The Impact of Environmental Qualities and Individual Differences on Spatial Orientation in a Mobile Context

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Abstract. To contribute to cognitive engineering for mobile users, we propose that mobility itself, the environment, and individual differences all have to be incorporated into a unified framework. To make this argument, we present both a position statement and results from a behavioral study. Forty participants were taken individually to 12 locations on different floors in a library where they estimated their location and orientation on a map. Participants were randomly assigned to perform these tasks under one of two mobility conditions—either being required to stand in a single location (static) or being permitted to move before responding (active). Locations in the library were characterized using space syntax measures and individual differences were assessed using a battery of established tasks. Results show that mobility, environmental qualities, and individual differences all affect performance but that overall active exploration results in better performance. Through establishing this unified framework our research addresses fundamental questions of what it means—from a cognitive perspective—to be mobile.

Keywords: mobility; indoor environment, spatial skills, spatial orientation

1 Introduction

The use of mobile devices has created a new context for wayfinding, which is different from wayfinding experiences that are associated with you-are-here (YAH) maps. Instead of consulting pre-installed navigational services such as a YAH map posted at a particular spot to learn where one is located, individuals using mobile devices can receive on-the-go information of their current location while moving in the environment. Studies have shown, however, that using mobile devices—in comparison to using traditional maps or direct exploration—results in longer traveled distances, longer travel times, and reduced accuracy in estimating directions [1]. Acquisition of spatial knowledge and wayfinding are complex tasks. In this article we focus on three factors that potentially influence wayfinding success in a mobile context: mobility, environmental qualities, and individual differences.

First, mobile devices obviously allow users to be mobile and receive on-the-go information. The acquisition of spatial knowledge is thus not restricted to the user's current location. In the present article we operationalize a narrow meaning of being mobile and contrast two conditions: *static* indicates situations in which individuals are required to stay at their current location once they have been asked to locate themselves and indicate their orientation on a map. In contrast, *active* indicates situations in which individuals are permitted to move around before they have to do the same tasks.

Second, qualities of environments are potentially correlated with wayfinding performance. Space syntax research has developed methods to quantitatively characterize environments. Methods such as visibility graph analysis (VGA) [2], axial map [3], and inter connection density (ICD) [4] have been used in studies relating environmental qualities to wayfinding performance (see examples [5-7]; a fuller review and introduction to these methods can be found in [8]). Complementing these earlier studies, we introduce global and local measures of environmental qualities to incorporate the critical concepts of *spatial homogeneity* and *spatial heterogeneity* into our framework. Details on both global and local measures are introduced in the methods section.

Third, individual differences also influence wayfinding performance. Individuals vary markedly in their measured spatial skills [9-11]. Studies have demonstrated an association between individual differences and performance of spatial orientation (see [12-14]). Here we adopted similar methods used by Liben and collaborators [12-14] to differentiate individuals regarding their spatial skills.

We chose an indoor environment in the present study given the rising interest in indoor navigation. To name just a few illustrative studies, Worboys and collaborators [15, 16] used bigraphs to model both outdoor and indoor environments; Giudice and collaborators [17] adopted an ontological perspective to address data models and functional models of both outdoor and indoor spaces; Richter and collaborators [18] address the hierarchical representation of indoor spaces.

In sum, the goal of the current study was to understand how spatial orientation is affected by different conditions of mobility; by different environmental qualities as measured by space syntax methods; and by individual differences as assessed by paper-and-pencil spatial tasks.

2 Methods

2.1 Participants

Forty college students recruited through a psychology subject pool were randomly assigned to one of two conditions, specifically either static (11 males and 9 females, M = 18.8 years, SD = 0.83) or active (5 males and 15 females, M =18.8 years, SD = 0.81). Participants received extra course credit for participation.

2.2 Environment

We selected two floors in the Central Stacks and Paterno Library within the main library on our campus (see Figure 1) because they differ with respect to their environmental qualities. The library has been anecdotally referred to as one of the most difficult buildings on campus in which to find one's way. We used VGA [2], axial map [3], and ICD [4] to characterize visibility, connectivity, and layout complexity of this environment, respectively. A global measure was calculated across each entire floor using each method. For the 12 locations (6 in the Central Stacks, 6 in the Paterno Library) that we selected for orientation tasks, we also calculated local measures, making sure to include an even combination of low and high values (see Figure 2). As the global ICD is negatively correlated with global VGA and global connectivity, the term "high global" as used in this article actually indicates low global values for ICD. More specifically, the 12 locations were divided into four different categories depending on their global and local values: low global/low local (locations 1, 2, 3), low global/high local (locations 4, 5, 6), high global/low local (locations 8, 10, 11), and high global/high local (locations 7, 9, 12). For example, location 1, 2, and 3, located in Central Stacks, had relatively higher values of local visibility and connectivity but low global visibility and connectivity.

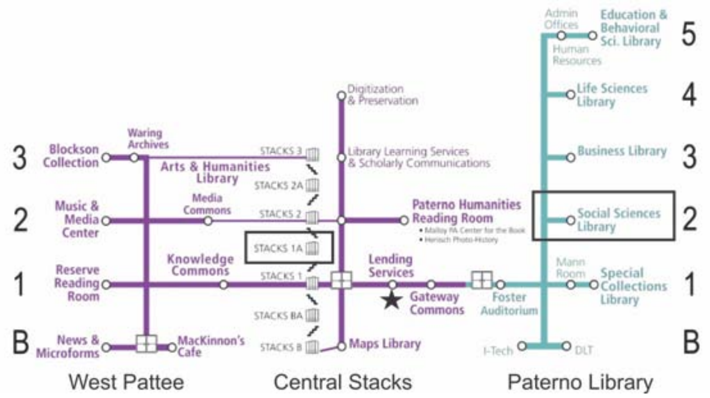

Fig.1. Transverse view of the main library (Courtesy of the Pattee and Paterno Libraries). Areas outlined in bold rectangles show the two floors in this study and the star indicates the starting location of the experiment.

2.3 Procedures

Participants were taken to one of the two floors in counterbalanced order. Within a given floor, they were taken to the six locations in an individually randomized order. The experimenter led participants to the floors using staircases. While participants were standing at each target location facing a designated direction, the experimenter asked participants to draw a dot or "x" on the map to indicate their location and then to draw an arrow on the map to show their orientation. The map was a simple floor plan showing the locations of book shelves and the basic geometry of the environment. This floor plan was simplified based on map schematization described by Meilinger and collaborators [19]. Participants in the static condition were asked to stand in place as they completed all tasks; participants in the active condition were free to move around before they provided their answers. Location responses were scored as correct if the mark was within the correct book shelf aisle and within a 10 mm radius scoring circle on the map. Orientation responses were scored as correct if the arrow was facing the correct direction within a 22.5° margin of error on either side.

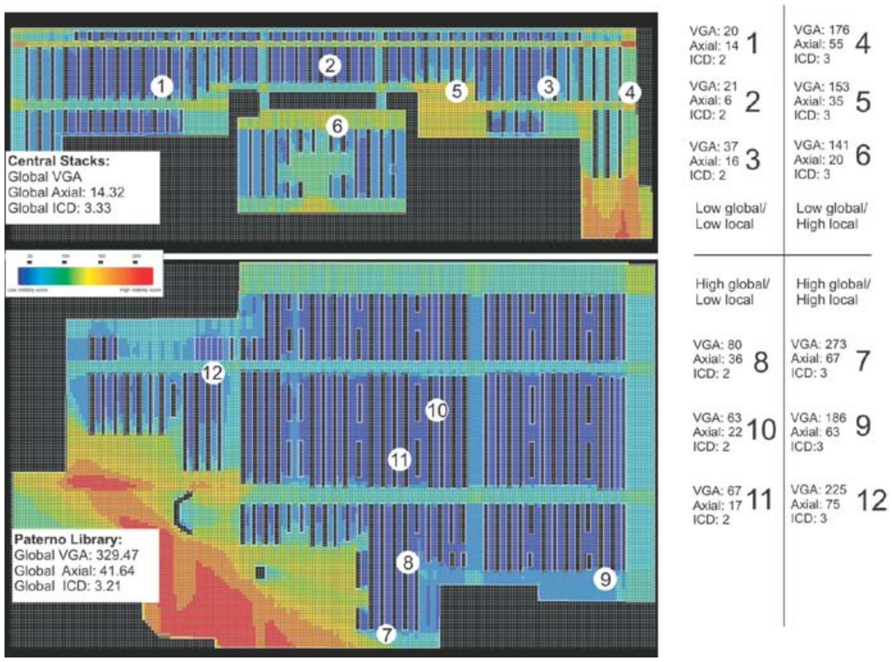

Fig.2. The 12 test locations, their global values (left) and local values in space syntax (right).

Pencil-and-paper spatial tests were given after all environmental tasks were completed. Tasks included an untimed water level test (WLT), a 3 min mental rotation test (MRT), and a 3 min paper folding test (PFT) which, respectively, assessed spatial perception, mental rotation, and spatial visualization [9]. The scores of MRT were chosen as a differentiating factor of spatial skills because mental rotation has been shown to correlate with orientation performance in some earlier studies [20, 21] and because it is a component of spatial skills that is virtually always identified in factor analyses [9, 22]. All three tests are considered in our continuing work on prediction models, which are not reported in this paper.

3 Results

Performance at the 12 locations in 4 categories (low global/low local, low global/high local, high global/low local, and high global/high local) was analyzed with two separate repeated measures analyses of variance: one with the number of correct location responses (maximum = 3 in each category) and one with the number of correct orientation responses (maximum = 3 in each category) as the dependent measures. In both analyses, between-subjects variables were mobility condition (static vs. active) and spatial skill (low vs. high). The latter division was based on a median split using participants' mental rotation scores. The two within-subjects factors were high or low global and local space syntax values.

3.1.1 Location estimations

The analysis of location estimates revealed a three-way interaction among global value, mobility, and spatial skill. As shown in Figure 3, participants in the static condition performed significantly worse on low than high global locations (*M* =1.08, *SD* = 1.70 vs. *M* =.75, *SD* = 1.11, respectively, maximum = 6.0), but these patterns did not differ in relation to participants' spatial skills. In contrast, in the active condition, performance varied with both environmental qualities and individual differences: at low global locations, performance by low spatial participants was significantly worse than by high spatial participants (*M* =.71, *SD* = 1.73 vs. *M* =1.69, *SD* = 1.27, respectively, maximum = 6.0) whereas at high global locations, performance did not differ in relation to participants' spatial skills (*M* =1.36, *SD* = 1.57 vs. *M* =1.54, *SD* = 1.16, respectively, maximum = 6.0). Subsumed by this interaction was a main effect of global value, $F(1, 36) = 5.81$, $p < .05$, with fewer correct responses at locations with low than with high global values (*M* = .84, *SD* = .78 vs. *M* =1.18, *SD* = .71, respectively, maximum = 6.0). The main effect of local values was only marginal, $F(1, 36) = 3.26$, $p = .083$.

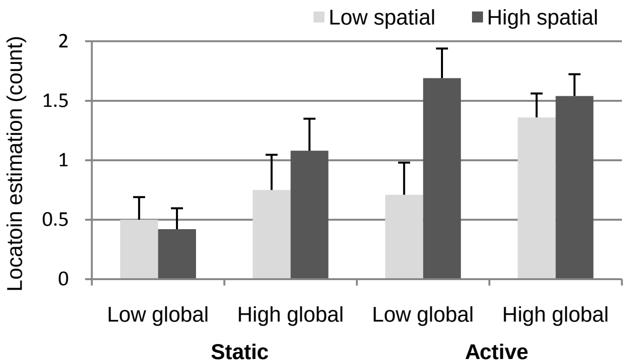

Fig. 3. Interaction effect of mobility, spatial skill, and global values on location errors

Also evident was a significant effect of mobility, $F(1, 36) = 12.08$, $p < .01$. Participants in the active condition had significantly more correct estimates than those in the static condition, (*M* =5.65, *SD* =2.48 vs. *M* =2.65, *SD* =2.03, respectively, maximum = 12.0). There was also a marginal effect of spatial skills on performance, $F(1, 36) = 3.68$, $p = .06$.

3.1.2 Orientation estimations

The analysis of orientation estimates revealed a two-way interaction between global and local values. When locations had low global values, orientation performance did not differ between low and high local values (*M* =2.14, *SD* =1.00 vs. *M* =2.10, *SD* =.95, respectively, maximum = 3.0). In contrast, when locations had high global values, orientation accuracy was significantly worse at locations with low than with high local values (*M* =1.40, *SD* =.97 vs. *M* =2.66, *SD* =.72, respectively, maximum = 3.0). Subsumed by the interaction was a significant main effect of local value, $F(1, 36) = 29.13$, $p < .01$. Orientation accuracy was lower at locations with low than with high local values (*M* =1.78, *SD* = .71 vs. *M* =2.38, *SD* = .72, respectively, maximum = 6.0).

Also evident was the effect of mobility, $F(1, 36) = 12.49$, $p < .01$. Participants in the active condition provided more correct responses than in the static condition (*M* =9.75, *SD* =1.55 vs. *M* =7.15, *SD* =2.87, respectively, maximum = 12.0).

4 Discussion

The mobility of a person is vital to the accuracy of locating and orientating oneself in buildings. Earlier studies have suggested that active exploration results in significantly better development of spatial knowledge [23] [24]. Similarly, our results show that being mobile facilitates adults' accuracy on both location and orientation performance. This is an important insight potentially relevant to the design of navigational services on mobile devices.

Adults have difficulty locating or orientating themselves in indoor environments, a finding that is similar to ones reported in wayfinding research in outdoor environments [12, 14]. Environmental qualities and individual differences each affect locating and orientating oneself in buildings, although their effects are intricate. The environmental qualities obtained from space syntax that differentiate locations based on their global and local values, are associated with performance. In the location task, adults show less accurate performance in buildings with low global values than in buildings with high global values. Additionally, performance is worse among adults with poorer spatial skills. Relating the factor of mobility to the environment and individual differences, our results show that adults with higher spatial skills benefit more from being mobile than those with poorer spatial skills. In the orientation task, adults have difficulty estimating orientation in a complex building. The local qualities of locations such as their visibility do not seem to be the factor that has a major impact. That is, when global values are low at locations, local values do not matter further. When global values are high, however, local values significantly modify performance.

5 Conclusion

Our study has addressed a core question relevant to an aspect of using mobile devices: mobility itself. We strive for a holistic perspective on people's performance in spatial environments by establishing a framework which incorporates not only mobility, but also environmental qualities and individual differences. In addition to supporting findings from earlier studies that related characteristics of the environment to individual wayfinding behaviors [5, 7], we demonstrated the influence of mobility, environmental qualities, and individual differences on location and orientation performance. Furthermore, we advanced the understanding of environmental qualities and individual differences by using theories from spatial information science as well as from classic cognitive psychology. In addition to the suggestion of Gunzelmann and Anderson [25] that features of location impact spatial orientation, we further explored locations with respect to their global and local characteristics, a theoretical construct well known in spatial analysis but not yet integrated into a science of mobility for which it seems to be particularly relevant.

Acknowledgement

Research for this paper is based upon work supported by the National Science Foundation under Grant No. 0948601. The views, opinions, and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied, of the National Science Foundation, or the U.S. Government.

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