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Effect of Information Modality on Geographic Cognition in Car Navigation Systems

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Abstract: Much research has focused on exploring the safest ways to present navigational information in vehicles. However, these efforts often neglect to focus on other measures of driver performance that may affect user satisfaction. Drivers may wish to gain an understanding of a geographic area in addition to simply navigating to a specific location. In this article, we complete an empirical study with tradeoff-based results of four navigational information modalities including visual only, visual with overhead map, audio only, and audio with overhead map based on their levels of interruption, reaction, and comprehension. Results confirm the safety of audio only implementations, but also show the strength of visual with overhead map for facilitating geographic cognition.

Keywords: Geographic cognition, notification systems, in-vehicle information systems

1 Introduction

The introduction of information systems into vehicles is a growing trend that can provide drivers with useful tools for navigation, communication, and exploration. However, in-vehicle information systems (IVIS) cannot be allowed to distract users from the demanding task of driving. This concern has inspired much research to ensure the safety of prospective applications and to explore common guidelines for IVIS.

Among these IVIS, car navigation systems have been among the most widely adopted technologies. These systems can greatly improve the driving experience by helping drivers navigate in unfamiliar settings and reduce the mental load of remembering where to go. It would be easy to ignore safety issues by pointing out the troubles with driving and looking at a paper map. The decision to open up the map is the driver's own. However, car navigation system manufacturers have a responsibility to society to produce safe systems in addition to possible liability caused by their systems facilitating accidents.

These concerns for safety should be paramount in decision making, but they can also lead to tradeoffs in other aspects of the system. Often drivers want to understand where they are going in addition to getting there safely, and the relation between safety, understanding, and other measures of user satisfaction is unclear. If a car navigation system can also be used as a learning tool for building a mental model of town layouts and important landmarks, then drivers will eventually become decreasingly dependent on the IVIS. Initially less safe modalities of navigation information may yield long term benefits in user satisfaction and safety.

2 Related Work

This research effort builds upon a large set of ongoing work in a variety of disciplines including human factors, HCI, and geographic information systems generally focusing on the best way to encode information that would not be interpreted as the user's primary task. Within HCI, notification systems research has developed guidelines and classification methods, such as the IRC Framework which provides a unifying foundation for the categorization of notification systems involving use of secondary displays simultaneously with a primary task (McCrickard 2003). This research can be leveraged in coordination with human factors efforts directly

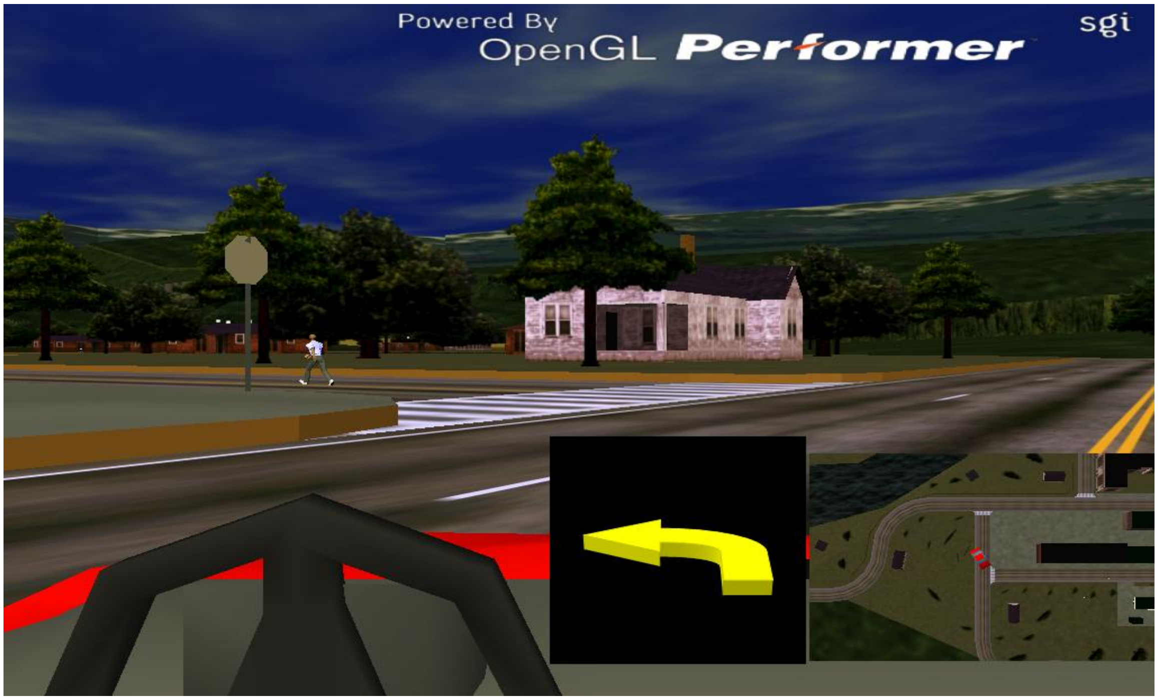

Figure 1: Screen shot of simulator with visual navigation indicator, overhead map, and obstacle around the next turn.

involving IVIS. There has been much research focused on finding the safest way to present navigation information including Srinivasan's study of five route guidance systems in a high-fidelity simulator yielding the lowest reaction times when using audio cues followed by a head-up turn-by-turn display (Srinivasan 1997). Chewar produced similar conclusions about audio messages and also suggested graphical arrows provided the ideal way to visually present directions based on statistical results showing arrows as best way to reduce navigation arrows and the second best way to reduce navigation time (Chewar 2002).

It is also important to understand the underlying theory behind learning associated with geographic areas so we can accurately measure geographic cognition in our tests. Research has shown geographic cognition follows a stage-based learning process (Siegel 1975; Thorndyke 1983). The first stage, called landmark knowledge, involves people learning and recognizing landmarks. The second stage, called route knowledge, has the person using those landmarks to form routes. The third stage, called survey knowledge, involves forming a coherent whole through the formation of minimaps, which are simply groups of landmarks.

3 Methodology

This effort seeks insight into the tradeoffs involving differing navigation modalities using a lab-based empirical study. We used pre and post-questionnaires to gauge user impressions and satisfaction, and a simulator was used to obtain actual performance metrics in interruption and reaction. While the simulator did not use a sophisticated physics engine or complicated car and pedestrian traffic, the controls and tasks included provided a simple interface and test scenario that was easy for subjects to learn. The resulting data allowed us to gain insight into a variety of tasks involving use of secondary navigation information for directions in a primary task.

3.1 Experimental Design

48 undergraduate Computer Science students voluntarily took part in experiment. The simulator used voice audio messages and visual arrows as the two modes of navigation directions. Selected groups were also given a north-pointing, car-centered overhead map to augment their navigation system resulting in the four modalities of audio only, audio with map, visual only, and visual with map.

The 48 students were divided into 12 per modality and tested individually. The navigation tasks were completed using a joystick-controlled simulator, shown in Figure 1. Each user was given a set of three predefined routes to follow through the town with a set of landmarks to look for on each route. This was followed by a multiple choice paper map, shown in Figure 2, in which they were instructed to match up landmarks displayed on another page to their position on the map which corresponds to measuring survey knowledge because it required them to understand the relationship of landmarks to one another. Next, they were given a list of three landmarks to navigate back to without any navigation assistance from the simulator. This corresponds to route knowledge because it required them to be able to form their own routes and backtrack. Finally, each user answered a post-questionnaire to evaluate their perception of the systems and to gain suggestions for future improvement.

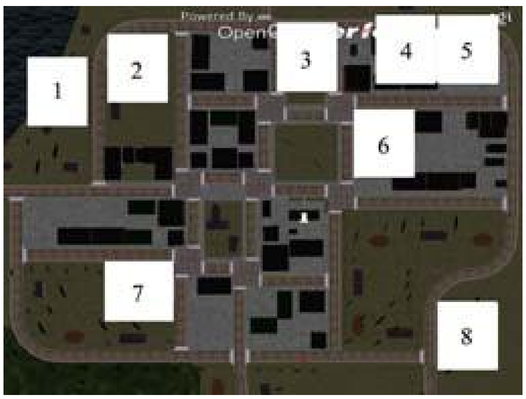

Figure 2: Screen shot of landmark worksheet to gauge geographic cognition

3.2 Metrics

Performance metrics gathered by the simulator included *obstacles hit, wrong turns, predefined route guided route completion time,* and *unguided route completion time*. The worksheet augmented the performance metrics by finding *landmark matches* and while the post-questionnaire measured user opinion of how the modality effected *distraction, reaction, geographic cognition,* and *landmark matching facilitation*.

These metrics each affected the modality's classification into the IRC framework as listed in Table 1. McCrickard's IRC framework was used because of its unification of system specific user goals with general goals for a notification system which allows our results to be discussed under a common language and made more applicable and understandable in relation to other notification systems (McCrickard 2003).

4 Results

Results in this section are based on analysis of data collected in our experiments. Because of the small set of test subjects, we used Student's *t* tests and included results with ($p < .10$). From our analysis, we categorized the highest and lowest rated modalities in interruption, reaction, and comprehension which are listed in Table 2. Full results and data can be found in (Moldenhauer 2003).

Interruption	Reaction	Comprehension
(+)Lane deviations	(-)Total time	(-)Incomplete target tasks
(+)Hit obstacles	(-)Wrong turns	(+)Landmark matches
(+)Total time	(+)User opinion of reaction	(+)User opinion of geographic cognition facilitation
(+)User opinion of distraction	(+)User opinion of ability to follow route	(+)User opinion of landmark matching facilitation

Table 1: Metrics used to gauge levels of interruption, reaction, and comprehension for each modality. (+) indicates a positive correlation and (-) indicates a negative correlation between the metric level and parameter level. For example, longer total time to complete route tasks would reduce the modality's score for reaction.

Interruption: Visual directions with overhead map were the most interruptive which had significantly more lane deviations than audio with map and visual, higher user perception of distraction than visual, and longer total time than audio and audio with map. Visual directions without overhead map were the least interruptive with significantly less lane deviations than visual with map, fewer hit obstacles than audio with map, and lower user perception of distraction than audio and visual with map.

Reaction: Audio directions caused the highest level of reaction with significantly less total time than visual with map and higher user perception of reaction than visual with map. Visual with map caused the lowest level of reaction with significantly longer total time than audio and audio with map as mentioned before, and lower user perception of reaction than audio.

Comprehension: Visual with map provided the highest level of comprehension with significantly more landmark matches than audio with map, higher user perception of geographic cognition facilitation than audio and audio with map, and higher user perception of landmark matching facilitation than audio and audio with map. Audio with map provided the lowest level of comprehension with significantly fewer landmark matches than visual with map, lower user perception of geographic cognition facilitation than visual and visual with map, and lower user perception of landmark matching facilitation than visual and visual with map.

	Interruption	Reaction	Comprehension
High	Visual with map	Audio	Visual with map
Low	Visual	Visual with map	Audio with map

Table 2: Classification of navigation modality into IRC framework.

5 Discussion

The results of our experiments illustrate an important tradeoff. Visual with map appears ideal for facilitating geographic learning, but is the least safe implementation. This result was in line with our expectations that an overhead map would help users build a better mental map of the town and prove less safe than audio implementations as in previous studies. The audio-only modality fulfilled expectations of being the easiest to react to, but was beaten by visual in having the lowest interruption. Pure visual directions did not carry the mental load of visual with map and immediate need for attention required by audio cues.

There were also some surprising results. We expected subjects using audio with map would also be better supported in geographic cognition, but the results suggested it was the least helpful. This may have been due to audio users forgetting to use the map feature whereas visual users had to divert their attention toward the arrow directions which likely encouraged taking glances at the map. This also suggests an inability to make a switch in context from audio to visual navigation information.

Stronger results could be made through improvements in the testing platform. Users complained about the existence of similar landmarks, the overly simple movement, and lack of other cues like street names. A more realistic physics engine has already been implemented and tests in an immersive environment, such as Virginia Tech's CAVE, could provide the realism needed for a more lifelike experience.

6 Conclusion

This research provides a foundation for the importance of investigating tradeoffs involving information presentation in in-vehicle information systems. Initial safety is of utmost importance, but this focus may lead to short-sighted implementations that yield long-term dependence and user dissatisfaction which in this case is affected by geographic cognition.

Our results should be considered in other notification systems research, particularly involving navigation and high risk activities. Information modality can inherently affect levels of interruption, reaction, and comprehension, and all means of communicating information to users are important to explore in the design and research of optimal systems.

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