Maps in the Head and Maps in the Hand

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Abstract

Using the perspective of situated cognition we studied how people interact with a physical map to help them navigate through an unfamiliar environment. The study used a mixture of cognitive ethnography and traditional experimental methods. We found that the difference between high and low performing navigators showed up in the speed they completed their task and also in the way they use maps. High performers plan routes using a survey method whereas low performers use a route strategy. We suggest that when people are given a task that does not match their cognitive style they try to transform the task to better suit their cognitive abilities and cognitive style.

Keywords: Map use, navigation, wayfinding, situated cognition, spatial cognition.

Introduction

Interest in human spatial cognition and navigational capacity has a long history, ranging from the pioneering work of Siegel & White (1975) to contemporary contributions by Montello (1998; 2005) and Hegarty et al. (2002; 2006). Spatial cognition is concerned with how people represent space and navigate through it. (Montello, 2005). In the "classical" view, knowledge, from the perceived environment, is represented as a *cognitive map* (Tolman, 1948, Galotti, 2008). Siegel & White (1975) distinguished three types of knowledge involved in forming and using cognitive maps: *i*) *landmark knowledge*, *ii) route knowledge*, and *iii) survey knowledge.* Landmark knowledge is information about the particular features at a location. Route knowledge is information about specific pathways for moving from one location to another; it may be coded procedurally or declaratively. Survey knowledge is metric information about the relative location and estimated distances between landmarks, the very thing captured in a standard map, showing the location of all paths and features in a Euclidean plane. All this work investigates the representational architecture of *internal* spatial representations, focusing on questions such as whether cognitive maps are map-like in nature or more like nodes in a graph representation.

Lawton (1994; 1996) found that people tend to report using one either an *orientation strategy* or a *route strategy* when navigating, but not both. Orientation strategies are cognitive processes that use survey knowledge, the umbrella term for world-centric relations. When a subject thinks in an allocentric reference frame using global attributes of a terrain such as cardinal directions, and Euclidean positioning of landmarks, they are using orientation or *survey strategies* (Prestopnik & Roskos-Ewoldsen, 2000) for wayfinding. Route strategies, by contrast, are based on an egocentric frame of reference, where paths are defined as those throughways available from where the subject is at the moment.

Research on spatial knowledge acquisition and navigation has mostly been confined to strict laboratory settings and virtual environments (e.g. Allen, Kirasic, Dobson, Long, & Beck, 1996; Montello, 1993), or to environments where the subject is led along a fixed route in an urban area (Kato & Takeuchi, 2003). In these studies maps have been used primarily as a diagnostic tool to reveal the subject's internal representation. For instance, a subject might be asked to sketch the route she followed, marking down all the landmarks she can recall. (Liben, 2010). Little or no attention has been paid to the actual practices of subjects when they use maps to navigate.

A map, if properly used, is an artifact that extends a person's *survey knowledge* (Montello, Hegarty and Richardson 2004). It behaves in the same way as an internal map except that it is external. Because we interact with internal and external representations differently, however, it is worth examining in detail the diverse ways that people interact with maps. Do all subjects rotate maps? When, why? How do they gesture? Do they point on the map and then to the world? How often do they glance at a map? When?

To study the practices of map use we videoed subjects using a map of UCSD campus as they found their way from a starting location to a goal location. In the analysis we divided our subjects into two groups – route-based navigators, and survey-based navigators – using the well-known measures developed by Lawton (1994). We report here on our findings and offer an explanation of the results in line with the ideas of situated, distributed and embodied cognition.

Clark (2008) has coined a term, or principle, to label this type of interaction in which epistemic actions (Kirsh & Maglio, 1994) can be incorporated – *The Principle of Ecological Assembly* (PEA). This principle states that "*the canny cognizer tends to recruit, on the spot, whatever mix of problem-solving resources will yield an acceptable result with a minimum of effort*" (Clark, 2008, p.13). But, given the existence of individual differences in cognitive styles, it is not obvious that "a minimum of effort" means the same thing for all people. A specific instance of this is the difference between persons who have a preference for a route strategy or a survey strategy. Another aim of the present work is to study how map use might differ between people depending on their preferred navigation strategies.

Since we are bridging or trying to relate two different research traditions, we address our research questions using a combination of the experimental methods traditionally used in research on navigation and wayfinding, with cognitive ethnography used in research on situated and distributed cognition.

Method

The study was undertaken on the University of California, San Diego campus. UCSD is sufficiently complex and covers a large enough area to be challenging for most navigators unfamiliar with the campus. It can also be considered representative of an urbanized area

17 participants were recruited using craigslist, which is an online ad-service where ads can be placed for a fee. The participants were between 20 and 58 years, *Mean* =32.1 (*SD* = 13.23), 8 female, 9 male; they were unfamiliar with the UCSD campus. To eliminate vision as factor in performance they had to have 20/20 vision – with or without corrective lenses or glasses.

Participants were asked to find their way from a starting point to goal location. Three different start-goal pairs were used. These pairs were chosen and evaluated during a pilot study, where they were determined to be equally hard. Criteria for hardness were the number of salient landmarks, the density of buildings throughout the area, length (air distance), visual access. By using start-goal pairs that overlapped and crossed through the campus center, the environmental features and vistas were as equivalent as possible, leading us to infer they were equally complex.

Materials

The materials used in this study included the official visitor map of the UCSD campus, which was handed to the participants and used throughout the navigation task.

Several recording tools were used, including the handheld video camera – Canon Vixia HG21 - and a head-mounted video camera – ContourHD 1300 LED 1080p Headcam - that captured the behavior of the participants. The motion pattern of the participants was recorded via a GPS – Victory Corp. Columbus V-900 Multifunction GPS data logger.

The Santa Barbara Sense of Direction Scale (SBSOD) was used to measure the participants' sense of orientation, or the awareness of location or orientation. This instrument is a self-report measure which has been found to predict objective measures of these abilities, such as dead reckoning (Hegarty et al., 2002). This instrument has proved to be internally consistent and has sufficient test-retest reliability. The SBSOD is highly correlated with measures of spatial knowledge acquired from direct experience in the environment, and Hegarty et al. (2002) has shown that it is related to knowledge that involve orienting oneself within the environment.

The Wayfinding Strategy Scale (Lawton 1994) is a survey that measures to what extent a person depends on strategies relying on survey knowledge or route knowledge respectively. The survey contains 14 items of the sort of propositions that participants have to grade the degree of agreement along a 5-point Likert-type scale.

To measure dead reckoning a pointing task was used. At a number of places the participants were asked to point in the direction of an unseen landmark; a traditional compass was used to assess the participants' error in this task.

Procedure

The study itself was divided into two separate sessions. The first session was a pretest, where participants filled out electronic counterparts to the physical instances of SBSOD and the wayfinding strategy scale over the internet. The surveys could be completed at any time the participants wished from the moment of agreement of participation in the study to the day when the experiment session began. The questionnaire was filled out prior to the experiment session, which was of vital importance as to ensure validity. If it would have been completed after the experiment trial, there would have been a possible risk that participants took into account their recent navigational performance, and thus affecting the self-assessment.

On arriving for the second session, a consent form was filled out by each of the participants, a parking permit was paid for and given to them if needed, and they were then told to step into a car for transportation to another location. From this moment on, the experimental session had officially started and they were instructed to try to pay attention to where they are located in the world from that point onwards. The participant was dropped off at one of the marked drop-off locations where they were picked up by another experimenter. On site of the drop-off point the equipment was set-up, which included mounting the headcam on the participant and getting a stable GPS signal. The participant was then told to estimate and point into the direction of the meeting point, the experimenter then used the compass to derive the correct azimuth which was then communicated to the participant.

After having been given the correct direction, the participant was led non-linearly to the actual starting point of the navigation task. The starting point was located approximately 100 meters away, occluded from the drop-off point. Another dead reckoning task was performed, where the participants were told to estimate and point into the direction of the *drop-off point* this time, after which it was time to initiate the primary task of the experiment session – the navigation task. At this point, the participants were given the campus map and told which building they were standing next to at the starting point. The participants were given time to find the building on the map, after which they were then told what destination they would be finding their way to. In similar manner, they were given time to locate the building on the map. Now, they were told to navigate to the destination by foot preferably using the shortest path. After any contingent questions and uncertainties had been mitigated, and after they had been instructed to try to verbalize their thoughts navigational strategies out loud, they were given the signal that it was OK for them to begin the navigation trial.

Throughout the navigation trial, the experimenters where filming the participants with the handheld camera while at the same time interviewing them according to a stipulated script, while given the freedom to *ad lib* when interesting observations were made. During the navigation task, the participant where given two instances of the dead reckoning-task where the azimuths were jotted down by the experimenter. Finally, when the participants reached their destination, they performed one last dead reckoning-task which concluded the navigation trial.

Coding procedure

Three experimenters were coding the video material, and although no formal kappa value was calculated to establish the inter-rater reliability, the experimenters were trained simultaneously and looked at each other's code at the outset and very beginning of the coding to establish a consensus. The coders also consulted each other whenever any phenomenon raised any doubts concerning how to code it.

The coding scheme included a time stamp for each observation, a high level transcription of the think aloud verbalizations, as well as gestures and other bodily actions such as body turns and visual references of the environment. Of specific interest was how participants interacted with the map. Thus, physical actions and manipulations of the map were pertinent to incorporate and code for in the coding schema, such as map rotations and folding of the map, in conjunction non-physical interactions with the map (e.g. coding for glances on the map), in order to reveal regularities of map use with respect to preferences of map interaction. In addition, gestures such as pointing on the map, or putting a thumb on the current location on the map, or running a finger across the map was coded for as well.

Results

In the first part we will report on the quantitative measures used, to set the ground for the second part where we will present detailed observations of the use of the map as well as other orientation strategies used by our participants.

Quantitative results

The results from the measures on The Wayfinding Strategy Scale, in the table called Orientation score, SBSOD score, dead reckoning error, number of map alignments and map consultation frequency, as measured by number of glances per hour, are presented in table 1 Note that the Orientation score test was introduced after the first 6 subjects participation.

All these three measures show considerable variation, SBOD from 34 to 94, navigation time from 14 to 58 minutes, and map consultation from 77 to 292 glances per hour, i.e. a ratio of approximately 4:1; the number of map alignments show an even higher variation, from 0 to 10.

There is a clear dependency between these measures. Dead reckoning error is negatively related to sense of direction as measured by SBSOD (*r* = .-43, p< .05), similar to results by Hegarty et al (2002). Also, as predicted, there

Table 1: Overview of results on performance measures and variables

Subject	Gender	Orientation Score	SBSOD-Score	# Map Alignments	Navigation Time	Dead Reck. Err.	Tot glances	Glances/hour
Subject 1	F	N/A	53	3	28	69	40	85,7
Subject 2	M	N/A	37	4	15	11	36	144
Subject 3	M	N/A	94	8	48	52,33	73	91,3
Subject 4	M	N/A	23	4	N/A	131	79	90
Subject 5	F	N/A	70	3	13	56	21	96,9
Subject 6	F	N/A	70	8	15	21	65	260
Subject 7	F	24	34	10	51	69,33	162	190,6
Subject 8	M	24	74	8	24	49,33	55	137,5
Subject 10	M	28	50	1	22	63	117	292,5
Subject 11	F	20	86	10	58	77,5	190	196,6
Subject 15	F	22	60	5	15	26	75	300
Subject 17	F	22	64	9	25	34,25	98	235
Subject 21	F	29	55	5	24	15	103	257,5
Subject 23	M	25	82	3	15	17,25	31	124
Subject 24	M	31	92	0	14	12,5	18	77,1
Subject 25	M	32	61	4	21	57,66	47	134,3
Subject 26	M	26	74	0	14	12	61	261,4

was a marginally significant negative correlation between SBSOD and map consultation frequency (r = -.52, p< .051).

To investigate the existence of any potential difference between people who claim to use orientation strategies in contrast to people who primarily rely on route knowledge when engaged in navigation, a median split was performed on the sample on the orientation score, creating two groups here named. "Orienters" (n = 5, $\bar{x}$ = 29.2, SD = 2.39) and "Non-Orienters" (n = 5, $\bar{x}$ = 22.4, SD = 1.67). The difference between the two groups was significant $t(8)$ = 5.22, p< .001.

It was noted above that the frequency of map use varied considerably between the participants, and that this was correlated with sense of direction. The question is then if the difference in map use is just a quantitative difference, or if there also is a qualitative difference in *how* the maps are used. One of the most obvious differences in how subjects use maps turns on alignment and registration: whether subjects prefer to leave the map it in its native upright position determined by the orientation of labels, or do they rotate it so that the features on the map align with what they see. Using this criterion there is a clear difference in map use between the two groups. Map alignment frequency is significantly lower for Orienters ($\bar{x}$ = 2) than Non-Orienters ($\bar{x}$ = 8.4) ($t(8)$ = 3.15, p <. 01.)

To get a deeper understanding of map use differences we turn to a detailed analysis of the way subjects interact with maps and the various orientation strategies used.

Navigation strategies

Our participants all make use of Siegel and White's (1975) three basic kinds of navigation information, survey, path and landmarks. But they do not do so in the same way. They use different cognitive strategies within each of these broad categories. When they extract information outside of their preferred mode they try to transform that information into their preferred form. To highlight these differences, we present excerpts illustrating the strategies used by high and low performers as measured by their orientation score. In the present study, we did not note any significant differences between high and low performers in the use of landmarks. But there are differences in the use of survey and path information.

Survey information strategy

As many authors have suggested, maps can be seen as an external form of survey knowledge. Our argument is that external representations still have to be interpreted and often a map user will physically interact with a map to facilitate interpretation. High and low performers interact differently.

Take the case of participant S24. He was a top performer on all the quantitative measures, one of two subjects who *never* rotated or aligned his map throughout the entire navigation task. S26 was the other. He kept his map in its canonical label reading position, that is fixed in a north-up position. Shortly after he began the task he was asked whether he has a particular strategy in mind. He answers:

> *"I think so, I mean the idea is that I'm just gonna go right down here* [pointing and tracing downwards along a depicted walkway on the map] *and probably take a left on Voigt* [traces with his finger to the right along Voigt Dr] *and go south on Hopkins Lane (…)"*

In the video we see that S24 leaves the map in a north-up position and slightly tilts it for the experimenter to see the map. S24 runs his finger quickly down the map – that is, in a southerly direction – and then hastily makes a perpendicular turn with is finger and traces rightwards on the map while saying "*and probably take a **left** on Voigt*". When he runs his finger southward on the map while simultaneously claiming that he will go "*down here*" his motion is in the same direction as he is. The map is egocentrically aligned. But when he runs his finger to the right (east) while saying "left", however, he is breaking the egocentric view. Arguably S24 is making an inference based on an imagined egocentric perspective. He *imagines* himself, or rather *projects* (Kirsh, 2008) his future location 'down there' onto the external representation – the map – and quickly translates between egocentric and allocentric perspectives. What is striking about this particular incident is the ease and speed with which he performs this multi-layered action.

By comparison one of the low performers, S11, uses the map in a very different way. She frequently stopped throughout the navigation task to look at the map and subsequently tried to align the map to correspond to the surrounding environment in order to extract and assimilate information of where to go next. In the following excerpt, she has a vague idea of *where* she is, but she is not sure of her bearings in terms of cardinal directions and exactly where she should go.

> *"…I'm trying to find that way.* [pointing on the map] *I'm gonna look at it upside down so I can see where I…then I know 'cause we were on Voigt* [Drive] *before…"*

Her ambition is to walk south on Voigt, but she is uncertain about her bearings. She previously saw a sign for Voigt Drive and has a rough sense of her self-location. She then rotates the map to align it with her view in her current position. In contrast to S24, who showed an impressive management of directionality in the map and world, presumably through internal computation of the relation between world-centric and egocentric information, S11 is unable (or unwilling) to make these internal transformations and instead rotates the map, adapting the map artifact to fit her internal representations. This allows her to deduce whether she should go left or right on Voigt Drive, i.e. thinking in terms of a path strategy, instead of thinking about the world in survey knowledge manner.

Route information strategy

Low-performers preferred to travel on straight roads and paths. Curving paths make it harder to keep track of one's cardinal direction. They also avoided travelling on paths with high visual complexity – such as dense buildings. High visual complexity makes it harder to identify one's preferred landmarks on a map; the more buildings the more visual distractors. Again, high-performers had no such aversions. They are sufficiently proficient in using cardinal directions that they do not hesitate to use curved paths, or take opportunistic short-cuts that twist, even if this means going through dense buildings.

Subject 11 explained why she preferred to walk along a path that clearly diverted from the direction of the goal destination and optimal solution:

"*I could have weaved through* [the buildings] *but I think it would have taken me much longer (…) this is a straight way, so it's good, I can avoid going through all the cluster of buildings, it's less complex (…) I get lost very quickly, to me it's a lot easier to navigate than having to go through and around buildings…*"

S24 has the opposite attitude. In this excerpt, he is walking on a pre-planned path eastbound but suddenly decides to take another path:

"I'm gonna head up this path, and I didn't go that way [pointing on the map on the original path he was supposed to take] *because it was directly east, and this path kinda branches southeast, which is the direction we're going towards, so I figure I'd take that one."*

In contrast to S11, S24 never hesitated to take a diagonal path, as long as it was a shorter path. He seemed indifferent to visual complexity, taking routes that required navigating through buildings located at the very center of UCSD campus where several large commercial stores and buildings are located. The whole time he managed to stay oriented and solved the navigation task with the least glances to the map and nearly the least travel time. It seems that high performers can use the world better. They can find paths using cardinal directions as a grid, while low performers instead develop and use paths that will minimize the need to orient using cardinal directions.

Transforming the information to suit the style

One way of describing the differences between high and low orienteers is that high orienteers think mostly in a world-centric manner whereas low orienteers think in a map-centric manner. For a high orienteer navigation involves keeping track of one's bearing. Because they have much better dead reckoning skills they always have a reasonable idea of where they are and where they have to go. When they look at a map it may be to see what is coming up next, but it is more likely to verify that they are where they think they are. They want to update their location relative to where they must go. They can do this by finding their location on the map in the orientation they have been holding it. They have no problem tracking themselves going south on a map facing north. They sense they are going south. They get too little cognitive saving from reorienting it to pay the price of the harder readability that comes from inverting labels.

Low orienteers, however, do their reasoning on the map. They orient the map so that it is aligned with their currently perceived view of the world. They put it in correspondence with the features that are in view so that they can then trace where they must go on the map to reach the destination. Since the two, map and world are in alignment, they can then take their bearing straight off the map. They need to walk in the same direction in the world as the map. The two can be laid on top of each other. Straight paths are to be preferred because each revision of direction requires re-checking the map and that is a cognitive effort. The cognitive cost exceeds the physical cost of walking farther. Similarly, it is easier to avoid high feature areas, where buildings are close together, because the more visual clutter there is the harder it is to align the map since it requires checking more buildings and more angles.

Strategy choice and performance

It may seem that low orienteers must be slower than good orienteers. Whereas in general this is true it is by means necessary. An efficient map-user can keep the map reasonably aligned by taking long straight paths. This saves them the cognitive effort of re-aligning the map, and it saves time too because realignment can be time-consuming. It is quite possible that the map-using time saved by taking a straight path more than compensates for longer distance.

An interesting case is S15, who has a very low score on the sense of direction test, but also has one of the shortest navigation times (15 min). S15 seems very aware of her preferences, as illustrated in the excerpt below.

"I'm gonna go straight [pointing with her arm and hand in forward direction] *and then straight* [pointing with the same arm in an orthogonal direction to the left] (…) *I don't like diagonals."*

When we look at S15's details we see that she glanced at the map 300 times, the most of any participant. But her glances were brief because she stayed on a map-aligned course. Given the straight line route she chose this meant that she could rotate the map just a few times (5).

If we assume that S15's performance is solid evidence that she is a good navigator then it does not follow that navigation ability always correlates with spatial ability. In previous work on navigation (Hegarty et al, 2006), navigation ability was found to correlate well with measures of spatial ability and with self-assessment of sense of direction. But the case of S15 illustrates that while this may be true in general there are outliers for whom it is not true. We hypothesize that people who know their own strengths and weaknesses in spatial understanding develop interactive strategies that compensate. They develop techniques for coordinating map use with route features to minimize time and cognitive effort.

Discussion

The results presented here show that how maps are used differs between different people, depending on their navigation abilities. Navigators with a high orientation score, keep the map in the same upright position regardless of how well this matches their current view of the environment. They have no problem in mapping the view of the map to their current view of the environment using internal or mental transformations. Navigators with a low orientation score, on the other hand, find mental transformations effortful, and instead prefer to externally manipulate the map to align it with their current view. These two also seem to differ in how they plan their route through the environment. Navigators with a low sense of direction prefer to walk along straight lines and in the open. Even though their paths are not the most direct, in effect requiring them to take detours, they still prefer them as long as they make the navigation task simpler. Navigators with a high sense of directions invariably prefer the shortest path even when that involves cutting across visually complex areas, following paths that wind. They even take opportunistic short-cuts on narrow pathways whenever they can.

Another way of looking at the difference between these two groups is that good navigators, comfortable with using a survey strategy have no problem using the terrain information in allocentric form, i.e. as a map. The other group is more comfortable with a route strategy, they tend not to use survey strategies and not surprisingly they prefer terrain information that is presented in egocentric form. They do this both by initially planning a simple route with no curves, and they manipulate the map to be able to read off bearing directly from the map without having to perform transformations from cardinal to egocentric direction.

The disparities between the two groups suggest that they confront their navigation task operate in different ways. Survey strategists have good sense of direction. They maintain a strong sense of where they came from and where they have to go. A map for them is a tool to help see the future but they consult it primarily to get confirmation that their sense of bearing is correct. The map is more for feedback than pure planning. Route strategists rely much more heavily on maps. They plan every step of their route on the map, and they make point wise decisions about where they are and where they must go next by orienting the map. It seems that route strategists do as much computation on the map as possible, whereas survey strategists do as much computation on their internal representation of the world.

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