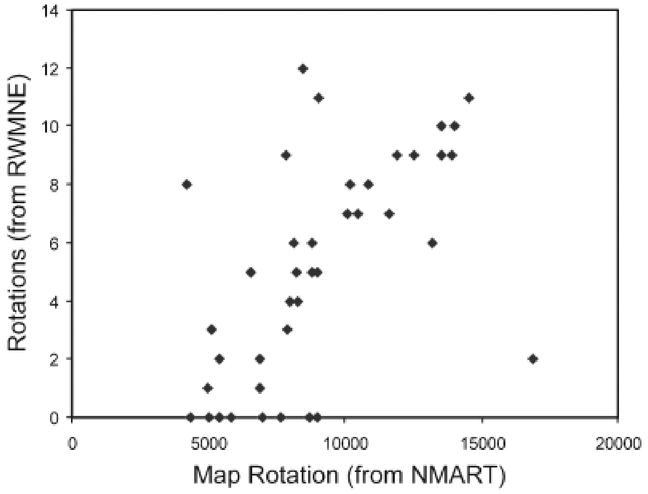

Figure 3. Scatterplot with Rotations (from RWMNE) and Map Rotation (from NMRAT); high leverages removed. RWMNE = Real World Map Navigation Exercise; NMRAT = Navigational Map Reading Ability Test.

pendent variable explains a considerable amount of variance for such a test of human abilities. The scatterplot (Figure 5), and a standardized coefficient of 0.737 show a relatively linear, positive relationship.

When the other sections of the NMRAT were regressed against STOPS, only route memory was revealed as a significant variable (Table 8). The relationship, though considerably weaker, does suggest that the independent variable of route memory cannot be discounted as participating in a reasonable amount of variance explanation.

Self-Location. The construct of self-location suggests that people use clues from the real-world environment to locate themselves on the map. The self-location section of the NMRAT was designed to capture this ability. The hypothesis was that the score from the self-location section of the computer test would predict a person's ability to perform the two locating tasks in the RWMNE. The scores from the computer test (independent variable SELFLOC) were regressed against the scores from the RWMNE (dependent variable LOCATING). The results (Table 9; scatterplot Figure 6) show that self-location on the NMRAT is a significant and strong predictor of the real-world task completion, explaining a substantial amount of variance and maintaining a strong, positive linear relationship. As before, all other test sections were regressed against LOCATING and none were significant predictors.

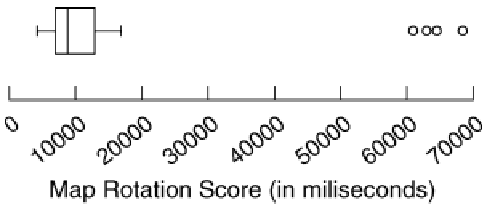

Figure 4. Box whisker graph of map rotation score.

Route Memory. The construct of route memory asserts that a person's ability to memorize a self-planned or prescribed route may influence how quickly a map navigation task is accomplished. Assessing the validity of the route memory construct should show how well the route memory section of the NMRAT actually measures the true ability as it is associated with map navigation. This construct validity was investigated by regressing subject scores from the route memory section of the NMRAT (independent variable RTMEM) against the score from the map navigation exercise (dependent variable LOOKS). The results indicate that route memory NMRAT section is not only a significant predictor, but a relatively high amount of variance is explained by the model, along with a reasonable positive linear relationship (Table 10; scatterplot Figure 7). No other NMRAT section was statistically significant.

Wayfinding (Without a Map). The construct of wayfinding without a map represents the extent to which a person learns, remembers, and navigates an area by working within it or without a map. The construct was measured in the wayfinding section of the NMRAT and also observed in a section of the RWMNE. Recall that the amount of time spent studying the map between navigation points 3 and 4 functioned as the real-world wayfinding task assessment. This assessment is represented as LOOK4 in the results. Validity was assessed by regressing wayfinding (from NMRAT) against Look4 (from RWMNE). But the results (Table 11; scatterplot Figure 8) reveal no significance in the relationship.

All other sections of the NMRAT were regressed against LOOK4, with only route memory identified as a variable of any significance. Although this result was unlikely to have occurred by chance, the amount of explanation is relatively low and unlikely to be of any practical significance (Table 12).

Section Interrelationships. Canonical correlation analysis was used to examine the extent to which the two assessments (NMRAT and RWMNE) measured the same ability (i.e., performance on corresponding tasks). The analysis extracts from each set of variables a set of canonical variates (or factors). Each successive pair of canonical variates is maximally correlated between the sets, and orthogonal to previously extracted variates. The analysis also provides an overall measure of corre-

Table 6. Map rotation difference of means test (grouped by sex)

Two-sample t test on ROTATIONS grouped by SEX

Group	N	Mean	SD
1	22	9013.000	3292.094
2	18	9157.765	3092.691

Separate variance $t = -0.142$ $df = 35.8$ Prob = 0.888
Difference in means = −144.765 95.00% CI = −2207.345 to 1917.815
Pooled variance $t = -0.141$ $df = 8$ Prob = 0.889
Difference in means = −144.765 95.00% CI = −2222.995 to 1933.466

Note: CI = confidence interval.

lation (Wilks's Lambda) between the sets of variables. Finally, the analysis provides a description of each variate, indicated by its canonical loadings (the correlation between each test variable and the canonical variate). In other words, these canonical loadings reveal the structure of the correlations among the variables in each variable set in a fashion similar to the way in which principal components do for a single group of variables. Variate-by-variate similarity in the relative sizes (absolute values) of the canonical loadings indicates that the two sets of variables measure the same basic navigational map-reading (sub)ability under scrutiny here.

The results indicate an overall significant correlation. Moreover, the pattern of highest canonical loadings for each variate is identical between the sets of tests (these loadings are highlighted in Table 13). For example, the first canonical variate is most highly correlated with the equivalent variables of PLRECOG (in NMRAT) and STOPS (in RWMNE), the second with SELFLOC (in NMRAT) and LOCATING (in RWMNE), and so forth. In every case, the most highly correlated variables on each canonical variate represent the same map reading ability construct. These results indicate that the two sets of tests are highly correlated, and describe the map reading abilities in a comparable fashion.

Criterion Validity (Test Prediction Power)

The second and third research questions associated with this project asked: (2) Can a sit-down computer test predict navigational map reading ability? and (3) What are the relative influences of individual abilities on overall navigational map reading ability? Answering these questions requires an analysis of the criterion validity (the extent to which the NMRAT predicts performance of the entire RWMNE), where subject performance on the NMRAT (in whole and in parts) is compared to performance of navigational map reading.

Subjects' scores from the five parts of the NMRAT (independent variables) were regressed against their RWMNE score (dependent variable). The results (Table 14) show varying influences of the independent variables on RWMNE. The dominance of self-location is clearly evident from both its high t-statistic and high standardized coefficient. The t-statistics recorded for route memory and place-recognition (1.987 and 1.912, respectively) suggest that the relationships are not coincidental. The relatively low standardized coefficients (0.139 and 0.141) indicate that the variables are substantially less influential.

Each of the five NMRAT sections was also regressed individually against the RWMNE performance. The results (Table 15) identify slightly different relationships between each of the NMRAT sections when evaluated individually against RWMNE. The models that include the independent variables of self-location, route memory, and map rotation identify significant relationships. The amount of variance explained by the two models that include self-location and route memory suggest that these two variables, on their own, explain a substantial

Table 7. Linear regression with STOPS from RWMNE (dependent) place-recognition from NMRAT (independent)

Dep Var: STOPS N: 40 Multiple R: 0.737 Multiple R^2: 0.544
Adjusted multiple R^2: 0.531 Standard error of estimate: 1.253

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2Tail)
CONSTANT	0.051	0.491	0.000	.	0.103	0.918
PLRECOG	0.000	0.000	0.737	1.000	6.726	0.000

Note: RWMNE = Real World Map Navigation Exercise; NMRAT = Navigational Map Reading Ability Test; PLRECOG = place-recognition.

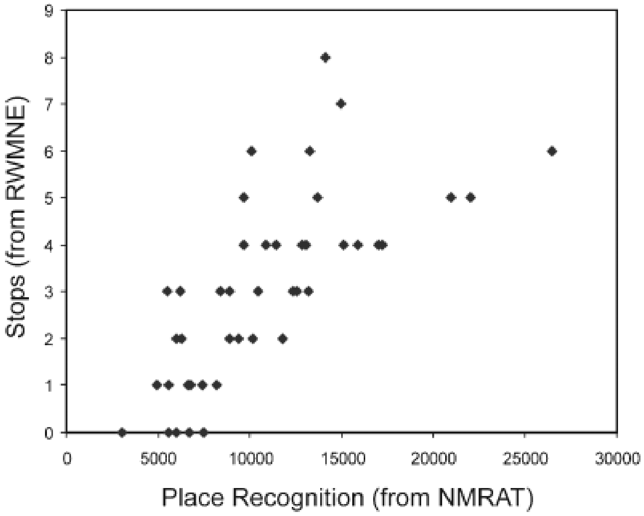

Figure 5. Scatterplot with Stops (from RWMNE) and Place-Recognition (from NMRAT). RWMNE = Real World Map Navigation Exercise; NMRAT = Navigational Map Reading Ability Test.

amount of variance. Although map rotation is clearly significant in the model, a relatively low multiple R^2 reveals that little of the variance is explained by the independent variable. The standardized coefficients and scatterplots (Figure 9) also reveal positive linear relationships between self-location and route memory, individually, with RWMNE scores.

Discussion

Reliability and Validity of the Test Instrument

Recall that the first question asked in this research was: Can a reliable and valid navigational map reading test instrument be designed? All sections of the NMRAT were proved reliable through the split-half reliability analyses (though the wayfinding reliability score of 0.612 is on the border of acceptability). However, not all of the individual sections of the NMRAT, which included map rotation, place-recognition, self-location, route memory, and wayfinding, proved equally valid. By regressing each of the individual NMRAT section scores against a subject's actual performance of the task in a field exercise, a validity assessment was made on how well each section actually represented a person's true ability. This assessment revealed the variable construct validity. The map rotation and self-location sections maintain the highest validity ($p = 0.000$, $R^2 = 0.820$ and 0.754, respectively), meaning that results from these NMRAT sections can be assumed (with high confidence) to predict a person's ability to mentally rotate a map and also to locate themselves on a map by using environmental cues. The place-recognition and route memory sections also show strong validity ($p = 0.000$ for both, and $R^2 = 0.544$ and 0.473, respectively). The reliability and validity represented in the analyses of these four NMRAT sections suggests that a reasonably high amount of confidence may be associated with inferences made when these NMRAT test sections are used as indicators of the respective abilities. Unfortunately, the validity of the wayfinding section is unfounded. As a result, this test cannot be used to effectively represent a person's wayfinding ability (as far as the manner in which that ability was field-assessed in this research).

Overall, though, the NMRAT was shown to be both reliable and valid. Therefore, the answer to the first research question number would be yes, at least as far as these results indicate. Even though each section did not perform perfectly (or, in the case of wayfinding, even adequately), the instrument may be used to predict performance on different tasks associated with map navigation. Nevertheless, as with many instruments that have been developed to investigate human traits, including ability, the NMRAT can be improved.

The most obvious section in need of improvement is the wayfinding section of the NMRAT, which failed to predict the ability as recorded in the RWMNE. Most likely, the inability of the instrument to predict the LOOK4 score resulted from poor construction of that test section, compounded with a poor validity task. Without exception, every subject was able to identify the correct hallway and the correct side of the hallway in the exercise; the only difference in

Table 8. Regression with STOPS from RWMNE (dependent) and place-recognition from NMRAT (independent)

Dep Var: STOPS　*N*: 40　Multiple *R*: 0.511　Multiple R^2: 0.261
Adjusted multiple R^2: 0.241　Standard error of estimate: 1.595

Effect	Coefficient	Std Error	Std Coef	Tolerance	*t*	*P*(2Tail)
CONSTANT	1.958	0.396	0.000	.	4.945	0.000
RTMEM	0.000	0.000	0.511	1.000	3.662	0.001

Note: RWMNE = Real World Map Navigation Exercise; NMRAT = Navigational Map Reading Ability Test; RTMEM = route memory.

Table 9. Linear regression with LOCATING from the RWMNE (dependent) and SELFLOC from NMRAT (independent)

Dep Var: LOCATING *N*: 40 Multiple *R*: 0.868 Multiple R^2: 0.754
Adjusted multiple R^2: 0.747 Standard error of estimate: 24.425

Effect	Coefficient	Std Error	Std Coef	Tolerance	*t*	*P*(2Tail)
CONSTANT	–33.017	8.332	0.000	.	–3.962	0.000
SELFLOC	0.003	0.000	0.868	1.000	10.780	0.000

Note: RWMNE = Real World Map Navigation Exercise; NMRAT = Navigational Map Reading Ability Test; SELFLOC = self-location.

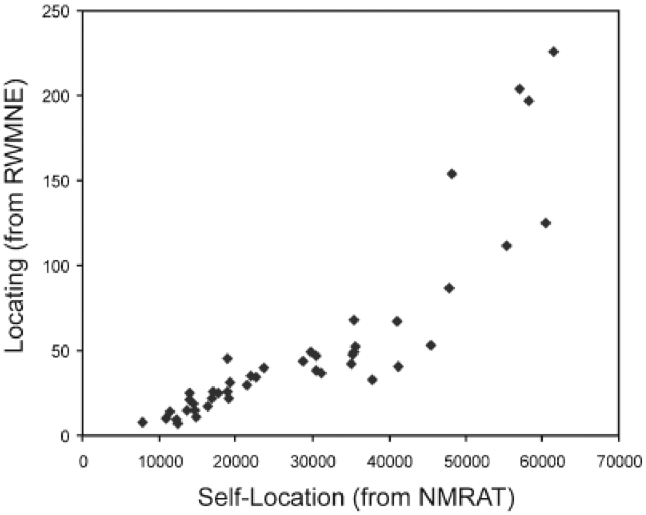

Figure 6. Scatterplot with Locating (from RWMNE) and Self-Location (from NMRAT). RWMNE = Real World Map Navigation Exercise; NMRAT = Navigational Map Reading Ability Test.

scores was in distance from the markers. The environment was too simple and, therefore, the wayfinding section of the test may not truly measure a person's ability to learn an environment without the aid of a map, but may actually measure a person's distance-estimation ability.

Predicting Map Navigation Ability

Research question 2 asked to what extent the instrument predicts the complex task of navigational map reading. Regressing all NMRAT sections against total score from the RWMNE resulted in a model that explained an overwhelmingly large amount of the variance. The self-location variable clearly exerted the most influence in the model; place-recognition and route memory, although less influential, cannot be discounted. Navigational map reading ability is complex and, as has been argued here, composed of many relatively simpler abilities. Even though the independent variables exhibited different significance and standardized coefficients, the results indicate that the NMRAT developed in this research may be used to predict (with high confidence) navigational map reading ability.

It is possible to predict a person's map reading and navigation ability using the NMRAT, but suggesting performance levels for the test is complicated by the idea that navigation ability requirements may differ from one application to another. The determination of a good or bad score is dependent on the acceptable level of navigation ability, which is determined by the content of the application. For example, using the test to select people with "good" navigation ability in conjunction with employment will be dictated by the importance of that navigation ability to job performance. Census takers, delivery persons, and police officers travel to many new locations and quite frequently are required to navigate using maps. Map reading and navigation abilities are less important for those in some other occupations, such as mail carriers, where navigation and map reading may initially be required, but subsequently the same route is maintained. The requirements of the employer and the specific job would determine acceptable test performance levels.

At the very least and in the practical, applied sense, the test seems to be a reasonable means of ranking a group of examinees into broad groups of higher to lower

Table 10. Linear regression with LOOKS from RWMNE (dependent) and route memory from NMRAT (independent)

Dep Var: LOOKS *N*: 40 Multiple *R*: 0.687 Multiple R^2: 0.473
Adjusted multiple R^2: 0.459 Standard error of estimate: 23.747

Effect	Coefficient	Std Error	Std Coef	Tolerance	*t*	*P*(2Tail)
CONSTANT	54.618	5.894	0.000	.	9.267	0.000
RTMEM	0.001	0.000	0.687	1.000	5.834	0.000

Note: RWMNE = Real World Map Navigation Exercise; NMRAT = Navigational Map Reading Ability Test; RTMEM = route memory.

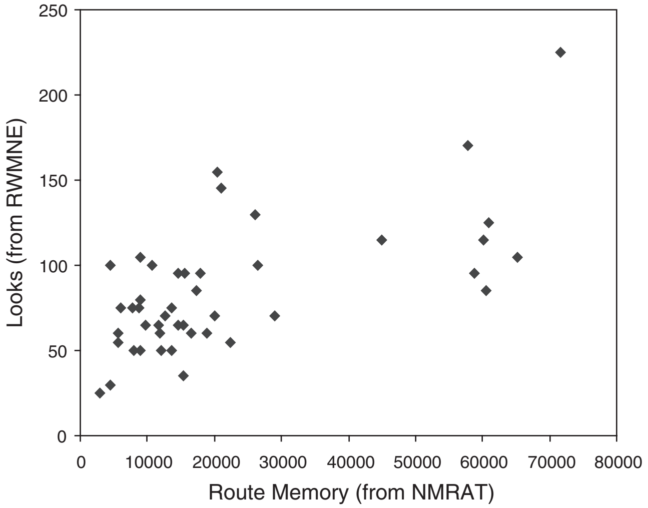

Figure 7. Scatterplot with Looks (from RWMNE) and Route Memory (from NMRAT). RWMNE = Real World Map Navigation Exercise; NMRAT = Navigational Map Reading Ability Test.

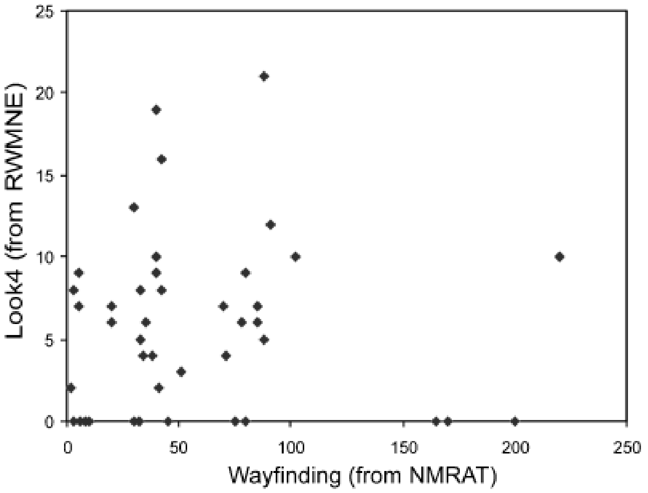

Figure 8. Scatterplot with LOOK4 (from RWMNE) and Wayfinding (from NMRAT). RWMNE = Real World Map Navigation Exercise; NMRAT = Navigational Map Reading Ability Test.

ability. Even if no specific acceptable versus unacceptable level were established, a comparison of subjects could be made. These findings are potentially very important as they suggest that researchers may be able to use a sit-down test to effectively predict a person's ability to read a map and navigate through an environment (a necessarily dynamic and complex exercise). The relationship of these two apects provides additional food for thought. Much research professes to potentially improve the map communication process, but without a way to easily and effectively measure map navigation ability, such suggestions may be of little practical importance. The research presented here identifies a way of representing navigational map reading ability, making possible additional research on the effects of factors such as strategy use or map design on navigational map reading.

Relative Influence of Individual Abilities on Map Navigation

The five individual sections of the NMRAT varied in their ability to predict performance. Through simple linear regression, self-location was overwhelmingly the best predictor, followed by route memory, then map rotation. Wayfinding and place recognition were not statistically significant.

These results suggest that self-location alone is a strong predictor of the highly complex and dynamic task of navigational map reading. Based on the research results, one may conclude that relative to the other four abilities, a person's ability to perform the self-location task is a means to discriminate overall navigational map reading ability. Thus, the answer to the question of why some people can navigate with a map better than others may be based, in part, on their self-location ability. Because this ability is complex, further study breaking down the individual components of this ability would be helpful in understanding its influence in navigational map reading. Results of the research presented in this article would indicate that self-location includes at least two primary components: the ability to successfully relate the environment to the map (and to identify location of the self on the map), as well as the ability to use environmental clues to identify direction on the map. In this case, identifying the direction someone is facing—their ability to rotate themselves within the map environment—may be a form of rotation. Therefore, an

Table 11. Linear regression with LOOK4 from RWMNE (dependent) and WAYFDG from NMRAT (independent)

Dep Var: LOOK4	*N*: 40	Multiple *R*: 0.008	Multiple R^2: 0.000
Adjusted multiple R^2: 0.000		Standard error of estimate: 4.634	

Effect	Coefficient	Std Error	Std Coef	Tolerance	*t*	*P*(2 Tail)
CONSTANT	5.091	1.118	0.000	.	4.554	0.000
WAYFDG	–0.003	0.014	–0.008	1.000	–0.048	0.962

Note: RWMNE = Real World Map Navigation Exercise; NMRAT = Navigational Map Reading Ability Test; WAYFDG = environmental mapping.

Table 12. Linear regression with LOOK4 from RWMNE (dependent), and route memory from NMRAT (independent)

Dep Var: LOOK4 N: 40 Multiple R: 0.494 Multiple R^2: 0.244
Adjusted multiple R^2: 0.266 Standard error of estimate: 4.625

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2 Tail)
CONSTANT	2.674	1.065	0.000	.	2.511	0.016
RTMEM	0.000	0.000	0.494	1.000	3.680	0.001

Note: RWMNE = Real World Map Navigation Exercise; NMRAT = Navigational Map Reading Ability Test; RTMEM = route memory.

exocentric rotation (an ability to mentally rotate the printed map) may not be of interest when differentiating between people's navigational abilities, but egocentric rotation may be an important factor.

Route memory presented the second strongest influence on overall navigational map reading. Memory in general appears to play a role in more than one of the investigated abilities, and the route memory section of the NMRAT exerted a significant amount of influence on LOOKS (how much time a subject spent studying the map; the task route that memory was hypothesized to predict), LOOK4 (how long a person studied the map between locations 3 and 4), and STOPS (the amount of time a subject stopped to get bearings, without consulting the map). Recall that wayfinding was hypothesized to predict LOOK4 and place recognition was hypothesized to predict STOPS. Although route memory was not as strong a predictor of STOPS as was place recognition, route memory predicted LOOK4 better than did the wayfinding section of the NMRAT.

These results may be products of two factors. First, the sections of the NMRAT may not have been designed well enough to predict only a single construct. Second, the three constructs of route memory, place-recognition, and wayfinding may all include memory as an influencing factor. As defined constructs, wayfinding represents a person's ability to learn and *remember* an environment through experience in that environment, and place-recognition represents a person's ability to recognize a real-world environment from the mental map that person created while studying the map. In all likelihood, the answer lies with both explanations. Although the relationships may not be coincidental, one cannot conclude from these analyses whether route memory, place-recognition, and wayfinding should be considered as separate abilities or as one.

Finally, one of the most interesting findings may not be which abilities substantially influence navigational map reading, but rather which ones do not. Map rotation was only a significant predictor of overall navigational map reading when regressed individually against RWMNE scores, and even then the strength of the relationship was low. This finding is important for two reasons. First, as an ability, map rotation may be the most frequently investigated cognitive ability associated with map reading. Several researchers (Hintzman, O'Dell, and Arndt 1981; Steinke and Lloyd 1983; Levine, Marchon, and Hanley 1984; Lloyd and Steinke 1984;

Table 13. Canonical correlation analysis—all sections of NMRAT and all sections of RWMNE

	1	2	3	4	5
Canonical coefficients for independent (x) set (NMRAT variables)					
RTMEM	0.617	0.308	0.258	**0.879**	–0.496
MAPROT	0.318	0.026	**–1.077**	0.109	0.254
PLRECOG	**0.742**	0.452	0.048	–0.596	–0.248
SELFLOC	–0.097	**–1.094**	0.447	–0.541	–0.056
WAYFDG	–0.037	–0.085	0.053	0.150	**1.137**
Canonical coefficients for dependent (y) set (RWMNE variables)					
LOOKS	–0.125	0.193	0.033	**1.205**	–0.843
ROTATIONS	–0.336	0.174	**–0.826**	–0.283	–0.377
STOPS	**–0.728**	–0.399	0.634	–0.662	–0.041
LOCATING	0.068	**0.961**	0.216	–0.429	0.389
LOOK4	–0.169	–0.203	–0.408	0.135	**1.144**

Note: Boldface numbers represent the highest canonical loading for each variate. RWMNE = Real World Map Navigation Exercise; NMRAT = Navigational Map Reading Ability Test; RTMEM = route memory; MAPROT = Map rotation, PLRECOG = place-recognition, SELFLOC = self-location, WAYFDG = environmental mapping.

Table 14. Multiple regression with total score from RWMNE (dependent) and each of the five sections from NMRAT (independent)

Dep Var: RWMNE N: 40 Multiple R: 0.940 Multiple R^2: 0.884
Adjusted multiple R^2: 0.867 Standard error of estimate: 9.916

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2 Tail)
CONSTANT	0.247	5.381	0.000	.	0.046	0.964
WAYFDG	−0.035	0.034	−0.068	0.796	−1.033	0.309
PLRECOG	0.001	0.000	0.141	0.630	1.912	0.064
MAPROT	−0.001	0.001	−0.094	0.661	−1.304	0.201
RTMEM	0.000	0.000	0.139	0.696	1.987	0.055
SELFLOC	0.002	0.000	0.871	0.757	12.968	0.000

Note: RWMNE = Real World Map Navigation Exercise; NMRAT = Navigational Map Reading Ability Test; WAYFDG = environmental mapping, PLRECOG = place-recognition, MAPROT = map rotation, RTMEM = route memory, SELFLOC = self-location.

Table 15. Linear regressions with total scores from RWMNE (dependent) and each section from NMRAT (independent)

Dep Var: RWMNE N: 40 Multiple R: 0.929 Multiple R^2: 0.863
Adjusted multiple R^2: 0.859 Standard error of estimate: 10.207

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2 Tail)
CONSTANT	0.971	3.482	0.000	.	0.279	0.782
SELFLOC	0.002	0.000	0.929	1.000	15.445	0.000

Dep Var: RWMNE N: 40 Multiple R: 0.491 Multiple R^2: 0.241
Adjusted multiple R^2: 0.221 Standard error of estimate: 23.990

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2 Tail)
CONSTANT	32.687	5.954	0.000	.	5.490	0.000
RTMEM	0.001	0.000	0.491	1.000	3.472	0.001

Dep Var: RWMNE N: 40 Multiple R: 0.160 Multiple R^2: 0.026
Adjusted multiple R^2: 0.000 Standard error of estimate: 27.179

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2 Tail)
CONSTANT	36.155	13.182	0.000	.	2.743	0.009
MAPROT	0.001	0.001	0.160	1.000	1.001	0.323

Dep Var: RWMNE N: 40 Multiple R: 0.249 Multiple R^2: 0.062
Adjusted multiple R^2: 0.038 Standard error of estimate: 26.664

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2 Tail)
CONSTANT	33.436	10.453	0.000	.	3.199	0.003
PLRECOG	0.001	0.001	0.249	1.000	1.588	0.121

Dep Var: RWMNE N: 40 Multiple R: 0.193 Multiple R^2: 0.037
Adjusted multiple R^2: 0.012 Standard error of estimate: 27.014

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2 Tail)
CONSTANT	46.642	6.517	0.000	.	6.543	0.000
WAYFDG	0.100	0.082	0.193	1.000	1.216	0.232

Note: RWMNE = Real World Map Navigation Exercise; NMRAT = Navigational Map Reading Ability Test; SELFLOC = self-location, RTMEM = route memory, MAPROT = map rotation, PLRECOG = place-recognition, WAYFDG = environmental mapping.

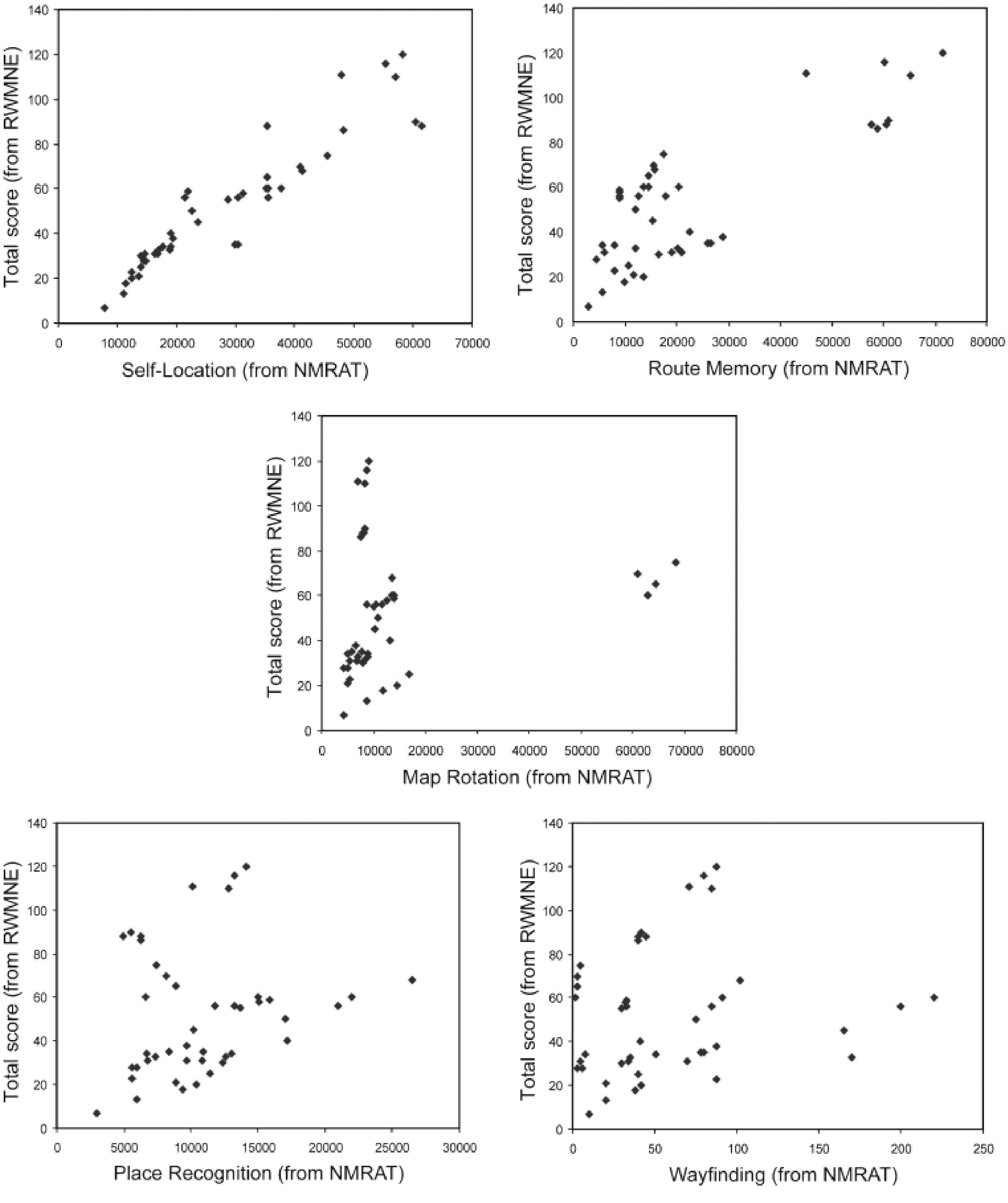

Figure 9. Scatterplots with total scores (from RWMNE) and each section (from NMRAT). RWMNE = Real World Map Navigation Exercise; NMRAT = Navigational Map Reading Ability Test.

Aretz and Wickens 1992) have suggested that map rotation may play a significant role in both the speed and accuracy of map reading. But the research presented in this article reveals that the role played by map rotation in *navigational* map reading, specifically, may not be as strong as has been assumed. Second, one of the most common methods of measuring spatial abilities has been assessing a person's ability to rotate two-dimensional and two-and-a-half-dimensional geometric objects. The finding that map rotation may not be an effective means of predicting overall navigational map reading may indicate that these traditional tests of spatial abilities also may not be reasonable means of assessing map navigation ability, though the relationship between map rotation and geometric object rotation is worth investigating.

Concluding Remarks

The research and questions addressed in this article begin to collectively focus on the relative influence of some potential cognitive processes of navigation with a map, an important function to spatial science. Although the objective of this research was not to create a map navigation test for actual employment selection, the results did demonstrate that a test designed to predict map reading/navigation ability in a real environment can be developed and then administered with relative ease. This discovery could be significant for those who need to identify people with map reading/navigation ability (e.g., researchers or employers), but for whom cost and practicality do not allow them to perform real-world assessments of the ability. Also, identification of the relative influences of the cognitive abilities may allow researchers to better understand the thought processes behind navigational map use. Even while recognizing the complexity of navigational map reading, educators have not been entirely successful in developing a method to satisfactorily teach students how to read a map and navigate through an environment. Identifying influential cognitive processes may result in more effective teaching of map reading and navigation. Self-location, for example, was identified in this research as being the most influential process in map reading. As a result, self-location may be not only a means to discriminate between good and poor map navigation but one of the keys to *teaching* better navigational map reading.

All geographers study the spatial environment in some way. Some, such as geomorphologists, may restrict their studies to the physical environment, whereas others, such as human geographers, study people within their space. In both cases, as well as in nearly all geographic studies, interaction with the environment occurs and this interaction necessitates the development of maps, both mental and physical. Understanding how a person navigates with or without a map may have direct, applied consequences to anyone faced with the task of moving from one point to another. As a result, "it is the need to communicate about spatial information and to understand behaviors taking place in environments that has caused geographers to be interested in cognitive maps" (Lloyd 1997, 1). There has been research focused on understanding the cognitive processes that may associate with navigational map use, cognitive mapping, or wayfinding, but few studies have investigated why individual differences exist (Allen 1999). Certainly it is not easy to design experiments that investigate the cognitive processes associated with map reading because, as Lloyd has pointed out, "two major obstacles have made it difficult to develop a theory of map reading. First, the cognitive processes are not easily observed. They take place in the brain of a map-reader who, for the most part, is unaware of how he is processing information. Second, most map reading tasks are complex and involve multiple cognitive processes that need to be understood" (Lloyd 2000b, 97).

So even if cartographic research has made significant contributions to the map design process (itself a controversial assertion), we still lack a general understanding of *how* a map-reader perceives, processes, and uses map information. The results from this research provide one of the first looks into the individual human abilities that influence navigational map reading. The results also suggest that a reliable and valid sit-down map-navigation ability measurement test can be created and administered in a group setting. Finally, identifying and understanding the abilities that influence map navigation provide initial answers to the question of why some people can navigate with a map better than others. But what influences these human abilities is still a great question—nature or nurture?

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