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# Wayfinding with a GPS-based mobile navigation system: A comparison with maps and direct experience

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**Abstract**

This study examined the effectiveness of a Global Positioning System (GPS)-based mobile navigation system in comparison to paper maps and direct experience of routes, by focusing on the user's wayfinding behavior and acquired spatial knowledge. Based on information received from one of these three media, participants walked six routes finding the way to goals. Results showed that GPS users traveled longer distances and made more stops during the walk than map users and direct-experience participants. Also, GPS users traveled more slowly, made larger direction errors, drew sketch maps with poorer topological accuracy, and rated wayfinding tasks as more difficult than direct-experience participants. Characteristics of navigation with these three learning media and possible reasons for the ineffectiveness of the GPS-based navigation system are discussed.


*Keywords:* Wayfinding; Navigational aids; Mobile systems; Cognitive maps; GPS

## 1. Introduction

People engage in various kinds of spatial behavior in their daily lives. One of the most frequently encountered examples is planning a route and moving through space to a destination. This behavior, called *navigation*, may be considered a straightforward and effortless task since it is so common, but it involves multilevel cognitive processing and thus has attracted much theoretical and practical interest from researchers in many fields (e.g., Allen, 1999; Klippel, Tappe, Kulik, & Lee, 2005; Montello, 2005; Timpf, 2002; Winter, 2003). Importantly, finding the way in the environment and moving freely between places is, at least for some people, a difficult and effortful task, as the ability to comprehend the layout of the environment shows large individual differences (Allen, Kirasic, Dobson, Long, & Beck, 1996; Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006; Ishikawa & Montello, 2006).

In successful navigation or wayfinding, people first need to orient themselves in space, namely to know where they are (location) and in which direction they are facing (heading). And then they need to plan a route with an understanding of where a destination is located. Finally, they execute the planned route to the destination. In all these three stages, people access stored knowledge about the surrounding space (internal representations), or refer to navigational aids such as maps (external representations), or do both (Fig. 1).

Traditionally, maps have played major roles in conveying spatial information and guiding people around in space. Recently, many kinds of navigational aids have been developed (e.g., Hightower & Borriello, 2001; Loomis, Golledge, & Klatzky, 2001). In particular, with the advent of advanced information technologies, devices equipped with GPS (Global Positioning System) receivers are now recognized as a promising tool for providing positional information, at least where accurate readings of satellite signals are possible (Shoval & Isaacson, 2006).

About map learning, research has shown that maps facilitate configurational (or two-dimensional) understanding of the represented space, compared to direct experience of the space. At the same time, knowledge acquired from maps is tied to the orientation in which the maps were

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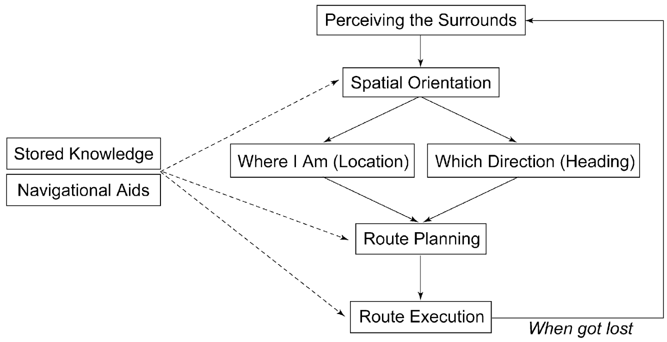


Fig. 1. Schematic explanation of stages involved in navigation. People first need to get oriented in space, by understanding their location and heading. Next, they plan a route to a destination knowing where it is located. And then they execute the planned route. In all stages, people access internal stored knowledge, external navigational aids, or both.

viewed (i.e., orientation-specific), and so it is effortful to imagine views from different perspectives (Roskos-Ewoldsen, McNamara, Shelton, & Carr, 1998; Sholl, 1988; Thorndyke & Hayes-Roth, 1982). Research has also shown that using maps in the field, which requires understanding the relationships between the map, the represented space, and the self, is not an easy task for children and even for adults (Liben, Kastens, & Stevenson, 2002). Liben et al. pointed out that although there is a large body of literature on map learning, systematic studies of map use in the real world have been very few.

With respect to navigational aids, various presentation formats of spatial information have been developed, including verbal navigational directions, static maps, interactive maps, 3-D visualizations, animations, and virtual environments (see Montello, Waller, Hegarty, & Richardson, 2004, for a review). Some studies compared the effectiveness of different presentation formats. Streeter, Vitello, and Wonsiewicz (1985) compared the effectiveness of a route map and taped verbal instructions for guiding drivers in an unfamiliar environment. They found that their carefully constructed verbal instructions were better than the route map in terms of travel time and distance and the number of navigation errors. Coors, Elting, Kray, and Laakso (2005) compared 2-D maps and 3-D visualizations as a means of presenting route instructions on mobile devices. Their participants located their positions and reached destinations faster with 2-D maps than with 3-D visualizations. Dillemuth (2005) compared an aerial photograph and a generalized map as representations for a handheld navigational device, and showed that the latter yielded faster travel speed and fewer navigation errors than the former. Despite these past attempts in the literature, more empirical research on the effectiveness of different types of navigational aids is needed.

In this study, we aim to examine the effectiveness of a mobile navigation system in comparison to paper maps and direct experience, by focusing on the user's wayfinding behavior and acquired spatial knowledge. The navigation system used in this study was a cellular phone equipped with a GPS receiver. On its small screen, a map of the surrounding area was shown and the user's current position and a route to a destination were indicated, being dynamically updated as the user moved in space. The paper maps used in this study showed the locations of a starting point and a goal, but not a route to the goal.

The mobile navigation system and the paper maps intended to assist the user in the three stages of navigation illustrated in Fig. 1. On both the GPS-screen map and the paper map, the user's position was indicated, but the user needed to understand the direction in which they were facing, that is, to align the map with the surrounding space, either physically or mentally. But navigation with these two media was different in two respects. First, with the GPS-based navigation system, once being oriented in space, the user only needed to follow the route shown on the screen (i.e., to see that the current position shown on the screen would not go off the indicated route); in contrast, map users needed to update their positions mentally in relation to the surrounding space. Second, the GPS-based navigation system presented information about routes in a piecemeal fashion, that is, the current position and route were dynamically updated, and the entire route from the starting point to the goal was not always shown on the same screen; whereas the paper map showed the starting point and the goal together embedded in a larger area of the surrounding space. A major objective of this study was to look at how these differences would affect people's navigation and spatial understanding.

To do that, we compared navigation with the GPS-based mobile system and the maps to navigation based on experience of walking routes accompanied by a person. In this direct-experience condition, participants first learned each route guided by an experimenter, and then followed the route from the starting point to the goal by themselves. Put differently, we took performance by participants in this condition as a baseline, and examined whether the two navigational aids were able to help people walk as if they had traveled the routes once before. To compare the effectiveness of these three learning media, we examined participants' performance on wayfinding tasks and the accuracy of their knowledge about routes. For the former, we looked at how much distance they traveled, how fast they reached the goals, and how often they stopped on the way to the goals. For the latter, we looked at the accuracy of configurational and sequential understanding of the routes.

## 2. Method

### 2.1. Participants

Sixty-six college students (11 men and 55 women) participated in the experiment. Their ages ranged from 18 to 28, with a mean of 20.4 years. They were paid ¥5000 in return for participation. None of the participants had been to the study area before the experiment.

### 2.2. Materials

#### 2.2.1. Study area and routes

We used as the study area a residential area in Kashiwa, Chiba. In that area, we selected six routes that were 144–298 m in length and contained three turns each (Fig. 2). On each route, the goal was not visible from the starting point, or vice versa. This area is free of high-rise buildings and therefore enabled us to conduct the experiment with a good accuracy (within 5 m) of the GPS-based navigation system.

#### 2.2.2. GPS-based navigation system

On a small screen of the GPS-based navigation system ($4 \times 5$ cm), a map of the surrounding area was shown in a north-up orientation; and on the map, the user's current position and a route to the goal were indicated (Fig. 3). The mapped area and the user's position on the screen were dynamically updated as the user moved in space, and an area within about a 250 m radius of the user's current position was covered by the screen map. Because the size of the screen was small, the starting point and the goal were not always shown together on the map, that is, the location of the goal became visible as the user moved on. The system occasionally provided speech guidance, for example, ''turn left after walking straight for 50 m'' or ''you are near the goal.''

#### 2.2.3. Maps

Participants in the map condition were given a paper map printed on A4-sized paper at the starting point of each

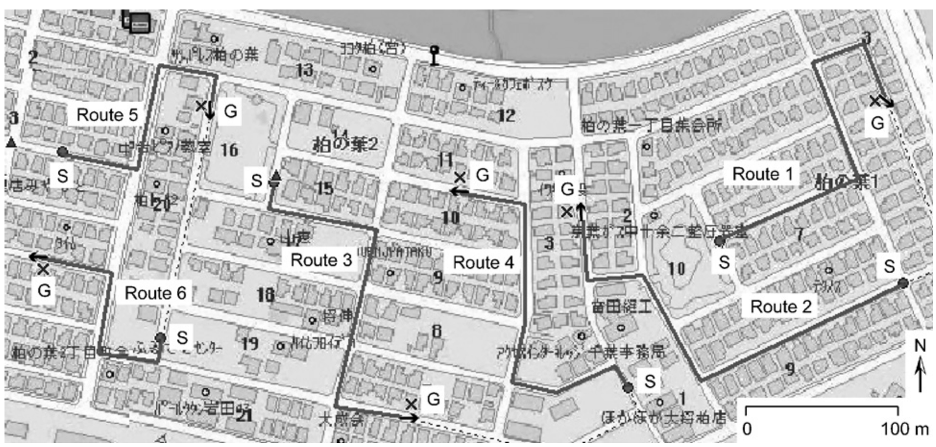


Fig. 2. Map of the study area. Six routes (Routes 1–6) were selected in the area, which were 144–298 m in length and contained three turns each. ''S'' represents the starting point and ''G'' the goal of each route. Arrows indicate the directions in which participants faced at the time of direction estimation.


Fig. 3. Pictures of the screen of the GPS-based navigation system (left) and the navigation system in use (right). The size of the screen is $4 \times 5$ cm. The symbol for a person shown at the center of the screen indicates the user's current position, and the solid lines toward the upper-right corner of the screen indicate a route to the goal.


Fig. 4. Map given to participants in the map group at the starting point of Route 1. Note that only the starting point and the goal are shown, not a route to the goal.

route. On the map, the starting point and the goal were marked, but not a route to the goal (Fig. 4). Participants needed to decide which route to take.

#### 2.2.4. Self-report sense of direction

Participants filled out the Santa Barbara Sense-of-Direction Scale, which consists of 15 seven-point Likert-type questions (Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002). Participants responded by circling a number from 1 (*strongly agree*) to 7 (*strongly disagree*). Seven of the questions are stated positively (e.g., "I am very good at giving directions," "I am very good at reading maps") and the other eight negatively (e.g., "I very easily get lost in a new city," "I have trouble understanding directions"). Hegarty et al. showed that people identified as having a good sense of direction on this scale were good at updating their orientation and location in space as a result of self-motion. We thus used this scale as a potential correlate with participants' wayfinding performance.

#### 2.2.5. Direction estimation task

At the goal of each route, participants estimated the direction to the starting point. (The directions in which participants faced at the time of estimation are indicated by arrows in Fig. 2). To do that, participants were given a sheet of paper on which a circle with a radius of 5 cm was drawn, and drew a line from the center of the circle to indicate the direction to the starting point.

#### 2.2.6. Map sketching task

At the end of the experiment, participants drew sketch maps of the six routes on A4-sized paper. They were instructed to indicate the shapes of the routes as accurately as possible, as if they were giving directions to a person unfamiliar to the area.

### 2.3. Design

Participants were randomly assigned to one of three groups: GPS ($n = 22$), map ($n = 23$), and direct-experience ($n = 21$). The male–female ratio was similar in the three groups. For a reason of experimental scheduling, participants in the GPS group traveled Routes 3, 4, 5, 6, 1, 2 in this order; participants in the map group, Routes 5, 6, 1, 2, 3, 4; participants in the direct-experience group, Routes 1, 2, 3, 4, 5, 6.

One participant in the GPS group had used a GPS-based navigation system frequently (about once a week), but the other participants in this group had never used one before. Three participants in the map group were graduate students in urban planning and earth science and so had used maps regularly, but the other participants in this group had not received specific instruction or training of map use.[1]

### 2.4. Procedure

At the beginning of the experiment, participants answered questions about their experience of using GPS-based navigation systems, and filled out the sense-of-direction questionnaire. Then they were taken individually

[1] Hegarty et al. (2006) administered the Santa Barbara Sense-of-Direction Scale to 221 people, and obtained a mean score of 3.6, a standard deviation of 1.0, a minimum of 1.6, and a maximum of 6.0. These values are very similar to the data for our 23 participants in the map condition: a mean of 3.3, a standard deviation of 1.2, a minimum of 1.8, and a maximum of 5.9. Considering that two of the 15 sense-of-direction questions ask about map use ("I enjoy reading maps," and "I am very good at reading maps") and that the Scale has good internal consistency with a coefficient alpha value of 0.88, we can say that our map participants constituted a typical group with respect to map use.

to the starting point of each route, and the experimental sessions of wayfinding tasks began.

Participants in the GPS group were given the GPS-based navigation system and practiced using the device (i.e., learned how to operate the system and walked a short distance using it). When they indicated that they knew how to use it, they started to walk the six routes. During the walk, no questions or complaints were raised from participants about the operation of the system, nor did we observe any apparent trouble among them with using the system. Participants in the map group were given a map at the starting point of each route, on which only the starting point and the goal were marked, and instructed to walk toward the goal. Participants in the direct-experience group walked each route guided by the experimenter first. Then they were taken back to the starting point via a circuitous route, and started to walk toward the goal by themselves. In all these three groups, the experimenter walked behind participants and observed their behavior, without providing any assistance. On each route, if participants got lost and did not reach the goal after 10 min had passed, the experimenter took them to the goal.

At the goal of each route, participants estimated the direction to the starting point, and rated how difficult it was to find the goal on a five-point scale (from 1 = *very easy* to 5 = *very difficult*). At the end of the experiment, participants drew sketch maps of the six routes on a piece of paper. It took 90–135 min to complete all these experimental tasks.

## 3. Results[2]

### 3.1. Sense of direction

As a measure of sense of direction, for each participant, we calculated the mean of their answers to the 15 sense-of-direction questions. We reversed their answers to positively stated questions so that a higher score means a better sense of direction, ranging from 1 to 7. Among the three groups of participants, there was not a significant difference in sense of direction (Table 1, first row).

### 3.2. Travel distance and speed

Using a GPS tracking system, we recorded participants' positions at approximately constant time intervals during the walk. Based on these data, we calculated for each participant the total distance traveled and the mean walking speed across the six routes. Owing to a malfunction of the system, we excluded three participants from the analyses of travel distance and speed (one in the GPS group and two in the map group).

Table 1
Means (and standard deviations) for each variable by participants in the three groups

| Variable | Group | | |
|---|---|---|---|
| | GPS | Map | Direct experience |
| Sense of direction | 3.6 (1.2) | 3.3 (1.2) | 3.2 (0.9) |
| Travel distance (m) | 1918 (437) | 1569 (347) | 1519 (244) |
| Travel speed (m/s) | 1.1 (0.1) | 1.1 (0.1) | 1.3 (0.1) |
| Number of stops | 2.5 (1.9) | 1.4 (2.0) | 0.1 (0.5) |
| Number of successes | 5.1 (1.2) | 5.4 (1.0) | 5.8 (0.4) |
| Direction error (°) | 34.2 (25.8) | 23.6 (13.5) | 19.2 (6.3) |
| Sketch-map accuracy | 1.3 (1.6) | 2.4 (1.7) | 2.7 (1.9) |
| Task difficulty | 3.0 (0.7) | 2.8 (0.7) | 2.3 (0.9) |

There was a significant difference in travel distance among the three groups, $F(2, 60) = 8.03$, $p < 0.001$. Post hoc paired comparisons showed that the travel distance for the GPS group was longer than that for the map group and that for the direct-experience group. The latter two did not differ significantly (Table 1, second row).

There was a significant difference in travel speed among the three groups, $F(2, 60) = 14.60$, $p < 0.001$. Post hoc paired comparisons showed that the travel speed for the GPS group and that for the map group were slower than that for the direct-experience group. The former two did not differ significantly (Table 1, third row).

### 3.3. Number of stops

We recorded when participants stopped during the walk for 30 s or longer, as an indication that they were trying to reorient themselves and find the way. For each participant, we calculated the total number of stops made on the six routes. Because its distribution was positively skewed, we computed a new dichotomous variable such that participants were assigned 0 if they made no stops and 1 if they made at least one stop.[3]

There was a significant difference in the number of stops among the three groups, $F(2, 63) = 19.8$, $p < 0.001$. Post hoc paired comparisons showed that the number of stops for the GPS group was larger than that for the map group, which in turn was larger than that for the direct-experience group (Table 1, fourth row, showing nondichotomized data).

### 3.4. Finding the way to the goals

With respect to whether participants reached the goals on the six routes within 10 min, they generally did well, and there was not a significant difference in wayfinding performance among the three groups (Table 1, fifth row). Of the 66 participants, 43 (65%) participants successfully reached the goals on all six routes, 15 (23%) on five routes,

[2]As in past research, there were sex-related differences on some measured variables in this study. We found male superiority on self-reported sense of direction, the number of stops, direction estimation, and sketch-map accuracy. In the ANOVAs reported below, we did not include sex as a factor, because of a small number of men.

[3]We obtained the same ANOVA result with nondichotomized data.

Table 2
Correlations between measures of wayfinding behavior and spatial understanding

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 1. Sense of direction | | | | | | | |
| 2. Travel distance | −0.15 | | | | | | |
| 3. Travel speed | −0.06 | −0.19 | | | | | |
| 4. Number of stops | −0.00 | 0.40** | −0.62*** | | | | |
| 5. Number of successes | 0.20 | −0.58*** | 0.23 | −0.29* | | | |
| 6. Direction error | −0.08 | 0.55*** | −0.13 | 0.24* | −0.40*** | | |
| 7. Sketch-map accuracy | 0.21 | −0.46*** | 0.31* | −0.40*** | 0.24 | −0.50*** | |
| 8. Task difficulty | −0.12 | 0.43*** | −0.33** | 0.46*** | −0.35** | 0.34** | −0.50*** |

*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.

3 (5%) on four routes, 4 (6%) on three routes, and 1 (1%) on two routes.

### 3.5. Direction estimates

For each participant, we calculated the mean absolute error of direction estimates across the six routes. We applied a log transformation to the mean errors because the distribution deviated from normality.

There was a significant difference in mean direction errors among the three groups, $F(2, 63) = 3.17$, $p < 0.05$. Post hoc paired comparisons showed that the mean absolute error for the GPS group was larger than that for the direct-experience group (Table 1, sixth row).

### 3.6. Sketch-map accuracy

We analyzed participants' sketch maps in terms of nonmetric (or "topological") accuracy. Specifically, we counted for each participant the number of routes that showed all the turns in the correct directions and sequences (e.g., left-right-right turns for Route 1 in Fig. 2). There was a significant difference in sketch-map accuracy among the three groups, $F(2, 63) = 3.65$, $p < 0.05$. Post hoc paired comparisons showed that the sketch-map accuracy for the GPS group was lower than that for the direct-experience group (Table 1, seventh row).

### 3.7. Ratings of task difficulty

There was a significant difference in the mean ratings of the difficulty of the wayfinding tasks across the six routes among the three groups, $F(2, 63) = 4.31$, $p < 0.05$. Post hoc paired comparisons showed that participants in the GPS group rated the wayfinding tasks as more difficult than those in the direct-experience group did (Table 1, eighth row).

### 3.8. Task correlations

Some of the correlations between different measures of wayfinding behavior and spatial understanding were significant (Table 2). Participants who traveled longer distances tended to make larger direction errors. Participants who traveled longer distances and those who made larger direction errors tended to make more stops, to fail to reach the goals, and to draw sketch maps with poorer topological accuracy.

Participants who made more stops during the walk tended to travel more slowly, and to fail to reach the goals. Participants who drew sketch maps with better topological accuracy tended to travel faster and to make fewer stops.

Concerning participants' self-ratings of the difficulty of wayfinding tasks, participants who rated the tasks as difficult tended to travel longer distances, to travel more slowly, to make more stops during the walk, to fail to reach the goals, to make larger direction errors, and to draw sketch maps with poorer topological accurately.

### 3.9. Relationships with self-report sense of direction

Although self-report sense of direction was not significantly correlated with mean performance averaged across all participants (Table 2), it was significantly correlated with travel distance and direction estimates in the map group. Map participants with a better sense of direction tended to travel shorter distances ($r = -0.44$, $p < 0.05$) and to make smaller direction errors ($r = -0.43$, $p < 0.05$). There were no significant correlations in the other two groups.

### 3.10. Changes in performance over the six routes

To examine changes in participants' performance over the six routes, we analyzed the development of travel distance, travel speed, and direction estimates over the six routes within each group. For travel speed and direction estimates, there were not significant trends indicating overall improvement. For travel distance, performance by the GPS and the map groups showed a significant improving trend. The ratio of travel distance to the shortest distance from the starting point to the goal changed from 1.48 on the first route to 1.13 on the sixth route in the GPS group, and it changed from 1.82 to 1.03 in the map group.[4]

## 4. Discussion

This study compared the wayfinding behavior and acquired knowledge by participants who received information about routes from a GPS-based navigation system, from maps, and from direct experience of the routes. The results are summarized in Fig. 5. With respect to wayfinding behavior, participants who used the GPS-based navigation system traveled longer distances and made more stops during the walk than participants who viewed maps and those who navigated based on experience of walking the routes. Also, GPS users traveled more slowly than direct-experience participants. These findings show that GPS users did not take the shortest route to the goal, by going off the route indicated on the GPS screen, and wandered around or stopped on the way to get (re)oriented in space. In fact, GPS users rated the wayfinding tasks as more difficult than direct-experience participants did.

With respect to acquired spatial knowledge, GPS users' configurational understanding of the routes was worse than direct-experience participants', as evidenced by larger errors in estimating directions from the starting points to the goals. GPS users' topological understanding of the routes was also worse than direct-experience participants', as shown by sketch maps depicting routes with fewer turns in the correct directions and sequences.

These results show that the GPS-based navigation system affects the user's wayfinding behavior and spatial understanding differently than do the maps and direct experience. The majority of our participants successfully reached the goals and there was not a significant difference in success rates among the three groups; thus the GPS-based navigation system anyhow allowed participants to find the way to the goals as well as the maps and direct experience did. But the GPS-based navigation system was less effective than the maps and direct experience as support for smooth navigation, and it was less effective than direct experience for helping people acquire accurate knowledge about routes.

One possible reason for that is the size of the maps shown on the GPS screen. The screen, measuring $4 \times 5$ cm, shows a map of only a small area around the user's current position (within a 250 m radius). GPS users need to get oriented in space (i.e., to identify location and heading) based on the dynamically updated information shown on the small screen map.[5] This is a major contrast between the GPS-screen map and the paper map, the former having yielded longer travel distances and more frequent stops than the latter. If the screen size (and correspondingly the scale of the map) is a factor making navigation with the GPS-based system less smooth, it poses an interesting question of how much surrounding area needs to be covered by a map so that it "works as a map," or fulfills its advantage of conveying the layout information about the space. For instance, even when there is a global landmark in the area that may be used as a navigation clue, it does not help navigation if not shown on the map. Also, as GPS users need to focus on the continuously updated information on the small screen, they pay less attention to the routes and surrounding space globally. This "local" focus of attention should interfere with the global processing of spatial information, which is required for getting oriented in space, by interrelating the surrounding space, the self, and the map (see Fig. 1).

| Group | Distance | Speed | Stops | Direction | Sketch maps | Difficulty |
|---|---|---|---|---|---|---|
| GPS | | | | | | |
| Map | | | | *ns* | | *ns* |
| Direct exp. | | | | | | |

Fig. 5. Comparison of performance among the three groups. Darker shades of gray represent better performance for each measure (i.e., shorter travel distance, faster travel speed, fewer stops made, smaller direction error, sketch maps with better topological accuracy, and wayfinding tasks rated as less difficult). "*ns*" means a nonsignificant difference from the other groups.

Another possible reason for the ineffectiveness of the GPS-based navigation system is its novelty. All participants but one in the GPS group used the navigation system for the first time. Our results show that the system is not helpful to people without experience of using it. So one question is how it can be more usable for such people. Our results also suggest that over repeated trials on the six routes, GPS participants got to take more direct routes to the goals. It would be interesting to see whether people's wayfinding performance improves with repeated use of the system, and if so, how.

In comparing direction estimates by GPS users and direct-experience participants, it can be noted that at the time of estimation GPS users had traveled the routes once, while direct-experience participants had twice (once before guided by the experimenter). So the better performance on direction estimation by direct-experience participants may partly be due to that. But also note Ishikawa and Montello's (2006) finding that the ability to acquire integrated configurational knowledge of routes did not improve greatly with repeated exposures to the routes alone, in the absence of feedback or instruction. And consistent with their finding, in our study, there was no improvement in direction estimates over the six routes. Apart from direction estimation, however, GPS users' performance was worse than direct-experience participants' in terms of travel distance and speed, the number of stops,

[4] Because the order in which the three groups traveled the six routes was different, comparison of their performance on each trial (from the first to the sixth routes) requires caution in interpretation, but the difference in travel distance among the three groups became nonsignificant on the fifth and sixth routes.

[5] Although the GPS-based system had zoom-in and zoom-out buttons and participants were instructed in the use of the buttons, most participants did not use the zooming function.

and sketch-map accuracy. That is, the GPS system failed to help participants navigate as if they had traveled the routes once before. For the GPS system to become a helpful "navigator," there is still room for improvement.

In our study, direction errors by participants in the map and direct-experience groups are not significantly different from each other. This is, on the surface, in contrast to Thorndyke and Hayes-Roth's (1982) finding that map learners did worse than direct-experience participants on pointing to unseen landmarks (orientation-specific vs. orientation-free mental representations). The difference between the two studies is that our map participants walked the routes with maps, whereas Thorndyke and Hayes-Roth' map learners only viewed maps (no direct experience of the study area). This might point to the finding that direct experience (or body movement in space) facilitates orientation judgments in multiple perspectives (e.g., Presson & Hazelrigg, 1984). Another possible factor is the difficulty of routes. The routes used in our study were not too complex, and the overall mean direction error for our participants (25.7°) is relatively small compared to the errors of 20–50° reported in previous studies (Allen et al., 1996; Hegarty et al., 2006; Ishikawa & Montello, 2006; Richardson, Montello, & Hegarty, 1999; Sholl, 1988; Thorndyke & Hayes-Roth, 1982).

Having said that, we note that this effect is dependent on the learner's ability, as evidenced by the positive relationship between sense of direction and the accuracy of direction estimates in the map group. This is in line with Sholl's (1988) finding that sense of direction is related to the ability to mentally rotate an image of the environment. We also point out that using maps in the real world is generally not an easy task for many people, as it requires understanding the relationships between the map, the represented space, and the self (Liben & Downs, 1993; Liben et al., 2002). Our participants in the map group made more stops during the walk than those in the direct-experience group, and in the map group, participants with a better sense of direction tended to travel shorter distances (similar to the finding by Dillemuth, 2005).

In this study, we did not find a significant relationship between participants' sense of direction and wayfinding performance, except in the map group. This may be explained by our participants' high success rates of reaching the goals. But it may also suggest that wayfinding in the environment taps into other abilities than is captured by the route-survey dimension assessed by the sense-of-direction scale, as discussed by Allen et al. (1996). In fact, there are large individual differences in our participants' wayfinding performance: their travel distances range from 1196 to 2763 m and their travel speeds range from 0.83 to 1.52 m/s. Thus, questions about what constitutes people's wayfinding abilities and why people differ in them deserve further investigation. And finally, the GPS-based navigation system we examined in this study was unfortunately not as effective as expected. Issues of theoretical and practical interest about the usability of navigational aids include: What is an appropriate level of generalization or simplification of information to be shown on a device's screen, especially when the screen is small? Is there a good way to represent the level of accuracy (or uncertainty) of positional information, and how do people react to or cope with it? Are there effective strategies of wayfinding with navigational aids, and can people's wayfinding abilities improve through training? We believe that for the development of effective navigational aids, continued empirical research on these issues is needed.

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