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# PAPER MAPS OR GPS? EXPLORING DIFFERENCES IN WAY FINDING BEHAVIOUR AND SPATIAL KNOWLEDGE ACQUISITION

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**ABSTRACT**

People undertake a range of daily activities that are characterised by spatial behaviour with one of the main examples being planning and navigating a route from an origin to a destination. Navigation is an extremely common task yet one that requires complex cognitive processing to find ones way in an environment. With the advent of GPS technology many navigation tasks have been given over to a computer so many car journeys are now directed by voice command and followed by human reaction. Increasingly, GPS receivers are available in hand-held devices and smartphones and similar navigation software has given rise to satellite navigation for pedestrians.

The research presented here explores the extent to which way finding behaviour and spatial knowledge acquisition vary between users who navigate using GPS –based devices and those who use conventional paper maps in unfamiliar environments. GPS-based navigation affects a user's way finding behaviour and results in poorer spatial understanding when compared to those who undertake similar tasks with paper maps yet people are now more familiar with digital representations rather than paper maps.. A number of reasons for the differences in results are explored and some possible solutions to resolve the discrepancies proposed. The move to increasing use of GPS-enabled navigation devices is likely not to abate but resolving the deterioration of spatial literacy is important to ensuring good spatial knowledge acquisition so that navigation can improve and be comparable to paper based navigation.

## 1. INTRODUCTION

Spatial behaviour defines the way in which we navigate our world. Our daily actions are governed by a need to cognitively process space as we move from place to place. The simplest form of this cognitive processing is navigating from one place to another from an origin to a destination though it is far from a simple process in real terms. Navigation makes use of multi-level cognitive processing which has been explored by a number of authors (Klippel et al. 2005; Timpf, 2002; Winter, 2003; Montello, 2005; Ishikawa et al. 2006; Hegarty et al. 2006; Gartner and Verena, 2007; Ishikawa et al. 2008). Further, research illustrates that the act of navigating unhindered between places can be a difficult task due to the way in which people recognise their environment (Hegarty et al. 2006; Ishikawa and Montello, 2006). Ishikawa et al. (2005) show that for successful navigation, people need to know three main aspects: where they are (their location); their orientation (heading); and some knowledge of the location of the destination in order to plan a route. At each stage in the process, people will cognitively process stored knowledge to represent space in order to facilitate recognition of their environment. This stored knowledge is part of our mental map of the world. In an unfamiliar environment, there is an absence of stored knowledge so people must resort to using navigational aids that externally represent the environment. While maps are the traditional form of aid to navigation, a number of alternatives now exist such as GPS, audio-guides, interactive maps, 3D visualizations and virtual environments (Shoval and Isaacson, 2006; Gartner and Verena, 2007) which can be used to simply provide positional information or to guide the user through a route using directions.

There have been relatively few studies that explore the effectiveness of map-based navigation but a common finding is that success is a function of the orientation of the map itself in relation to the heading of the person (Roskos-Ewoldsen et al. 1998). Verbal directions have been shown to be more effective for navigation than a paper map (Montello et al. 2004). Likewise, traditional 2D maps have been found to be more effective than 3D representations when displayed on similar handheld devices (Coors et al. 2005) and a map more effective than an aerial photograph (Dillemuth, 2005). In all these assessments, travel time and distance are the main variables of interest and the more effective medium is that which reduces travel time and distance for the journey. Ischikawa et al. (2008) also compared navigational behaviour using electronic navigational devices (GPS), paper maps and direct experience and found GPS users travelled further, more slowly, made larger directional change errors and made more stops than the other users. Further, in a secondary experiment, they found that GPS users were unable to draw sketch maps of their route as effectively as other users. Gartner and Verena (2007) explored alternative map types (city level map, schematic and simplified street graph) as a function of effective navigation and concluded that alternative route choices are preferable to support a range of routing decisions (e.g. shortest, most scenic) and those with increased familiarity of their environment had less difficulty using the schematic and simplified street graph representations. While map style is important depending on a user's familiarity, for all forms, navigation was improved when landmarks were highlighted to assist the route description and providing at least one additional form of aid (e.g. verbal or visual) also improved navigation.

Here we extend the work in this area by exploring the use of GPS as a specific tool for navigation in comparison with a traditional street-level map. With the advent of GPS technology many navigation tasks have been given over to a computer so many car journeys are now directed by voice command and followed by human reaction. Increasingly, GPS receivers are available in hand-held devices and smartphones and similar navigation software has given rise to satellite navigation for pedestrians. The research presented here explores the extent to which way finding behaviour and spatial knowledge acquisition vary between users who navigate using GPS –based devices and those who use conventional paper maps in unfamiliar environments. The research sought to determine whether those who now live predominantly in a digital age find GPS a more familiar medium than the paper map and whether increased familiarity with the medium gives rise to improved navigation compared to previous studies.

## 2. METHOD

A series of experiments were undertaken using participants in unfamiliar surroundings to explore their ability to know where they are (location) and to identify which direction they are facing (orientation). Routes were followed based on either the use of a GPS-based navigation device or a street-level paper map through a series of common points to a destination. The navigation system used was a Garmin eTrex which did not have any base map data installed. The screen display simply presented an arrow indicating the position and straight-line direction to the next waypoint as well as the position of the various waypoints. The paper maps indicated the starting points, waypoints en route and destination. The two approaches provided users with assistance to their navigation by giving the users different information. On the GPS, a user can see their location and can follow the arrow which provides a general heading to the next waypoint. The paper map does not identify the precise location automatically and the paper also needs to be rotated manually to align with the environment to identify a heading for the next waypoint. In this sense, the map user is required to constantly update their positions mentally rather than relying on the GPS. In terms of route planning, the GPS unit only indicated the current position and heading. It was not possible to see the whole route at once whereas on the map, the entire context of the route and waypoints were in view.

At pre-determined stops (waypoints) during the journey, participants were required to complete a series of tasks designed to yield information about the reactions to their environment, the stored knowledge they had acquired en route and basic location and orientation activities. The GPS units were set to capture tracklog information which could be later analysed and the participants who were using paper carried a GPS unit for non-navigation purposes which also captured tracklog data. From these an assessment can be made of the distance travelled, the time taken to arrive there and the stops made en route to consult their navigation aid. At each of the waypoints participants were required to complete a series of tasks that sought to test their understanding of the route as well as the perception of their environment. Tasks completed at the end of the journey provided information about the acquired knowledge of the whole route which could then be compared to tracklogs of the journeys and participants self reporting of their spatial literacy using the Santa Barbara Sense-of-Direction scale as a baseline assessment.

Eighteen University students participated in the research as part of a field course to Malta. They ranged in age between 19 to 52 and none of them had been to the study are prior to the work. The study area used was between Sliema and the capital city Valetta and contained five route segments comprising six waypoints. None of the destination waypoints were clearly visible from the origin. Figure 1 illustrates the paper map provided to half of the participants which was printed at A4 size showing the six waypoints.


*Figure 1. Map extract of the Sliema to Valletta route showing 6 marked waypoints*

Routes were not provided so the navigation task here was one of orientation and then route selection in relation to processing the represented environment of the map to the real environment.

Figure 2 illustrates a typical screen shot of the Garmin eTrex unit used by the remaining half of participants for their navigation. As well as showing the position, alternative screens allowed the user to see the breadcrumb trail of their path to that point and in relation to the destination waypoint. This group of participants had no other contextual detail so the navigation task was one of following the bearing of the GPS unit and relating that to possible routes as they appeared in the real environment. Participants were provided with grid coordinates for the six waypoints on the route that they pre-programme into the Garmin eTrex.


*Figure 2. Typical eTrex operation showing direction of waypoint from current position*

All participants were students of GIS so had a working knowledge of map coordinates as well as the operation of the Garmin GPS units. In order to assess their different levels of self-reported navigational ability, participants completed a Santa Barbara Sense of Direction Scale (Hegarty et al. 2002) prior to the exercise. The seven-point Likert-scaled questions were completed by responding positively or negatively to a range of questions. The purpose of this pre-exercise test was to provide baseline data which could be used to analyse the results of the navigation exercise. Hegarty et al. (2002) found that people who identified themselves as having a good sense of direction (a lower score) were also good at performing navigational tasks and this is one aspect which we wished to explore in this study. Interestingly, with a slightly higher mean score, standard deviation and maximum score the participants reported slightly less ability in map use than that of the participants in the Hegarty (2002) study or the Ishikawa et al. (2008)

study (Table 1). This may be because the participants were generally younger though it was surprising (worrying?) given they were all students on GIS degree courses.

| | Hegarty (2002) | Ishikawa et al. (2008) | Current study |
|---|---|---|---|
| No. participants | 221 | 23 | 18 |
| Mean score | 3.6 | 3.3 | 3.9 |
| Standard deviation | 1.0 | 1.2 | 1.4 |
| Maximum score | 6.0 | 5.9 | 6.4 |
| Minimum score | 1.6 | 1.8 | 1.7 |

*Table 1. Comparison of Santa-Barbara sense-of-direction scores with previous studies*

At each waypoint, participants were required to complete a series of tasks as follows without consulting either the printed map or the breadcrumb image on the GPS receiver.

1. Draw a sketch map of the immediate area showing the road layout drawn with north at the top of the piece of paper
2. Draw on the map the route taken from the previous point, trying to make the map to the same scale
3. Label the point of origin and the point of destination on the sketch map.
4. Place a score on the map to indicate how difficult it was to locate the goal (from 1 = very easy to 6 = very difficult)
5. Add a scale bar to the map (in metres)
6. Estimate the distance travelled from the previous point (in metres)
7. Estimate the time it took to complete the journey segment (in minutes)
8. Estimate what proportion of the time was spent stopping to work out the route (in minutes)
9. Annotate the map with any interesting features passed on the way
10. Using Twitter, send a tweet to the collaborative Malta map mashup identifying three keywords that best describe the immediate surroundings at the location

The participants were given six blank pieces of paper that contained a border for their map, a rudimentary scale bar (un-numbered) and a north point pointing to the top of the page. The task was essentially to draw a sketch map of the five route segments, plus one at the final waypoint for the complete journey as accurately as possible. The use of Twitter as mechanism to create a real-time online map mashup of the exercise is well documented elsewhere (Field and O'Brien, 2010a; 2010b; Field et al. 2011) but the point was to provide a way of not only timing the student's arrival at waypoints but giving a sense of what environmental features they used to describe their environment and whether any differences existed between the GPS and map users.

Participants were led to the vicinity of the start point for the exercise and released to complete the exercise. In completing the exercises they were asked not to refer to the GPS device or paper map when completing the sketch maps, not to draw a map as they went along and not to work as a team to either navigate or complete tasks. The whole exercise lasted approximately 90-120 minutes

**3. RESULTS**

In analysing the results of the experiment, one paper user participant was excluded from the results due to a major navigational error. The journey from waypoint 3 to 4 involved a boat trip across Sliema harbour. This was part of the test and all but one participant was able to determine that waypoint 4 was across the harbour and the boat would be the most obvious method of transport. Instead, he chose to walk around the coast, adding over 4000m and 3hrs to his journey. Figure 3 illustrates the excluded participant's GPS tracklog (yellow) compared to two other tracklogs (blue).

*Figure 3. GPS tracklogs of three participants illustrating the route of the discounted participant (yellow) in relation to two more direct routes (blue)*

Table 2 reports the basic comparative metrics of navigation between the GPS users and the map user. Discounting the excluded participant, the measure of sense of direction between those who were using a GPS and those using a paper map showed no significant difference.

| | GPS users Mean (SD) | Map users Mean (SD) |
|---|---|---|
| Sense of direction mean | 3.9 (1.3) | 4.1 (1.4) |
| Travel distance mean (m) | 3236 (790) | 2512 (170) |
| Travel distance min (m) | 2103 | 2284 |
| Travel distance max (m) | 4531 | 2834 |
| Travel speed mean (m/s) | 0.5 (0.1) | 0.3 (0.05) |
| Stop time mean (min) | 17 | 28 |
| Sketch map accuracy (mean number of route segments) | 11 (3.3) | 12 (4.1) |
| Sketch map accuracy (mean direction from start to finish) | 190 (105) | 180 (114) |
| Self reported difficulty mean | 3.7 (1.7) | 3.1 (1.0) |

*Table 2. Analysis of metrics of route navigation by group*

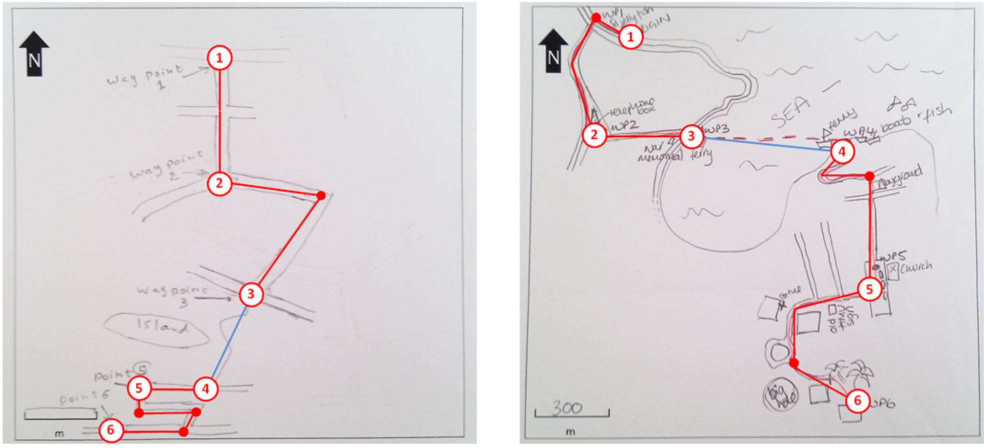
The shortest distance of the route is 2000m. The GPS users, on average, travelled further than their paper map counterparts and had a much higher maximum distance compared to the paper users. The speed of the map users was slower, a function in the main of the increased time taken to stop and consult the map compared to GPS users who tended to walk at the same time as using the GPS receiver.

The sketch maps produced by the participants at each of the waypoints and the final, complete route were analysed to explore their topological accuracy. The analysis determined the number of individual road segments drawn on the sketch map (unique segments delineated by a change in orientation). The accuracy of the sketch maps for the GPS group was broadly the same as that for the map users. Table 1 shows that the GPS user's sketch maps contained an average of 11 segments whereas the map user's maps contained an average of 12. This compares to the actual number of 15 unique segments in the shortest route. In terms of direction error, there are many internal direction errors that might be calculated since the route can be broken down into many sections for analysis. Reported here, is simply the overall direction error between the origin of the exercise and the final destination as determined on the final map of the whole route. The actual angle from the origin to destination is 165o (where 0o is north). On average, both GPS users and map users maps showed a direction greater angle greater than the real angle and the difference is not significant. Curiously, three participants from each group drew their final maps entirely the wrong way round with north at the bottom of the page.

With regard to the difficulty of the task, participants were required to self-report on a scale of 1-7 where 7 was most difficult. GPS users reported a higher average difficulty that paper users (Table 2).

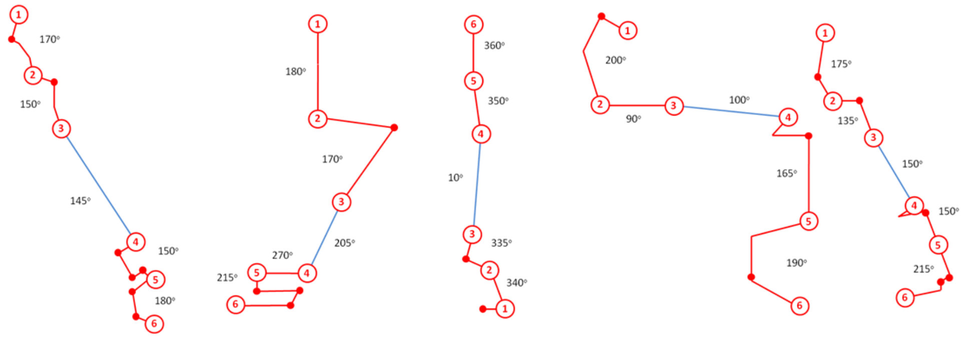
Whilst there are numerous other analyses that can be performed on the data, for instance to explore correlations between travel distances and direction errors, travel speed and number of stops, or self-reported difficulty and travel distance/direction error, there is not scope within this paper to provide a full statistical report. Similarly there is the potential to undertake a comprehensive analysis of the topology and detail in the sketch maps. Figure 4a illustrates a sketch map from a GPS user compared with Figure 4b from a map user. It is clear that there are differences in the recall of environmental information as well as a more detailed approach to mapping the route. The maps illustrate the potential for a fuller analysis that will form the subject of a further paper to analyse more fully the relationship between stored knowledge and accuracy of its representation.

Figure 5 also illustrates the schematics that can be digitised from the sketch maps which provide detail about distance and direction that might also be further explored.




(a) (b)

*Figure 4 sketch map examples (a) GPS user, (b) Map user*




(a) (b) (c)

*Figure 5 digitised schematics (a) actual route, (b) GPS user routes, (c) Map user routes*

## 4. DISCUSSION

Results explored the participants' sense of direction, travel distance and speed, stops and ability to successfully orient towards the destination through the pre-determined stopping points. Those who used a GPS-based device tended to travel longer distances, travel more quickly and stop for less time than those who used paper maps. GPS users did not take the shortest route to the goal and tended to have to reorient themselves more frequently. These last two findings are different to those found by Ishikawa et al. (2008) and may suggest that individuals are becoming more familiar with the use of digital devices for navigation. Whilst the topology of the routes did not differ much between the groups, the representation on the final sketch maps did with the map users able to portray a higher level of detail that suggests a greater degree of acquired spatial knowledge of the route as a function of the process of reading the map and relating it to the environment.

This tends to suggest that while the gap between the different navigation aids is becoming less problematic in terms of operation there still remain differences in the spatial knowledge acquired through navigating with different aids. GPS-based navigation results in poorer spatial understanding when compared to those who undertake similar tasks with paper maps. It should also be remembered that whatever the navigational aid, all users were able to find their way to the destination successfully. Only one map user made a large error though in general the results suggest that use of a map provided a smoother navigational experience. A reason for this could be the relative size of the aid. The GPS screen is only 4x5cm and only illustrates the current position with no surrounding detail whereas the paper map was 21x17.5cm and shows the whole route in context. Whilst the paper user has to determine their position on the map at any given location this appears to be less problematic than the interpretation of an environment using a GPS receiver. In terms of orientation, the map users can easily face a particular direction and rotate the map to give spatial context and form a link between the represented knowledge of the map and reality. For GPS users, orientation is only achieved by identifying a heading without spatial context.

The issue of acquired knowledge and ease of navigation may be more subtle than the simple difference between a GPS receiver and a paper map. The Garmin eTrex does not illustrate map data because of the size and scope of the display. Smartphones and other GPS enabled devices can contain map data and display it dynamically. A further experiment might compare different smartphones to the use of paper maps and then to explore the difference between screen size as a function of acquired knowledge. For instance, would an iPhone (960x640 pixels at 3.5") provide sufficient detail to provide a similar experience to a paper map, or would a digital device user require something more akin to an iPad size (1024x768 pixels and a diagonal size of 9.7"). The crucial factor is that landmarks that are clearly used by map users to navigate by must also be shown on digital maps. The size of the map display is therefore a potential limiter to the detail that can be adequately displayed and the fact that a digital device constantly updates relative to position means that it is the position that occupies the attention of the user rather than the surrounding detail. Ishikawa et al. (2008) refer to this as local focus and suggest it interferes with the global processing of spatial information that slows down users of digital navigation aids. Related issues that might be further explored are to determine the appropriate level of generalisation or simplification of information on a digital navigation aid as well as the type, quantity and style of symbols required. These issues are inextricably linked to the size and resolution of the screen and form important considerations for map design.

## 5. CONCLUSIONS

The move to increasing use of GPS-enabled navigation devices is likely not to abate and, in fact, it is likely that more people will choose to use digital navigation aids in place of paper maps. This study has provided further evidence that navigation by paper map still provides a more effective support for navigation but that use of GPS receivers is becoming more commonplace and reducing the barrier of technology. Attention should turn to exploring design issues for digital navigation aids to ensure their use is as effective as that of navigation by paper map. Perhaps of some concern is the overarching question of the deterioration of spatial literacy more generally since evidence was found in both groups of poor spatial literacy, low levels of map use skill and inability to effectively acquire and represent acquired knowledge. It is important to ensure good spatial knowledge acquisition as part of a navigational task regardless of device.

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