Exploring a Map Survey Task's Sensitivity to Cognitive Ability

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Abstract— **The present work discusses an exploratory study aimed at understanding how users' cognitive abilities influence performance and method during a series of address verification tasks. College students were given a paper map and asked to verify seven residential addresses scattered throughout a neighborhood. This approach, as opposed to using a mobile device as the verification medium, allotted participants more freedom with respect to address verification style and map interaction. The study methodology and results are discussed. The key contribution of the work described in the paper has been the identification of map usage behaviors that are sensitive to visualization and perspective taking.**

Keywords-human-computer; interaction, individual differences; location-based; usability component.

I. INTRODUCTION

Individual differences research in computing focuses on the physical, cognitive, psychological, social, and cultural distinctions of users in various settings. Individual differences have been shown to influence behavior and performance in desktop computing scenarios [4,6,10,11,12,27]. Similar findings have been presented for field studies using mobile devices, e.g., Nusser and Murphy [25] and Nusser [26] suggest that a user's spatial-visualization ability is especially pertinent to task performance.

A pilot study was conducted to look at the role that cognitive ability plays on paper map usage with respect to a series of address verification tasks [34]. These tasks were modeled around those typically performed by U.S. Census Bureau employees. The results of the pilot study implied that task performance was sufficiently related to participants' spatial-visualization and perspective-taking ability. Some interesting participant behaviors were also observed that seemed applicable to location-based software design. The favorable outcome of the pilot encouraged us to refine the methodology in terms of sample size, protocol, and setting. The study discussed in this paper is a culmination of these refinements.

The goals of this study were: (1) to demonstrate that user performance during address verification is sensitive to cognitive abilities for which participants can be tested; (2) to collect data on address verification and map usage behaviors—some of which might be tied to these cognitive abilities; and (3) to identify behaviors that might be incorporated into the design of a mobile, map-based prototype—to be evaluated in a subsequent study. These findings could be relevant to a variety of applications where users must orient themselves with respect to their geographic position in order to complete a task.

II. BACKGROUND

Several investigators have examined strategies to improve the usability of map-based software. Cox [9] looked at very low-level user actions to identify strategies when working with Geographic Information Systems (GIS). Malczewski and Rinner [24] evaluated decision making based on GIS usage. Haklay and Zafiri [15] utilized GIS usage snapshots. In a recent study on a web-GIS system, Ingensand and Golay [18] found several different strategies and pointed out "users performed differently depending on their strategy". Fern et al. [14] used data mining techniques to extract strategies from data logged during software usage.

Individual differences have been recognized as an important aspect of human performance. Benyon et al. [4] note that individual differences help explain the variation in strategies among computer operators. Spatial ability has been found to be the most important of the individual differences with regard to predicting computer performance [10,11,12,33]. Spatial ability is seen as being composed of five subcomponents by Carroll [7] and Lohman [22]: visualization, speeded rotation, closure speed, closure flexibility, and perceptual speed. Visualization is the most often cited spatial ability related to computer performance [6,29,30,31,32,33,35]. Pak et al. [27] note that the importance of spatial ability depends on the task difficulty while Ackerman [1] suggests that task type is more critical.

Carroll [8] suggested that spatial visualization involves manipulation of spatial configuration in visual short-term memory. Baddeley [2,3] has modeled working memory to include verbal (phonological loop) and visual (sketchpad) components. Luck [23] shows that visual memory is limited and that performance drops systematically when individuals have more than three or four items to remember. Spatial orientation has been distinguished from spatial visualization [20] and shown to influence the way that the user visualizes self within the geographic space defined by a map. Klatzky [19] discusses the distinctions between allocentric and egocentric spatial representations. Burgess [5], Lafon et al. [21], andIgloi et al. [17] suggest that these two spatial representations are acquired and exist in parallel, a position

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recently corroborated by electroencephalographic evidence in Plank et al. [28].

III. METHODOLOGY

A. Screening

Three cognitive tests were administered during the screening phase: spatial visualization (VZ-2) [13], visual memory (MV-2) [13], and perspective-taking (PT) [20]. Twenty-seven college students were selected to participate from a tested pool of over 100. The intent was to create a sample consisting of students with high combined scores and students with low combined scores. We expected this partitioning to allow us to observe greater differentiation among participants.

B. Materials

Topologically Integrated Geographic Encoding and Referencing System (TIGER\Line) Shapefiles were combined using ESRI's ArcGIS Desktop© to create the map. This map contained two layers of information: (1) a street layer that provided all of the streets and their respective labels and (2) an address layer that depicted each residential address as a small dot accompanied by an address number. The decision to provide such sparse map to the participants was motivated by two issues. First, our goal was to use maps similar to those used by Census Bureau staff. Second, the bare and abstract presentation of the map encouraged participants to enrich the map with detail that supported their actions. Address numbering and placement errors were deliberately added to the map to make the verification tasks more challenging.

Each participant was given a clipboard with the paper map attached to the front side in landscape orientation and a randomized list of the seven target addresses attached to the back. A multi-colored pen was provided so that participants could edit the map and list with the appropriate level of detail. Participants were outfitted with an audio device that was used throughout the exercise to record think-aloud comments and to capture responses to an exit questionnaire. The questionnaire probed participants on the effects of setting, map design, planning, task difficulty, and previous knowledge/experience. Observers used coding sheets throughout the exercise to capture supplementary data. The map, list, audio recording, and coding sheets were collected for later analysis. Additionally, these materials were used to reconstruct participant routes. These routes were input into Google® Earth so that the individual travel distances could be estimated.

C. Residential Area: Grid vs. Non-Grid

The field exercise took place in the cross section of the residential area depicted in *Figure 1*. The western half is designated the *grid section*. It is made up of streets that are homogeneous and closely aligned with the cardinal directions. The three-way intersections of this area are exclusively comprised of T-junctions; the 4-way intersections are similarly perpendicular. These features give this area an orthogonal, uniform structure. The resulting blocks are approximately rectangular in appearance.

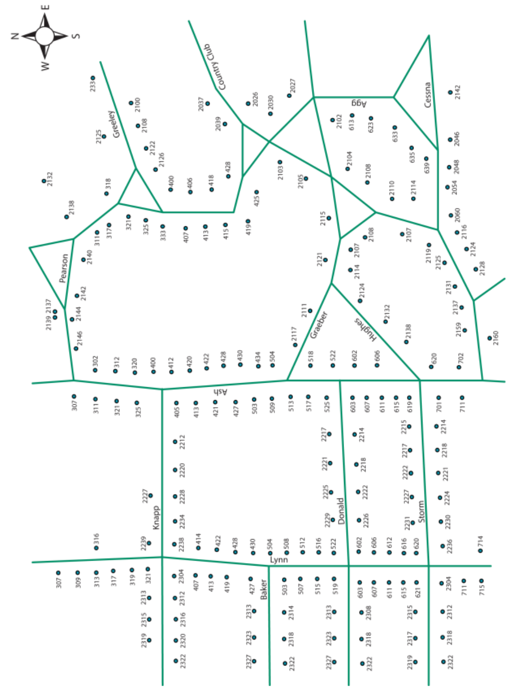

Figure 1. Field exercise map given to participants (right-side up).

The eastern half of the area contains non-uniform streets that seldom run parallel with the cardinal directions. The three-way intersections formed by these streets are Y-junctions, rather than T-junctions. The four-way intersections occur at varying angles. The large triangular medians are another notable feature—they are formed when three Y-junctions interconnect. This area is not orthogonal in nature and is designated the *non-grid section*.

It is thought that these contrasting halves would add variation to the verification scenarios encountered by participants.

D. Field Exercise

The participants selected for the field exercise were taken, one at a time, to the residential neighborhood. Each session contained one participant and one observer. The exercise began at a uniform starting location, where the observer explained the task flow, the think-aloud protocol, and the possible outcomes of verification. Each participant was instructed to verbalize his or her cognitive processes and thoughts related to the exercise. The participant was then asked to complete three training scenarios on a simplified map containing only two streets. At the end of the training session, the participant was given an answer key and received feedback from the observer on verbalization. The participant and observer then returned to the starting location, where the participant received the exercise map and the list containing seven addresses to be verified.

The participant was told that each of the seven target addresses required one of these basic address-verification actions: (1) *add-to-map*, (2) *move-on-map*, (3) *delete-from-map*, and (4) *confirm-on-map*. The grid and non-grid sections of the map each contained three addresses that required address-verification actions *1*, *2*, and *3* (no replace); the major street that divided these sections contained a single address requiring address-verification action *4*. Participants were told to edit the map at their discretion; the only requirement was that they clearly convey the address-verification actions chosen. After answering any final questions, the observer would no longer communicate with the participant, other than to encourage a person who had fallen silent or to request more detail with regard to a participant's response.

E. Method of Analysis and Variables Used

The performance variables, *total time*, *distance traveled*, and the number of *errors made*, were tested against the cognitive test scores using pair-wise correlations. Participants' behaviors were categorized via the analysis of qualitative data found in the observer coding sheets, the coded think-aloud transcripts, participant annotations on the provided maps and target address lists, and participants' responses to the field exercise questionnaire. Behavioral variables (excluding questionnaire data) that could be quantified across participants were tested against the cognitive test scores and the performance variables. Pair-wise correlations and a two-tailed Welch's *t* test were used when appropriate. The available records did not allow for coding of some measures, so the number of observations per variable can be fewer than 26. The significant coded variables are described below.

1) Variables Found in Transcriptions.

- *Address error pre-detection* – The number of times a participant recognized address errors at the start of the exercise; they had not yet seen the actual address.
- *Nearest address selection* – The number of times a participant chose their next target address based on its proximity to the one previously verified.
- *Cardinal heading usage* – The number of times a participant described their heading in terms of cardinal direction (north-south-east-west). This was interpreted as a proxy for an allocentric frame of reference.

2) Variables Found in Maps/Lists.

- *Target streets highlighted on map* – True if the participant highlighted the street labels associated with the target addresses.
- *Map verification annotations* – True if the participant annotated target addresses on the map in excess of what was required to indicate a solution.
- *List verification annotations* – True if the participant annotated target addresses on the list in excess of what was required to indicate a solution.
- *Route sequence on list* – True if the participant enumerated each target address to indicate the route sequence.

IV. Results

A. Correlation Among Cognitive Test Scores

Table I contains the pair-wise correlation coefficients of the 26 participants' three cognitive test scores, along with the p-value of a test determining whether the true correlation is zero. The results offer moderately strong evidence of a correlation between spatial visualization and the two other cognitive tests. There is suggestive evidence that visual memory and perspective-taking scores may also correlate.

TABLE I. COGNITIVE TEST SCORE CORRELATION.

Cognitive Test	**Cognitive Test**	***n***	***r***	***p***
Spatial Visualization	Visual Memory	26	0.54	0.00
Spatial Visualization	Perspective-taking	26	0.44	0.02
Perspective-taking	Visual Memory	26	0.36	0.07

B. Correlation of Cognitive Test Scores with Performance Variables

Participants took from 30 to 66 minutes to complete the field exercise and traveled between 1.77 and 3.02 km (1.10 and 1.88 mi). Total time was negatively correlated with scores on spatial visualization ($r = -0.44$, $p = 0.02$) and perspective-taking ($r = -0.51$, $p = 0.01$). This indicates that participants with higher spatial visualization or perspective-taking ability tended to finish the exercise faster. Distance traveled was negatively correlated with spatial visualization test scores ($n = 21$, $r = -0.65$, $p = 0.00$). Visual memory test scores showed no significant correlation to the performance variables.

Clearly, there are other participant characteristics that could influence time, e.g., walking speed. We didn't investigate the connection between physical characteristics and cognition scores. However, the fact that the total distance traveled by the participants was negatively correlated with spatial visualization leads us to believe that the relationship between time and cognitive abilities is more likely influenced by the fact that lower ability participants walked farther than by any physical characteristics.

C. Cognitive Test Scores & Coded Variables

Spatial visualization test scores are positively correlated with *address error pre-detection* ($n = 21$, $r = 0.44$, $p = 0.05$) and *nearest address selection* ($n = 21$, $r = 0.45$, $p = 0.04$). This indicates that participants with high spatial visualization ability (1) identified more map errors at the onset of the exercise and (2) consistently chose their next target address based on its proximity to the one previously verified. Perspective-taking test scores are positively correlated with *address error pre-detection* ($n = 25$, $r = 0.49$, $p = 0.01$) and *cardinal heading usage* ($n = 23$, $r = 0.51$, $p = 0.01$). This suggests that participants with higher perspective-taking ability (1) identified more map errors at the onset of the exercise and (2) were more likely to describe their heading from a cardinal, allocentric frame of reference (north-south-

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east-west) rather than an egocentric one (forward-backward-right-left).

A two-tailed Welch's *t* test was used to test for associations between the cognitive test scores and the variables found in the collected maps and lists (Table II). Spatial visualization test scores were negatively associated with *map verification annotations*, suggesting that participants with lower spatial visualization ability added more supporting detail to the map. Participants with lower perspective-taking ability exhibited similar behavior with regard to the target address list—as shown by the negative association between perspective-taking test scores and *list verification annotations*. Additionally, perspective-taking test scores showed negative association with *target streets highlighted on map*, indicating that participants with lower perspective-taking ability tended to identify the streets that the target addresses were on; they then highlighted the street labels on the map. Visual memory test scores showed a positive association with *route sequence on list*, implying that participants with higher visual memory tended to enumerate a sequential route order on their target list of addresses.

TABLE II. ASSOCIATION OF COGNITIVE TEST SCORES WITH MAP AND LISTS VARIABLES (WELCH'S *T* TEST)

Behavior	**Cognitive Test**	$Y_1 - Y_0$ *	$SE(Y_1-Y_0)$*	***p***
Target streets highlighted on map	Spatial Visualization	-4.25	1.54	0.01
Map verification annotations	Perspective-taking	-4.45	1.52	0.02
List verification annotations	Perspective-taking	-4.31	1.90	0.05
Route sequence on list	Visual Memory	3.29	1.11	0.01

* Y_1 is the mean of cognitive test scores for all who exhibited the behavior and Y_0 is the mean of cognitive test scores for all who did not exhibit the behavior.

D. Additional Behaviors Observed

Behaviors that were sporadic and difficult to capture could not be adequately linked to cognitive test scores, however, they may be worthy of consideration in the follow-up study.

- Participants preferred either a north-up or track-up map orientation and some north-up users seemed to temporarily switch orientations in confusing areas of the neighborhood.
- Participants covered addresses and map elements that were unrelated to their current target address.
- Participants used color on the maps and lists to indicate and differentiate their various actions and decisions.
- Participants inferred detailed relationships between cardinal directions and street numbering patterns, e.g., "even-numbered addresses are on the north on east-west streets and on the west on north-south streets".

V. DISCUSSION

A. Relation of Participant Performance to Cognitive Test Scores

Our findings support the hypothesis that cognitive test scores are related to participant performance on a map survey task. Spatial visualization scores were a strong prior indicator of performance, being significant against distance traveled, total time and *nearest address selection*. Perspective-taking ability was also correlated with total time, *nearest address selection*, and *address error pre-detection*. Conversely, we did not find visual memory to be linked to performance metrics. Errors were not statistically relevant.

Predictably, distance traveled and total time are significantly correlated; however, *nearest address selection* was not correlated with distance traveled. This could result from two or more participants traveling different distances despite their similar *nearest address selection* scores. Another explanation may be that, in some cases, a tendency to choose the next target address based on distance is inadequate when a given route will cover multiple addresses—a holistic approach should be taken in this case.

Address error pre-detection was positively correlated with perspective-taking scores. One explanation is that in order to excel on the perspective-taking test, one must assess the relative placement of a target to its surroundings. This same ability might be applied to target addresses with respect to the map, allowing these participants to hone in on discrepancies. Furthermore, this finding, when taken together with the fact that perspective-taking scores are correlated with *cardinal heading usage*, suggests that people with higher perspective-taking ability are capable map users.

These results provide evidence that the address verification task was sensitive to cognitive abilities. The literature further indicates that spatial visualization scores predict computer performance [6,29,30,31,32,33,35]. Tailoring interfaces for cognitive differences appears to be a desirable direction in map survey software design.

B. Behaviors Linked to Test Scores and Software Design

Behaviors associated with the cognitive test scores provided some evidence that address verification software can benefit from features sensitive to the respective abilities of a user.

Participants who detected target address errors on the map (missing addresses, for example) without physically examining the target location typically did so at the beginning of the field exercise. This practice might be emphasized in software through an initial planning step. Participants with higher perspective-taking ability tended to prefer describing their movement in cardinal (north-south-east-west) terms. This finding seems to suggest that a software presentation that facilitates or even emphasizes the cardinal directions would be appropriate for users with high perspective-taking ability. A compass rose, for example, helps to fill this void.

Modifications that were made to the provided map and list should also be considered. Participants that added additional address verification annotations to the map had a lower overall spatial visualization ability; thus, textual cues may have served to alleviate deficiency in this ability. A software feature that allows custom tagging of map elements may benefit these users. Analogously, participants who added extra address verification annotations on the target list had a lower overall level of perspective-taking ability. This group may be assisted through embedded note-taking features or some sort of checklist. Participants who highlighted target streets had a lower overall level of perspective-taking ability than participants who did not. This group may also appreciate the ability to tag map elements via a highlighting tool. Finally, some participants added the order in which they verified addresses to their target list. They had a higher overall level of visual memory than the rest of the sample. Their bookkeeping can be automated in software, or alternatively, they may benefit from a planning tool that links map areas to a sequence of target addresses.

C. Observed Behaviors and Software Design

The behavioral variables found on the maps and lists and cardinal direction were not statistically related to performance metrics but suggested enhancements to the software design space. Some participants would use a pen or their hands to obscure addresses that they had verified. This preference might be accommodated by presenting dissimilar levels of detail for different areas of the map; one example would be a "fish-eye" map viewport. Pan and zoom functions could be extended to allow for more freedom, also addressing user dispositions with regard to map detail. Additionally, pan and zoom "bookmarks" could enable the retention of serendipitous map views. Color-coding can be employed not only to differentiate among survey actions (as used by participants), but also to highlight the odd or even-numbered sides of streets and to convey relationships between these streets and the cardinal directions.

VI. CONCLUSTION

Our study presents evidence that an address verification task, driven by a paper map, is sensitive to the cognitive abilities of the verifier—especially their spatial visualization and perspective-taking abilities. Performance and some behaviors were significantly associated with psychometric test scores, thereby improving the plausibility of a software design that incorporates enhancements sensitive to users' cognitive abilities. The behaviors that were observed also suggest a number of software design considerations. While our tests were specific to address verification, we believe that several of the lessons learned in this study will be applicable to other areas of map-based surveys. In particular we have seen that spatial ability played a role in initial planning (pre-planning), how the participants used the map during way finding and how they used the map in the area around the target address. Most map-based applications will involve one or more of these activities.

Our future work in this area will include the development of a software interface that incorporates the enhancements previously discussed. This software will be the focus of a study that will evaluate the efficacy of these enhancements with respect to the cognitive abilities of the participants. We will also use the data collected during this study to develop decision models as a means of providing a clearer picture of how spatial abilities impact the participant's work.

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