Learning-oriented Vehicle Navigation Systems: A Preliminary Investigation in a Driving Simulator

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ABSTRACT

Vehicle navigation systems aim to reduce the mental workload for drivers by automating elements of the driving task. Concern has been raised, however, that their long-term use may cause unforeseen problems, including suppressing cognitive map development.

A driving simulator study was conducted to discover if this effect could be ameliorated by the use of a novel, learning-oriented, navigation system. The user-interface of this system provided a range of additional features including landmarks, compass bearings and previously driven routes within the visual and auditory guidance instructions.

It was found that the users of the learning-oriented system displayed better memory for driven routes, when compared with those using a basic guidance system. It is also suggested that they had developed a better cognitive map of the area. Glance analysis demonstrated that the learning-oriented system was no more visually demanding than the basic system.

Categories and Subject Descriptors
H.5.2 [Information Interfaces and Presentation]: User Interfaces - User-centred design, Graphical user interfaces (GUI).

General Terms
Design, Experimentation, Human Factors.

Keywords

1. INTRODUCTION

Vehicle navigation systems are increasingly popular examples of mobile computing devices. A 2007 Gallup survey for the European Union found that up to 35% of its citizens, approximately 159 million people, currently use, or are intending to purchase navigation systems [6]. These devices automate the strategic driving task of route selection whilst supporting the tactical task of route following - by issuing timely turn-by-turn directions. To date, mobile HCI research on user interfaces has focused on producing guidelines to address issues of usability and efficiency and their relation to navigational effectiveness or driving performance, e.g. [10, 17]. Several researchers have raised concerns, however, about the longer term effects of reliance on vehicle navigation devices and in particular the effect on traveling patterns and navigational uncertainty [18]. A crucial determinate of behaviour in these areas is the ability, over time, to develop an accurate mental representation of large-scale environments. This internal representation is usually described as a cognitive map (see [13] for a review of the term). The ability to develop a cognitive map is an important skill which provides for greater transport efficiency and may also have social and psychological benefits. These may include the ability to select alternative routes to a destination and to provide directions for others [4]. Moreover, the ability to develop an accurate and comprehensive cognitive map will empower drivers to find locations not included in a navigation system’s database (for example districts or specific buildings) or to resume the task of navigating should the system malfunction.

A previous study, at this university, sought to explore this area by investigating the cognitive map formation of a virtual town, in the controlled environment of a driving simulator [4]. Together with previous research [1, 11] it provided clear evidence that a driver’s spatial learning of an area was negatively affected by the use of a simple turn-by-turn navigation system. Several possible causes were suggested including the low level of attention given to the environment, the simplicity and shortened timescale of navigational decision making and the limited stress incurred when using a guidance system.

This previous study proposed the idea of a learning-oriented navigation system which would seek to support the development of spatial knowledge in the driver, as well as minimizing...
navigational uncertainty. This should enable the driver to move
towards a point of independence, from the system, for frequently
travelled routes or areas. The current paper describes a
preliminary evaluation of the concept. Uniquely the study sought
to explore the relationship between navigational learning and
workload. Workload and visual demand are crucial factors to
consider mainly because of the safety-critical context of vehicle
navigation system use. A driver’s workload is also related to
navigational uncertainty. Navigation systems may initially have
the effect of reducing workload but, by slowing cognitive map
development, may suppress the natural drop in workload as an
area is learnt. Exploration of this relationship could lead to
valuable pointers for future designs.

2. METHOD
The study was a between subjects experiment, using sixteen
participants, twelve male and four female. The majority of the
participants were in the age group 21-30. Three were older than
this range and one younger (mean age 25.4, range 17-53).
Twelve were experienced drivers (over two years experience).
Ten of the participants rated themselves as good navigators, six as
not very good.

2.1 The Driving Simulator
The experiment was conducted using a fixed-base, medium
fidelity, driving simulator, located in the Mixed Reality Lab at the
University of Nottingham (Figure 1). The participants were
randomly allocated so that eight of them drove the routes using
basic guidance and eight using a learning-oriented guidance
system. The participants were videoed during the driving so that
glance behaviour could be analysed, and the visual demand of the
two systems assessed.

![Figure 1. The simulator](image1)

2.2 The Virtual town
The three routes driven by the participants around the virtual town
are shown in Figures 2, 3 and 4.

The routes were chosen to overlap significantly and intersect at
multiple points. Eight of the ten junctions on the routes were
shared by more than one route and four were shared by all three
routes. Approximately 75% of the total area covered by the
routes was shared by two or more routes.

![Figure 2. Route 1](image2)

![Figure 3. Route 2](image3)

![Figure 4. Route 3](image4)

It was hoped that this design would facilitate the development of
an integrated knowledge of the area. In real-life environments the
development of a cognitive map involves significant time and
multiple exposures to the environment. The short timescale of
this experiment was therefore a potential limitation. Careful
design of the routes attempted to overcome this by providing
maximum exposure in a relatively short timescale. Additionally, distinctive landmarks, including a public house a church and a fast food restaurant, were positioned at major junctions, or decision points, along the routes and in positions where they could be seen from a distance and in conjunction with other landmarks (see Figure 5). This was in order that they might act as both reference points along the route as well as orientation devices.

2.3 Guidance System Design

After reviewing the literature on navigation system design and cognitive map development it was decided to produce two interfaces for comparison. The basic guidance system would present information in terms of distance to turn, as well as a view of the junction layouts (similar to most commercially available systems). The learning-oriented system would include features which have been suggested as facilitating cognitive map development [8, 12]. These included landmarks along the routes, compass bearings and also highlighting of previously driven routes, (represented by tyre-marks on the display). The highlighting of previously driven routes in this way was intended to reinforce the learning process by aiding the integration of the three routes into a cognitive map of the area. Both systems would provide both visual and auditory guidance.

The guidance system prototypes were produced in the form of Microsoft™ PowerPoint™ show files. These were run on a laptop and displayed on a 12 inch screen in the central console of the driving simulator. (See Figures 6 and 7). Sound was played back through a dashboard mounted speaker. The presentation was controlled by the experimenter in a “Wizard of Oz” approach to provide guidance instructions at the same points on the routes for each participant, in order to standardise their experience.

The auditory instructions were recorded in a female voice and played back at the same time as each new screen was displayed. The verbal instructions were identical for each guidance system except that the learning-oriented system included reference to a landmark, as below:

- Basic guidance – “In 50 yards turn right”
- Learning-oriented guidance - “In 50 yards turn right, at the church”

The messages presented the landmark reference after the turning instruction in each case. This order of presentation was shown by a previous study to be more effective in aiding cognitive map development [12].

2.4 Measuring Cognitive Map Development

Cognitive map development has been researched and discussed by geographers, urban planners and psychologists [13]. As with all psychological processes there is uncertainty and disagreement about how mental representations develop and the form they take. There is no single accepted process by which cognitive map development takes place and therefore some difficulty in defining and measuring it. However, a widely quoted model for the development of spatial knowledge of large-scale environments, describes a three phase development in complexity. This starts
with place, or landmark knowledge moves to route knowledge and culminates in survey or configurational knowledge. Survey knowledge, when attained, enables a person to accurately estimate straight-line directions and distances to unseen locations and to plan routes to new destinations [19]. The three stage model has been widely used to inform methods of study and measurement of cognitive maps. Methods used to attempt to measure cognitive map development include sketch-map analysis, scene and route recognition tests, cross route pointing tasks and exercises requiring participants to repeat routes they have previously travelled [4, 7, 9].

2.4.1 Landmark Knowledge

To test recall of landmarks in the virtual town for this study, participants were presented with eight scene cards, four of which they could have seen in the town and four which they could not. They were asked to sort these into two piles of four according to whether they remembered the scene or not. The scene cards used for this, and the route knowledge exercise, included views of one or more landmarks in the town. Participants were awarded one point for each scene they allocated to the correct pile.

2.4.2 Route Knowledge

A scene ordering task was used to measure memory of the third route driven. Participants were presented with nine scenes cards. Seven showed scenes taken from the final route and two were scenes which were not in the town. The first and last scenes were in the correct position. This was pointed out to the participants to remind them of the route. They were asked to sort the remaining seven cards into the correct order discarding any they had not seen. The test was scored using the method shown in Table 1.

<table>
<thead>
<tr>
<th>Scene cards route 3</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correctly identified as on route</td>
<td>+1</td>
</tr>
<tr>
<td>Correctly identified as not on route</td>
<td>+1</td>
</tr>
<tr>
<td>Incorrectly identified as on route</td>
<td>-1</td>
</tr>
<tr>
<td>Incorrectly identified as not on route</td>
<td>-1</td>
</tr>
<tr>
<td>Max 3 in correct order</td>
<td>+1</td>
</tr>
<tr>
<td>Max 4 in correct order</td>
<td>+2</td>
</tr>
<tr>
<td>Max 5 in correct order</td>
<td>+3</td>
</tr>
</tbody>
</table>

A maximum score of 10 was possible if all the cards were identified correctly and placed in the correct order. The scoring method was arrived at after considering the methods used in other card sorting studies of spatial cognition [4, 7, 9]. The scoring method was considered to be an acceptable method of providing ordinal data indicating recall of the route and the landmarks visible along that route. Points were awarded if 3 or more cards were in the correct order. Two cards in the correct order did not score, as this was as likely to have occurred by chance.

2.4.3 Survey Knowledge

A sketch map exercise was used to attempt to measure the level of survey knowledge achieved by the users of the two interfaces. Participants were given an A4 sheet of paper and asked to draw a map of the area they had driven around on the three routes. They were asked to include as many roads and landmarks as they could remember, and to label the landmarks. They were given as much time as they needed to do this. The sketch maps drawn by the participants were scored by recording the number of elements included as below:

- Landmarks – Number drawn which occurred in the town
- Nodes – road junctions drawn and correctly related to a landmark
- Path Segments - segments of the map drawn correctly (i.e. which link two locations/landmarks with a correct road layout)
- Landmark Orientation – correct orientation of a particular landmark with respect to other landmarks.

It has been noted that qualitative analysis of sketch maps can be very difficult due to the high variability between subjects [2]. In common with many other sketch map studies, we looked to the classification of sketch maps as used by Appleyard. This classifies sketch maps into two major categories spatial (displaying knowledge of topography and layout) and sequential (which displays more linear knowledge) [3]. Appleyard further divides these into five categories, based on connectivity, giving an ascending order of complexity. However, attempting to categorise freely drawn maps according to this classification is difficult and somewhat subjective. It was therefore decided that an additional measure for this study would be a pragmatic assessment by two independent assessors. This was based on how useful the sketch maps would be to a visitor who needed to navigate around the virtual town. Whilst this would also be a subjective measure, it would at least be related to the real life navigation use for which sketch maps are often drawn.

2.5 Questionnaire

Finally, the participants were asked to complete a questionnaire. Personal details were requested (age, sex, driving experience etc.) and participants were asked to rate their own navigation skills. The users of the learning-oriented system were asked to provide a subjective rating of how useful they found the various components of the system, in helping them to develop a mental image of the layout of the town.

3. RESULTS

3.1 Route and Landmark Knowledge

The scores for the route knowledge task showed a high level of variance, indicating a wide range of performance by the participants. This reflects the fact that many of the participants found this test quite challenging. Only seven of the participants got more than two scenes in the correct order and only one got four in order. Nobody got the order completely correct. Performance was better for the landmark knowledge test. Thirteen
of the participants identified six or more of the eight cards correctly and only one scored less than four.

Average scores for the groups using the basic guidance system and the learning-oriented system are shown in Table 2. There was a noticeable difference in the performance of the two groups for the route knowledge test (2.1 compared with 5.1). Analysis with a non-parametric Mann-Whitney test revealed this to be a statistically significant difference: $U(15)=11.5; p<0.05$, two-tailed. The users of the learning-oriented system also scored higher on average in the landmark knowledge test but the difference was not statistically significant when analysed with an independent samples t test ($p=0.063$).

Table 2. Guidance group scores

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Basic system (n=8)</th>
<th>Mean Score</th>
<th>SD</th>
<th>Learning-oriented system (n=8)</th>
<th>Mean Score</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Route Knowledge</td>
<td></td>
<td>2.1</td>
<td>2.7</td>
<td></td>
<td>5.1</td>
<td>2.1</td>
</tr>
<tr>
<td>Landmark Knowledge</td>
<td></td>
<td>5.3</td>
<td>1.8</td>
<td></td>
<td>6.8</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Mann-Whitney tests on the effects of driving experience on the scores for the route knowledge test revealed a significant difference between the scores for experienced drivers ($p=0.029$) but no significance for inexperienced drivers ($p=0.683$).

3.2 Sketch Maps and Survey Knowledge

Figures 8 and 9 are two examples of the sketch maps produced by participants and give some indication of the wide range in complexity and number of items drawn. The mean scores obtained for number of elements included in the sketch maps are shown in Table 3. On average users of the learning-oriented system scored better in all the categories except for the number of path segments drawn. The scores in this category were generally low and the averages for each of the two groups were the same. Analysis with t tests revealed that the differences did not reach a statistical level of significance ($p=0.062$ for the number of landmarks drawn and $p=0.21$ for the orientation of these landmarks with respect to others).

Table 3. Sketch Map - quantitative analysis

<table>
<thead>
<tr>
<th>Measure</th>
<th>Basic system (n=8)</th>
<th>Mean Score</th>
<th>SD</th>
<th>Learning-oriented system (n=8)</th>
<th>Mean Score</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Landmarks</td>
<td></td>
<td>3.1</td>
<td>2.3</td>
<td></td>
<td>4.9</td>
<td>0.8</td>
</tr>
<tr>
<td>No. of Nodes</td>
<td></td>
<td>1.3</td>
<td>1.8</td>
<td></td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>No. of Path Segments</td>
<td></td>
<td>1.1</td>
<td>1.0</td>
<td></td>
<td>1.1</td>
<td>1.4</td>
</tr>
<tr>
<td>Landmark Orientation</td>
<td></td>
<td>1.0</td>
<td>1.3</td>
<td></td>
<td>1.9</td>
<td>1.4</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>6.5</td>
<td>9.5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Qualitative assessment of the sketch maps was also performed both by comparing with the categorisation scheme designed by Appleyard [3] and by independent assessors. These methods revealed that, to some degree, the participants using the learning-oriented system drew more complex maps. Five of the eight users of this system drew spatial maps and three sequential. When the maps were placed in rank order by two independent assessors five of the maps ranked in the top eight were drawn by participants who used the learning-oriented system. It was notable that the map which scored best on all measures was drawn by a participant who used this system whereas the three poorest were drawn by users of the basic guidance system. The qualitative
analysis does point towards there being an effect of the learning-oriented system but the high variability of the maps made this difficult to show quantitatively.

3.3 Visual Demand

Post-hoc analysis of the videos for each participant enabled the visual demand of the two interfaces to be compared by measuring glance behaviour. The definition of a glance was that specified by the ISO; that is the time from when a subject first took their eyes from the road until they brought their eyes back to the view ahead [5]. The measures used were glance frequency, glance duration and glance allocation (the percentage of journey time spent looking at the guidance display). There was a high degree of variability between participants. Some made many more glances at the display and spent longer studying it than others. For instance, the percentage of the journey time looking at the display ranged from just 4.16% to over 30%. Table 4 shows the averages, for these measures, of the groups using each system.

Table 4. Visual demand comparison between groups

<table>
<thead>
<tr>
<th>Measure</th>
<th>Basic system (n=8)</th>
<th>Learning-oriented system (n=8)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Score</td>
<td>SD</td>
</tr>
<tr>
<td>No. of Glances</td>
<td>20.50</td>
<td>7.03</td>
</tr>
<tr>
<td>Glance Duration (secs)</td>
<td>0.82</td>
<td>0.29</td>
</tr>
<tr>
<td>Glance Allocation</td>
<td>15.58</td>
<td>6.56</td>
</tr>
</tbody>
</table>

The number of glances and the glance allocation were lower on average for the learning-oriented guidance system. The average glance duration was slightly higher, however. Statistical analysis (using independent samples t tests) revealed no significant differences between any of these measures for the two groups. Interestingly, when the glance measures were compared against the amount of driving experience of the participants a significant difference was found between number of glances and driving experience; t(14)=2.2; p<0.05, two tailed. This indicates that a major influence on glance behaviour was the driving experience of the participants. The less experienced drivers looked away from the road more frequently and on average for a longer duration (18.6% of the route time compared with 14.1%). However, the small number of inexperienced drivers in the sample (four) make this conclusion unsafe and indicate the need for a larger study.

3.4 Subjective Data

Subjective feedback from the participants indicated that the landmarks were rated highly in terms of their ability to facilitate learning. In answer to question 3 in the questionnaire: “Rate how useful you found the different items of guidance information in forming a mental image of the layout of the town you drove around”, landmarks were the only feature of the learning-oriented guidance to score consistent highly (see Table 5).

Table 5. Questionnaire (Q3)

<table>
<thead>
<tr>
<th>Feature of guidance</th>
<th>Average participant rating</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 to 6 (1 = Not at all useful, 6 = very useful)</td>
</tr>
<tr>
<td>Distance to turn</td>
<td>2.75</td>
</tr>
<tr>
<td>Tyre-marking of previous routes</td>
<td>2.63</td>
</tr>
<tr>
<td>Landmarks</td>
<td>5.63</td>
</tr>
<tr>
<td>Compass bearings</td>
<td>2.63</td>
</tr>
</tbody>
</table>

4. DISCUSSION

Results from this preliminary study showed that the participants who drove around the town using the learning-oriented system displayed significantly better route recall, even after a relatively short exposure. The fact that there was no significant difference in the landmark recognition test (i.e. both groups had achieved similar landmark knowledge) may indicate that the enhanced route knowledge consisted of more than just recognition skills, and actually involved an element of route learning. The effect seemed to be more pronounced in experienced drivers (those who had held a license for over two years). It may be that the inexperienced drivers were less aware of the exterior environment and paid less attention to the road scene. This was backed up by the findings from the glance behaviour evidence which showed that the inexperienced drivers looked away from the road more frequently and for a longer duration.

Previous studies have found that many factors play a role in cognitive map development. Of these perceived navigation ability and driving experience are important and may play a more important role than gender [9, 11]. The size and limitations of the sample did not permit balancing of these factors in this study. Full analysis of the variability caused by these factors involves comparing each factor within each guidance group. The small numbers in the sample made this unreliable but some analysis was possible. No significant differences were found which could be attributed to gender or reported navigational ability.

The preliminary study raises the question as to which features of the learning-oriented system were most beneficial in promoting spatial learning. Subjective feedback from the participants indicated that the landmarks were rated highly in terms of their ability to facilitate learning. It appears that the other features (tyre-marks and compass bearings) were not rated as useful factors. However, unlike the landmark guidance these features did not appear in the auditory directions. It may be their implementation on the display alone was too subtle to make an impact. Conversely, it may be they would have more effect over a longer period, or for particular users. Two users did rate the tyre-mark guidance as very useful and one rated the compass bearing information as very useful. Participants reported feeling
It is suggested that in terfaces which can take account of
be given to the wide range of experience and abilities of potential
barrier to the benefits that will result. Consideration should also
with the definition and permanence of landmarks should not be a
presenting guidance and promoting learning. Practical difficulties
and distances for navigation systems. In D. De Waard, K.A. Brookhuis, C.M.
through features which can support cognitive map development need not
increase the workload for the driver using the interface. Over
time the reduction in navigational uncertainty resulting from a
better cognitive map should also see a reduction in workload.

5. CONCLUSION AND FUTURE WORK
This was a short-term, small-scale study, but it has demonstrated the potential of a learning-oriented vehicle navigation system to enhance the process of cognitive map development. The concept of a navigation system that can reduce navigational uncertainty in the short term as well as promote cognitive map formation in the longer term is an attractive one. It is too early to draw extensive conclusions about the implications for design but some suggestions can be made. Interfaces for learning-oriented systems should not rely on distance to turn information alone. People are generally poor at judging distance accurately and this study, alongside others, has demonstrated the value of landmarks in presenting guidance and promoting learning. Practical difficulties with the definition and permanence of landmarks should not be a barrier to the benefits that will result. Consideration should also be given to the wide range of experience and abilities of potential users. It is suggested that interfaces which can take account of

6. REFERENCES


