Supporting Drivers' Cognitive Map Construction with Visual Geo-Centered and Auditory Ego-Centered Guidance: Interference or Improved Performance?

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ABSTRACT

Commercially available in-vehicle routing and navigational systems (IRANS) present a generic form of route guidance information to all users. However, a growing body of literature suggests that drivers differ in their navigational strategies and abilities. The current investigation was designed to examine the impact of IRANS display modality on drivers' ability to navigate through and form cognitive maps of unfamiliar areas as a function of drivers' self-reported navigational strategy and ability. Drivers were required to navigate through unfamiliar areas along specified routes in a high-fidelity driving simulator using an ego-centered auditory route guidance system (ARGS), a geo-centered visual-map guidance system (VMGS) or both the ARGS and the VMGS. Drivers in general reported lower subjective ratings of workload when using the ARGS either by itself or in combination with the VMGS. However, drivers reporting a high degree of awareness of cardinal orientation and a tendency to use survey style navigational strategy benefited from use of the VMGS, relative to both the ARGS and the ARGS in combination with the VMGS. The current results warrant further investigation of the influence of individual differences in order to design appropriate navigational aids for supporting drivers of all types.

Keywords: Navigational aids; Area-learning task; Survey map; Driving simulator

INTRODUCTION

Invehicle routing and navigational systems (IRANS) are one of the many important types of in-vehicle technologies (IVTs) found in the modern automobile. IRANS potential advantages for the driver include ease in finding destinations, avoidance of traffic congestion and delays, shorter travel routes, fewer instances of disorientation or getting lost, shorter duration routes, greater confidence, and less stressful driving experiences (Eby & Kostyniuk, 1999). Despite these many advantages, IRANS have the potential to increase the attentional processing requirements or mental workload of the driving task. Due to the potential for IRANS to increase mental workload, the most effective system is one that assists the driver in establishing a cognitive map of the route to be taken through an unfamiliar area in the most effective way. Developing an internal cognitive map of the route to be taken decreases the information processing requirements of obtaining navigational information and ultimately decreases reliance on the system in the shortest amount of time.

Currently available systems can be categorized by key distinguishing factors including display modality, and geo-versus ego-centered display orientations. Display modality refers to whether navigational information is presented through visual, auditory or both visual and auditory channels. The second key distinguishing characteristics is whether navigational information is presented in a geo-centered orientation (north-up) or ego-centered (driver-forward view) orientation.

In addition to these key design characteristics, a growing body of literature suggests that drivers differ in their preference for and utilization of differing types of navigational information (Baldwin & Reiss,

2000; Carpenter, Baldwin, & Furukawa, in press; Lawton, 1994, 1996; Takeuchi, 1992; Thorndyke & Hayes-Roth, 1982). Constructs used to identify individual differences in drivers' navigational styles and abilities appear to remain stable across geographical location and cultural ethnicity (Carpenter et al., in press; Lawton, 2001). Important constructs include preference for a route (point by point) versus survey (global overview), use and memory for landmarks and general awareness of orientation. Current IRANS typically combine auditory "route" style navigational instructions with a visual map presenting an overview or "survey" of the area. Drivers' ability to utilize navigational information from different guidance systems may therefore depend on drivers' navigational strategy preferences as much as the modality used for presenting the information.

The aim of the current investigation was to examine the influence of individual differences in drivers' navigational style and ability on their ability to navigate through and form cognitive maps of unfamiliar areas using IRANS displays of differing types. Specifically, drivers' preferred navigational style and overall navigational abilities were assessed and their ability to develop a cognitive map after driving through an unfamiliar area using one of three styles of navigational aids was examined. It was predicted that drivers who relied on a route-style navigational strategy would benefit most (construct a more accurate cognitive map) when using an ego-centered ARGS, relative to a VMGS. Conversely, it was predicted that drivers who reported preference for survey strategy navigational information would demonstrate better cognitive map formation when using a geo-centered VMGS. Drivers' navigational performance in general was expected to follow these same trends.

METHOD

The current investigation was designed to examine the relative influence of existing navigational formats, specifically ego-centered auditory route style navigational instructions and visual maps presenting a geo-centered survey of the driving area on cognitive map formation.

Participants

Twenty female and fourteen male university students (thirty-six in total) whose ages ranged from 19 to 42 years (mean 23.7) voluntarily participated in this experiment. All participants reported that they drove the car almost everyday and had normal or corrected to normal vision and hearing.

Equipment and Materials

A high fidelity driving simulator (Capital I-Sim Driving Simulator, made by General Electric) was used to examine the efficacy of navigational aids for the navigational task as well as area-learning task. The simulator consists of three 40-inch screens, capable of presenting a 180-degree driver's front view. Participants controlled the simulated car using a steering wheel, accelerator and a brake pedal.

Routes. Two intersecting routes were constructed for each of the three urban areas. Each route had two turns and crossed each other at three intersections. A salient landmark was present on or near each of the intersections, such as a parked panel truck, a construction sign, tall trees, a fire engine, and a group of people. Participants were familiarized with the specific landmarks to be encountered in each route prior to beginning the route-learning task. The three urban areas represented different parts of the city with no overlap between the areas.

IRANS format. Three formats of navigational aids were implemented. One consisted of visual only (VMGS), a second consisted of auditory only (ARGS) and the third consisted of concurrent presentation of both VMGS and ARGS.

VMGS. The geo-centered visual-map guidance system (VMGS) format consisted of a visual map

displayed on a liquid crystal display that was set up in the dashboard area on the right-hand side of the drivers' seat just below the simulated front windshield. The display location required participants to move their heads to the lower right to see the map (a typical display location for actual IRANS). The navigational map was drawn using geo-centered, north up coordination. Previous research has provided initial evidence that geo-centered maps may be more effective than ego-centered maps in facilitating cognitive map construction during navigational tasks (Azekura, 2003). The driver's location while traveling through the route was presented on the moving map display in real-time.

ARGS. The ego-centered auditory route guidance system (ARGS) format was presented via the existent audio system of the simulator. Terse auditory commands were recorded from a native English-speaking female speaking at a normal conversational level of approximately 65 dB and then digitized. Commands consisting of, "Turn left," "Turn right," or "Continue forward" were presented at each intersection to guide participants along the specified route. Auditory commands were always presented in an ego-centered (driver front view) perspective.

Procedure

Participants completed two navigation-related questionnaires (obtained from Takeuchi, 1992 and Lawton, 1994). The former assesses three types of self-evaluated perceived ability in space cognition, which are ability of using maps, memory for visual landmarks, and awareness of orientation (modified classification based on results from an independent factor-analysis using data reported in Carpenter et al., in press). The latter depicted self-reported preferred strategies for wayfinding tasks in normal life: route strategy and survey strategy (see Carpenter et al., in press for further description).

The navigational aid format was counterbalanced across areas. In each area, participants drove a simulated vehicle along the two predetermined routes using VMGS, ARGS, or both VMGS and ARGS guidance. Participants were instructed to watch for specific landmarks along the route and then were asked a series of questions designed to ascertain the accuracy and breadth of their cognitive map construction. The questions pertained to cardinal relationships between a landmark and a starting or an ending point. There were six questions for each route. For example, "The tall trees are to the _____ of the starting point," where the alternatives were North, South, East, West, NE, NW, SE, and SW. The score for exact answers was 2, and 1 was assigned to answers deviating by 45 degrees, e.g., answers of "NE" or "NW" for the correct answer "North." Participants answered the questions for each route immediately after driving through it. Following the questions pertaining to the second route in each area, they answered the same type of queries about the overall area in which they had driven. There were six questions pertaining to each overall area. Following completion of all area questions participants completed the NASA-TLX as a subjective index of mental workload for the navigational task using each type of navigational aid, not the difficulty of the questions that followed each route.

RESULTS

Grouping with Sense of Direction and Wayfinding Strategies

To examine the relationships between the efficacy of each type of navigational aid and individual differences in space cognition ability and wayfinding strategies, the participants were classified into two groups based on the results of the questionnaires. In Extreme Grouping, "Lower" is a group of participants whose total points are less than "mean – standard deviation (SD)," and "Higher" is a group of participants whose total points are greater than "mean + SD." In Coarse Grouping, the threshold for "Lower" is "mean – 1/2 SD" and "mean + 1/2 SD" for "Higher." Table 1 shows the number of the participants in each group.

Accuracy of Cognitive Map Knowledge

A repeated measures ANOVA was performed to examine participants accuracy for the questions pertaining to route and area as a function of the navigational aid used. The ANOVA test for all the participants revealed no significant differences among the types of navigational aids with respect to accuracy of overall cognitive map knowledge, nor among the types of aids for either the cognitive map construction task of local area routes or total area.

Table 1. The number of participants in each group classified by their ability in space cognition or wayfinding strategies.

Grouping	"Extreme"		"Coarse"	
Groups	Lower	Higher	Lower	Higher
Maps	6	7	10	10
Landmarks	3	6	11	11
Orientation	6	7	16	8
Route Strategy	6	3	10	11
Survey Strategy	4	7	15	10

Individual Differences. A significant interaction was observed between the types of navigational aids and the ability in awareness of orientation with the Coarse grouping (p=0.025*). Figure 1 shows the means and standard errors in the conditions. The results of pairwise comparison (Bonferroni) shows that participants with lower ability in awareness of orientation answered more questions correctly than those with higher ability when they were using the VMGS and the ARGS (p=0.030*).

In the task of construction of local area knowledge, a strong nonsignificant trend was observed for the interaction between the type of navigational aid and the preference of survey strategy regardless of type of grouping (p=0.053 at Extreme and p=0.056 at Coarse). The results of pairwise comparison shows that participants preferring a survey strategy generally tended to answer more questions correctly relative to those not preferring a survey strategy when they were using only the geo-centered map regardless of

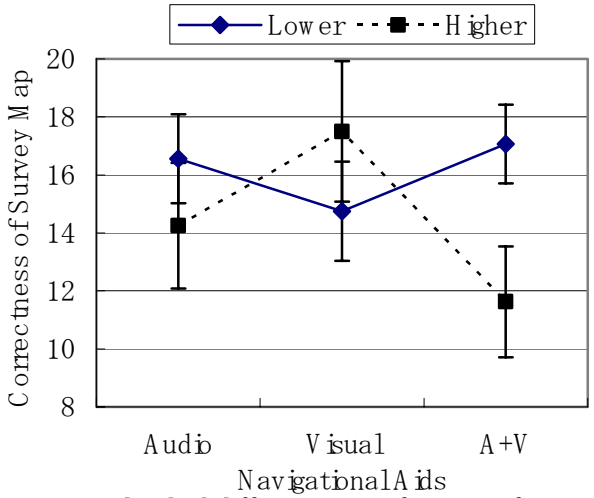

Figure 1: Individual differences as a function of navigational aid and awareness of orientation

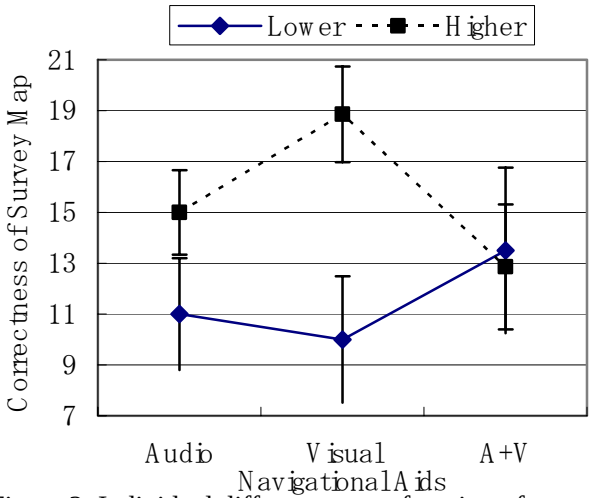

Figure 2: Individual differences as a function of navigational aid and survey strategy (Coarse Grouping)

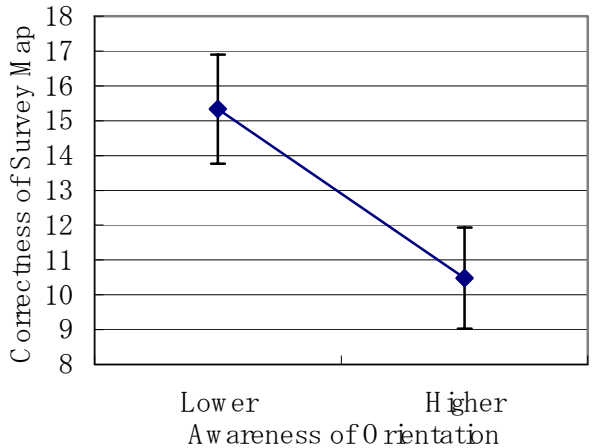

Figure 3. Individual differences as a function of awareness of orientation

type of grouping (p=0.019* at Extreme, Figure 2, and p=0.011* at Coarse). With the Extreme grouping, the participants with lower ability in awareness of orientation answered more questions correctly than those with higher ability (p=0.044*). This finding is counterintuitive, as we would expect that people with higher ability in awareness of orientation would be better at construction of cognitive maps than people with lower ability. The means and standard errors are depicted in Figure 3.

Mental Workload

Participants' workload was significantly lower when using the ARGS or the VMGS in combination with the ARGS relative to the VMGS only (p=0.006** and p=0.000**, respectively).

DISCUSSION

The results indicate that use of the auditory ego-centered information may support drivers' navigation without harm to cognitive map development with two important exceptions. Individual differences in performance were observed as a function of navigational aid and navigational strategy as assessed by Takeuchi's and Lawton's questionnaires.

Individual Differences Related to Aids and Awareness of Orientation

With the coarse grouping, participants with lower ability in awareness of orientation answered more cognitive map assessment questions correctly relative to those with higher ability when they were presented with the VMGS and ARGS concurrently. People with high ability in awareness of orientation benefited most from the VMGS format only and suffered performance decrements when presented with the concurrent ARGS aid. This result suggests that the auditory ego-centered information may interfere with the process of construction of cognitive map knowledge by people with higher ability in awareness of orientation. There may have been a resource cost associated with trying to ignore the auditory information. If persons with lower ability in awareness of orientation were relying on the auditory aid, it would likely have been easier for them to disregard the visual display.

The results on NASA-TLX indicated that participants' workload for the navigational task was significantly lower when they were able to use the auditory guidance aid either by itself or in combination with the visual map. The auditory ego-centered information may be particularly useful for people with lower ability in awareness of orientation. The geo-centered visual map required participants to reference their driver front view to the north up map, a task that people lower in awareness of orientation have difficulty with. People with higher ability in awareness of orientation appear to be able to use the auditory aid to navigate the route, however the auditory ego-centered information appears to harm their ability to form a cognitive map

Individual Differences Related to Aids and Survey Strategy

In the task of construction of a cognitive map during the navigation task, participants preferring a survey strategy tended to perform better when they were using the geo-centered map only, relative to those not preferring a survey strategy. However, there was no significant difference between the two groups under the condition with the concurrent geo-centered map and auditory ego-centered aid. This result may indicate that, similar to persons with a high ability in awareness of orientation, the auditory ego-centered information disrupts cognitive map construction for people preferring a survey strategy. However as previously stated, the ability to use the auditory ego-centered information appears helpful in performing the navigation task and, at least for people who do not prefer a survey strategy, the auditory information

does not appear to disrupt cognitive map construction.

Individual Differences Related to Awareness of Orientation

With the extreme grouping, participants with lower ability in awareness of orientation correctly answered more of the cognitive map assessment questions than those with higher ability. There are two at least two possible explanations for this result. It is possible that people with extremely high ability in awareness of orientation may actually just have lower ability in cognitive map construction. A more plausible explanation is that participants reporting a higher ability in awareness of orientation may have an over-reliance on their ability. The results of the NASA-TLX indicated that there were no significant differences between participants with the higher and lower ability on perceived mental workload in performing the navigational task. This finding, along with the lower cognitive map assessment performance, lends support to the possibility that persons scoring higher in awareness of orientation may have a tendency toward over-reliance on their ability. Further research is needed to examine this issue.

CONCLUSION

This experimental study emphasizes the importance of considering individual differences in navigational strategy and ability when designing in-vehicle routing and navigational systems. Ego-centered auditory aids may mitigate the difficulties in navigation with geo-centered maps without cognitive resource interference for some drivers. However, for other drivers the auditory aids may present an additional source of distraction that does not affect the navigation task directly, but rather interrupts the formation of a cognitive map of the area being navigated. Further research and analysis on the cognitive processes involved in the navigational task and area-learning task are necessary to identify appropriate navigational aids for supporting both tasks simultaneously.

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