Comparison of Mobile Device Navigation Information Display Alternatives from the Cognitive Load Perspective

Murat Can Cobanoglu, Ahmet Alp Kindiroglu, and Selim Balcisoy

muratcan@su.sabanciuniv.edu, akindiroglu@su.sabanciuniv.edu,
balcisoy@sabanciuniv.edu

Abstract. In-vehicle information systems (IVIS) should minimize the cognitive load on the drivers to reduce any risk of accidents. For that purpose we built an experiment in which two alternatives for information display are compared. One alternative is the traditional information display method of showing a map with the target route highlighted in red. This is compared against a proposed alternative for information display in which prior to a junction a ground-level photo is displayed with a large red arrow pointing at the correct route the driver must take. The photo-enhanced information display method required 39% more time spent while gazing at the screen but provided a 10% reduction in the total number of headturns. Based on the participant comments, 80% of whom opted for the non-photo enhanced method, we concluded that the cognitive load brought on by the photo-enhancement is not worth the return.

Keywords: Cognitive load, information display, navigation, time-based comparison.

1 Introduction

1.1 Foreword

The market for mobile devices that offer navigation help has been growing exponentially. The development in hardware technology that yields more processing power as well as higher storage capacity allows experimenting with new interfaces and information display methods. We have identified a potentially helpful information display technique which is to provide ground-level photographs in complex junctions with clear directives on top of these images to help the driver. However the cognitive load of these new possibilities should be assessed carefully, most of all for safety reasons. The impact of cognitive load on safety is very fundamental as emphasized in the research of Pompei et al. [1]

Therefore we have assessed the attention time and headturns required when using the photo-enhanced technique and the more traditional way of simply displaying the map of the area immediately around the driver. We have found in our experiment that the ground-level display technique requires a lower number of headturns for the driver to find the correct way therefore showing that it causes less distraction. Be that as it may, the amount of time the driver spends gazing at the screen per each headturn increases in the photo-enhanced method therefore suggesting that the driver spends

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more effort trying to figure out what he is being shown. This might in turn point at increased cognitive load and worse cognitive ergonomics. The questionnaire that was given to the participants points out that shorter but more frequent looks are cognitively more ergonomic than the other way around.

The ground-level photos would be taken from vehicles travelling in the same junction and further supplemented with clear brightly-colored arrows pointing at the turn the driver must take.

1.2 Background Information

The tasks that a driver performs while driving a car are usually categorized as follows: Primary tasks that are directly related to operating the car and travelling safely [4] and secondary tasks that are performed by the driver while driving but are not directly related to the process of operating the vehicle [5]. Primary tasks are generally considered to be the rotation of the steering wheel, the observation of the surroundings, operation of the pedals. Secondary tasks are usually considered to be the operation of a cell phone, radio or navigation equipment [6].

Cognitive load is measured in a number of different ways in literature which can broadly be distinguished into two categories: subjective and objective techniques. An important example of the subjective techniques used is the NASA task load index (TLX) which computes the Overall Workload Index using several questions with answers on a 1-100 scale [8]. Within the objective tests, two main classes can be defined: first category being tests in which the time it takes for participants to complete certain tasks is measured whereas research falling into the second category uses the tracking of certain biological indicators such as glances, headturns or eye-movements [7], [10].

While building a navigation device for use within the context of this experiment, we conducted a search on the current standards and design guidelines. We aimed to make the appearance of the software compliant with the ISO 15008 standard for determining the contrast, color and characters on the display screen [11]. While positioning the device, we followed the guidelines of the European Statement of Principles [4] and positioned the device so that it would not occlude any of the road or surroundings but still be easy-to-reach for the driver by a slight headturn. Another design principle that concerns design of in-vehicle information systems (IVIS) is the 15-second rule. The rule states that any task, when viewed as a continuous sequence of actions, should not exceed 15 seconds [12].

1.3 Motivation

It is stated by Klinker and Tonnis that arrows have reached the end of their informative capacities through overloading in information visualization for road vehicles [9]. It is intuitive that the occlusions of different road levels in multi-leveled junctions do not contribute to the informative quality of simple arrows within the navigation context. In this research we have aimed to assess the potential of a candidate alternative to be used in information display with this motivation.

To assess the usability as accurately as possible, we have used a combination of the techniques used in literature. Headturn tracking and glance time-keeping were used as objective indicators, and this was supplemented by a questionnaire as a subjective indicator. This intuition came from the literature as similar techniques have been utilized in both [8] and [10]. To be able to focus solely on the cognitive load of navigating, we thought it necessary to exclude any manual input on the side of the participant driver but instead decided to provide a completely automated system. As the user needs to provide no manual input, the 15-second rule is not applicable in that sense to this research. The only task that needs to be accomplished is identifying if a particular turn must be taken or not and that task took far less than 15 seconds in all the trials. Thus the claim that the experimental setup complied with the 15-second rule cannot be rejected.

2 Methodology

2.1 Participants

There were five participants which were selected from a body of volunteers that were available. Due to the limited funding we had, we could not endorse participation but rather had to rely on volunteers as participants. However we imposed the restriction that each participant had to be the holder of a valid driving license by the time of the experiment. This was necessary as the experiment was conducted on public roads. To further minimize any risk of accidents, every participant had to admit that they were comfortable with driving a car and using a GPS navigation device at the same time or else they were not accepted to the experiment. The age range of the participants was 20-35 and two out of five participants were females.

2.2 Experimental Design

Cognitive load brought on by using a mobile navigation device while driving is measured by two metrics in our study: number of headturns to look at the screen and the time spent looking at the screen (in milliseconds). Measuring the average time of attention is a technique that has been used in previous research about information display on mobile devices. [2] The first of the alternative information display methods used is the rather traditional method of displaying a map of the area immediately around the user with the target route highlighted in a color different than others. This method could mislead the user in complex junctions - where we take complex to mean junctions with multiple levels, each at a different height since the user could potentially fail to understand which level she was on. Such hindrances coupled with the fact that traffic gets heavier on complex junctions, possibly drawing even more driver attention - could significantly increase cognitive load. To bolster usability, ground-level photos of the junction to be displayed on the mobile device screen could potentially be helpful. These photos give the viewing driver exactly what she already sees outside the window, making it easier to decide to drive straight or to turn. A false turn in a complex junction could potentially create serious deviation from the intended route resulting in large losses of time and effort at the least. This problem of deviation of the user from the route and possibly even getting lost is so crucial that there are researchers like Viitala-Kiss et al. [3] that produce sophisticated methods of correcting these deviations as effectively as possible.

Fig. 1. Experimental Setup

Fig. 2. Experiment Route and Positions of the Eight Turns with Photo-Enhancement

Each participant would be instructed to complete a route following the directives displayed on the device screen. Participants were given the driver seat with two other aides in the car; one recording the session while the other kept the device in a position that the driver deemed comfortable. Figure 1 is a photo showing the experimental setup.

The experiment design was aimed to compare the usability difference between two alternative methods of information display on mobile device screens in complex junctions.

The experiment took place on a route that included four turns in a complex junction as well as four turns on a normal road without any complex junctions. The screen in default

Fig. 3. The Screenshot of the Device in Photo-Enhanced Information Display Mode 50 metres Before Turn 1

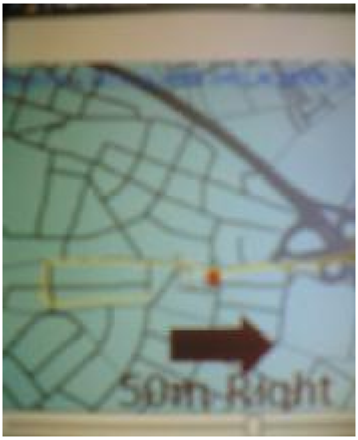

Fig. 4. The Screenshot of the Device in No Photo-Enhancement Mode 50 metres Before Turn 1

mode displayed a map of the local area immediately around the vehicle with a magnification of approximately 2.75 cm per 100 meters. In photo-enhanced mode, when the car was closer than 50 meters to a turn the screen displayed a ground-level photo showing the road ahead of the driver with a bright red arrow pointing at the direction she must go - you can see a screenshot at Figure 3. In case the device was in the traditional mode, it kept displaying the map with a small auxiliary arrow at the bottom pointing at the direction of the turn - screenshot at Figure 4.

While calculating the results we made our calculations twice, one excluding the time or glances that the driver gave while the car was at a halt i.e. when waiting for a red light.

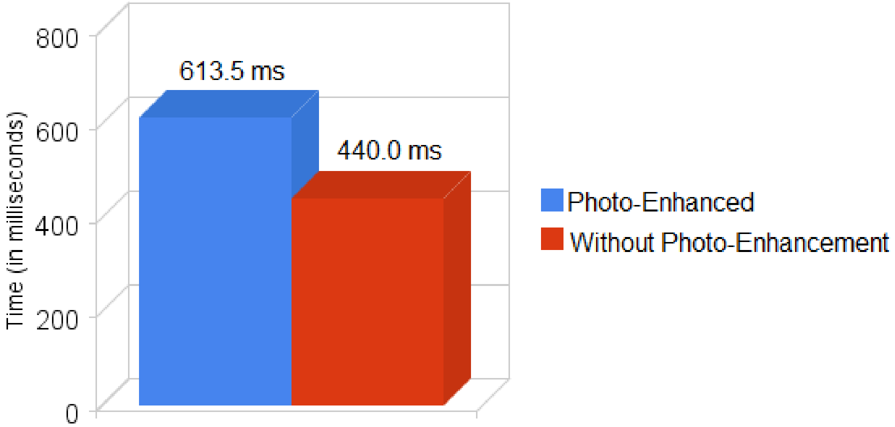

Fig. 5. The Average Gaze Duration per Each Headturn When the Vehicle is Non-Stationary

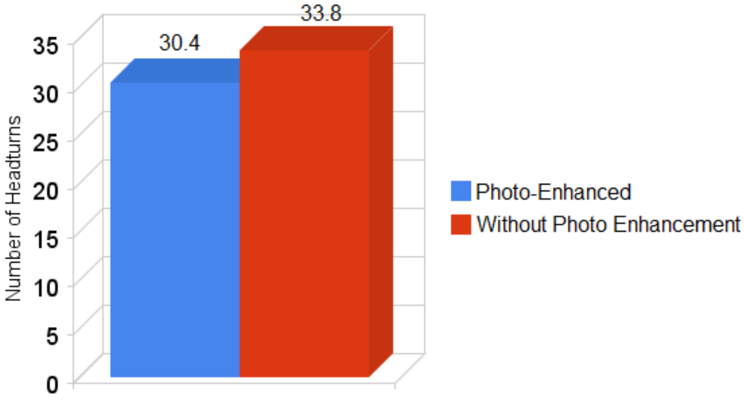

Fig. 6. Average Number of Headturns to Look at the Device Screen When the Vehicle is Non-Stationary

3 Result

On average the photo-enhanced method had 3.4 headturns - accounting for 10.6% - less than map view (as shown in Table 2) but in turn the photo-enhanced display required 170 millisecond increase in attention time per look (as seen from Table 1). The average time spent while staring at the screen per each headturn is higher by 39% in the photo-enhanced method. The questionnaire that was given to the participants following the experiment shows that 80% of the participants thought the classical map view was more helpful than the photo-enhanced method.

Table 1. Average Time Spent Gazing at the Screen (in *seconds*)

	TOTAL	WHILE DRIVING
Photo-Enhanced:	21.85	18.65
No Photo-Enhancement:	19.88	14.87

Table 2. Average Number of Headturns to Look at the Screen

	TOTAL	WHILE DRIVING
Photo-Enhanced:	31.2	30.4
No Photo-Enhancement:	34.4	33.8

Table 3. Average Time Spent Gazing at the Screen per Headturn (in *seconds*)

	TOTAL	WHILE DRIVING
Photo-Enhanced:	0.70	0.61
No Photo-Enhancement:	0.57	0.44

Table 4. Experimental Results for Photo Enhanced Method

	Headturn Count	Total Glance Time (seconds)	Driving Glance Time (seconds)	Preferred Method
Participant 1	29	21.04	21.04	
Participant 2	44	28.41	28.41	
Participant 3	21	8.65	7.65	
Participant 4	35	40.6	25.6	YES
Participant 5	27	10.54	10.54	

Table 5. Experimental Results for Non-Photo Enhanced Method

	Headturn Count	Total Glance Time (seconds)	Driving Glance Time (seconds)	Preferred Method
Participant 1	24	25.92	20.90	YES
Participant 2	52	31.30	25.307	YES
Participant 3	25	7.30	6.30	YES
Participant 4	33	16.12	16.12	
Participant 5	38	18.76	11.76	YES

Note that we exclude gaze times or headturns while the car is stationary for two main reasons: Firstly when the car is stationary (for example, waiting in a red light) there is almost no cognitive load on the driver. Secondly the traffic was often fluid which never provided the driver with an opportunity to observe the device screen while not driving the car. As a result of these factors using the non-stationary time measurements does not change the observations definitively but just slightly distorts them as the main focus of this research is on cognitive load while driving and navigating.

4 Conclusion

Photos provide more information per each look but at the cost of higher cognitive effort. Despite the reduction in headturn count, extra attention demanded per each headturn seems too expensive in terms of cognitive load. This extra cognitive effort spent to parse the photo, while driving and negotiating lane changes with other drivers, can possibly increase the risk of cognitive capture and lead to accidents or fatalities.

Our conclusion is that the photo-enhanced method demands higher cognitive effort from the driver. This conclusion is based on the observation that in the photo-enhanced method on the average there is a 39% increase (170 milliseconds) of gaze duration per each headturn. Although the amount of information supplied to the user per headturn is slightly higher in photo-enhanced information display as shown in the fact that it requires 10.06% less headturns overall (Tables 1,2 and 3); the subjective tests show that this slight benefit does not justify the 39% increase of attention time required per each headturn. Subjective tests in which the participants have been asked to name the preferred method have shown that 80% support the arrow-based simpler model to the photo-enhanced method, further supporting this conclusion (Tables 4, 5).

This conclusion gets more pronounced in complex junctions where simply driving the car requires heavy mental effort. The consequence is that the photo-enhanced method gives significantly more information per look - as shown by the number of headturns metric. However this comes at the cost of longer attention time per each headturn. The post-experiment evaluations show that this extra effort is just too precious in very high cognitive load environments therefore reducing the attention time needed per look must be taken as a higher priority than reducing the number of headturns to enhance cognitive ergonomics.

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