Visual demand for maps at different scales of in-route guidance and navigation system

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Abstract. This work evaluates drivers' visual demand for maps at different scales when they perform simple maneuver (i.e. 'Turn right') and complex maneuver (i.e. 'Take the second exit at the roundabout') using in-vehicle route guidance and navigation system. A group of 52 subjects (26 males and 26 females) participated of an experiment in a driving simulator. Drivers were required to navigate using maps at scale 1:3,000 and 1:6,000. Results show that both scales were equally satisfactory to support drivers in simple maneuver. However, the more generalized map was more efficient in complex maneuver, since it has required low visual demand for drivers. Results also show that drivers' performance is related to their gender. Results are discussed in terms of the different stages which compose the navigation task. To reduce drivers' distraction, it is suggested to adopt map scale according to complexity of maneuver. We also suggest driver's gender be taken into account on interface designs for route guidance and navigation system, since this group characteristic has influenced the amount of time that drivers spend their eyes off-road to get information on these interfaces.

Keywords. In-vehicle route guidance and navigation system, visual demand, map scale selection, usability

1. Introduction

The usability issues of In-vehicle Route Guidance and Navigation Systems (RGNS) interfaces have been widely discussed over the last decades (Green et al. 1995, Liu 2001, Nowakowski et al. 2003, Pugliesi et al. 2009, Ching-Torng at al. 2010, Lavie et al. 2011, Burnett et al. 2013). One of the main concerns is that drivers require diverting their eyes from the road to receive visual information from these interfaces. Diverting eyes from the road to interact with interfaces, like RGNS, has been linked with drivers' visual dis-

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traction, and this topic has become a major concern for traffic safety (NHTSA 2012) especially because the use of in-vehicle systems has grown significantly in recent years (ABIresearch 2014). Another important issue that should be highlighted, since it may enhance risks at driving task, is related to difficulties to get information from maps while car is moving due to cartographic communication problems (Lavie & Oron-Gilad 2013).

In-vehicle route guidance and navigation systems may be much more efficient if they provide relevant information without overloading drivers' cognitive processing system (Pugliesi et al. 2013). To avoid high mental workload on drivers and consequently serious impacts on transportation safety, designers of RGNS should take into account that drivers have to get information on navigation map in an easy and rapid way. The design of efficient and effective maps for RGNS involves several variables (Pugliesi et al. 2009, Lee & Jun 2010, Marques et al. 2012). One fundamental variable refers to map scale selection, since it can improve drivers' performance at decision points when following a route (Ramos et al. 2014c).

Several measures have been adopted to evaluate usability of in-vehicle route guidance and navigation system interfaces. One of them is visual demand which is related to drivers' visual distraction (Pugliesi et al. 2013). The visual demand refers to the amount of time that drivers need to acquire information in a visual interface and it can be quantified in terms of a several quantitative measures, such as the number of glances, the mean duration of glances and the minimum duration of glances (Tsimhoni & Green 2001, Pugliesi et al. 2013). The number of glances refers to the number of time that the driver looks at the display to complete a task (Tsimhoni et al. 1999). Duration of glance includes the time from the moment the driver's eyes were fixed on the road, started to move to the display, and then returned to the road again (Pugliesi et al. 2009). The minimum duration of glances consists of the shorter time required to get information from a visual interface (Pugliesi et al. 2009), and the mean duration of glances consists of the mean amount of time required to acquire information from a visual interface (Tsimhoni et al. 1999). The mean duration of glances is represented by the ratio between the sum of glances and the number of glances.

This work aims to evaluate drivers' visual demand for maps at different scales to perform simple and complex maneuver using RGNS. Number of glances, minimum duration of glances and mean duration of glances were the variables used to quantify the visual demand. The research questions are: "In which scale do navigation maps demand more number of glances?"; "Is mean duration of glances influenced by map scale?"; "In which scale are maps more quickly to be read?"; and " Is drivers' gender related to visual demand when using navigation maps at different scales?"

2. Method

2.1. Subjects

A total of 52 subjects from Presidente Prudente town (Brazil) participated voluntarily of a controlled experiment. The group of participants was composed of 26 males and 26 females with mean age of 28.05 years (±4.62). To recruit them, the following criteria were adopted: to be regular drivers for at least 2 years, having normal color vision and having no or little knowledge of the town used in the experiment.

2.2. Experimental route

The experimental route is located in a small town and is composed of thirteen maneuvers. The maneuvers were classified as simple (i.e.: 'Turn right') or complex maneuver (i.e.: 'take the second exit at the roundabout') according to the exits number of the junction. This route was filmed and used to represent the real world at the driving simulation task.

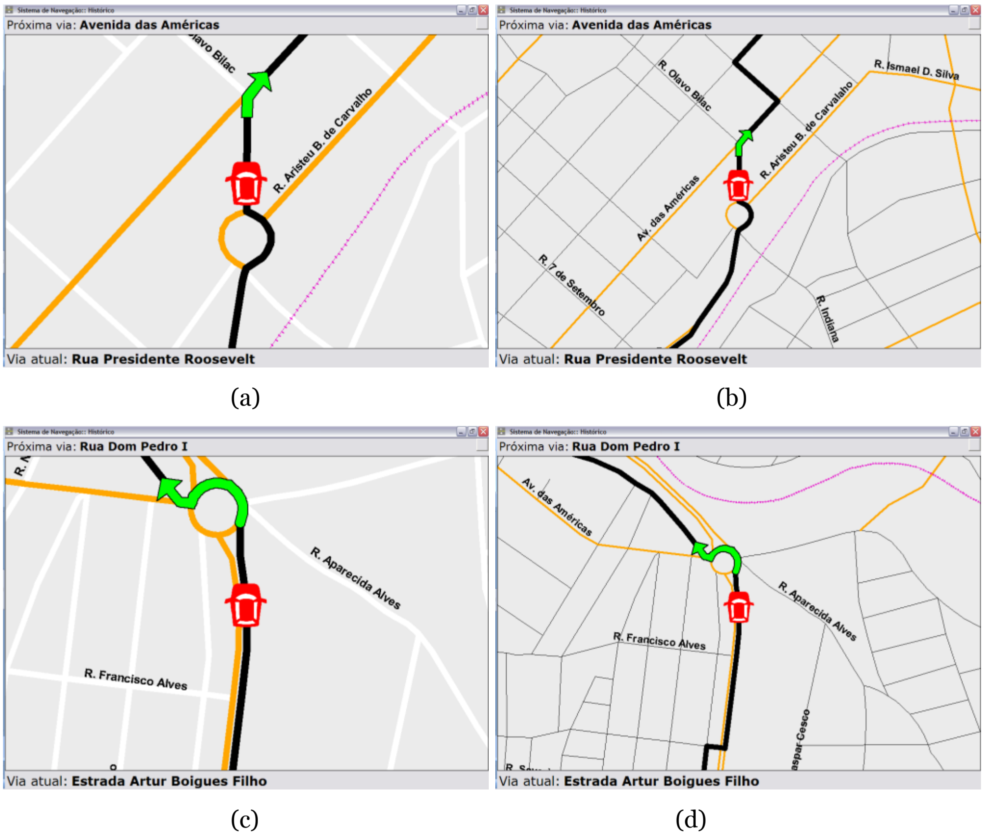
2.3. Map design

Maps were designed at two different scales 1:3,000 and 1:6,000. These values of scales were defined based on the results of the researches developed by Marques et al. (2012) and Ramos et al. (2014a). The map design was based on the proposal of map for RGNS implemented by Pugliesi et al. (2009) initially and then improved by Marques et al. (2012). This proposal is based on cartographic communication principles, like perceptive grouping principles and figure–ground principles as pointed out by MacEachren (1995), Dent et al. (2009) and Slocum et al. (2009). Moreover, we also designed the maps based on the results of Brazilian drivers' preference for color of map elements (route and direction arrow) which were recently presented by Ramos et al. (2014b).

2.4. Map production

Maps at different scales were implemented in a RGNS prototype using ESRI MapObjects with Microsoft Visual Basic. This prototype has been developed by members of research group (Pugliesi et al. 2009, Marques et al. 2012, Ramos et al. 2014c). Maps are presented in heading-up orientation with orthogonal view and are composed by features, such as car (RGB=250,0,0), route (RGB=0,0,0), direction arrow (RGB=0,255,0), street name (RGB=0,0,0) and road network divided into main (RGB=255,166,0) and secondary (RGB=255,255,255) road types. The RGNS prototype also presents a beep a few meters before each maneuver to indicate the beginning of each tactical task. This is an important task since it refers to the preparation for making maneuvers (Michon 1985) and it is responsible to overload the drivers' cognitive processing system (Kaber et al. 2012). Maps at 1:3,000

(Figures 1a and 1c) and 1:6,000 (Figure 1b and 1d) are shown to represent simple (Figure 1a and 1b) and complex maneuver (Figures 1c and 1d) for the tactical task.



(a) (b) (c) (d)

Figure 1. Maps at different cartographic scales representing different types of maneuvers.

2.5. Driving simulator

The experiment with 52 drivers was conducted in a low-cost and fixed-base driving simulator (Figure 2). This simulator is comprised by several materials and equipments. A large screen-image (180 cm height and 240 cm width) located in front of the car was used to display a video movie of the experimental road. To show the maps for drivers, it was used a small-screen LCD display of 7-inches (XENARC 700-TSV) with video resolution of 1024 x 768. This monitor was placed on the dashboard, in the right side of the steering wheel as recommended by Burnett et al. 2012.

The video movie of the route was displayed on the screen-image using a video projector which was connected to a computer via a serial connection.

Another computer was used to run the RGNS prototype which was connected via VGA port to the navigation display. The auditory information was presented using personal computer speakers which were positioned behind the driver's and passenger's seats. The drivers' visual demand was recorded using a Tablet of 7-inches with video resolution of 1024 x 768.

Figure 2. Driving simulator images.

2.6. Procedure

To perform driving simulation task, drivers were divided into two equal-sized groups of 13 males and 13 females. Group 1 started driving task using maps at 1:3,000 scale (maneuvers 1 to 6) and finished the travel using maps at 1:6,000 scale (maneuvers 7 to 13). Group 2 started the driving task in a different sequence, first with maps at 1:6,000 scale (maneuvers 1 to 6) and then maps at 1:3,000 scale (maneuvers 7 to 13).

For driving simulation task, initially drivers were familiarized with the simulator, map scales, tactical task and beep. After that, drivers were required to suppose that they should be navigating by car in an unknown town using a RGNS. Drivers were also advised to pay the necessary attention to the video movie to avoid traffic accidents and to look at the navigation display by taking quick glances to get map information, preferably after the beep. Finally, after driver signing a consent form and saying the test could begin, the driving simulation task started.

3. Results

The visual demand data were extracted using a manual video frame capture with Microsoft Windows Movie Maker. Because tactical task time is influenced by traffic conditions and road feature, the analysis and comparison of visual demand among different maneuvers was focused on the shortest tactical task time which corresponded to 11 seconds.

Table 1 lists the descriptive statistics (minimum, maximum and median value) and normality test results for each dependent variable, like number of glances, minimum duration of glances and mean duration of glances considering simple and complex maneuver which were visualized at two different scales 1:3,000 and 1:6,000.

	Scale	Number of glances			
		Min.	Max.	Median	p-Value*
Simple maneuver	1:3,000	1	7	3	0.001
	1:6,000	1	5	2	0.001
Complex maneuver	1:3,000	1	6	3	0.121
	1:6,000	1	4	2	0.137
	Scale	Minimum duration of glances (seconds)			
		Min.	Max.	Median	p-Value*
Simple maneuver	1:3,000	0.48	1.76	0.80	<0.0001
	1:6,000	0.48	2.48	0.80	<0.0001
Complex maneuver	1:3,000	0.40	5.33	1.96	<0.0001
	1:6,000	0.58	2.68	1.04	<0.0001
	Scale	Mean duration of glances (seconds)			
		Min.	Max.	Median	p-Value*
Simple maneuver	1:3,000	0.49	1.79	1.03	0.001
	1:6,000	0.68	2.48	0.97	<0.0001
Complex maneuver	1:3,000	0.74	2.66	1.32	<0.0001
	1:6,000	0.81	3.17	1.31	<0.0001

Table 1. Some statistical for visual demand data. *p-Value was calculated by Shapiro-Wilk. When p-Value was greater than 0.05, the normality assumption was approved.

The Shapiro-Wilk test results showed that the majority of data related to each variable of interest has no normal probability distribution. The only exception was the data related to the number of glances in the case of complex maneuvers. Therefore, as recommend by Conover (1999), to perform statistical analyses considering data with normal distribution will be adopted non-parametric tests, such as wilcoxon and Mann-Whitney test. While to perform statistical analyses considering data with normal distribution will be adopted parametric tests, such as Paired-Samples T test and Independent-Samples T test. All data were processed using SPSS 16.0 (Statistical Package for the Social Sciences Software) for a confidence level of 90%.

Table 2 lists the statistical results and shows that the influence of scale was significant (p<0.05) in at least two of the three dependent variables. Taking into account tactical task in simple maneuver, Wilcoxon test results revealed that there is no difference between 1:3,000 and 1:6,000 scales in terms of the number of glances (p=0.382), of the minimum duration of glances (p=0.809) as well as of the mean duration of glances (p=0.774). Thus, both map scales are equally efficient to support drivers to perform this kind of maneuver. However, taking into account the tactical task in complex maneuver, statistical results show that both the number of glances (p<0.0001) and the minimum duration of glances (p<0.0001) were significantly higher when a more detailed map (1:3,000) was used by drivers. There is no difference between the two map scales in terms of the mean duration of glances (p=0.456) in complex maneuver. It may be pointed out that mean duration of glances is not influenced by the map scale, even if it has been considered maneuvers with different levels of complexity.

	Comparison between: First x second	Number of glances			
		Wilcoxon (rank sums)			
		First	Second	Z	p-Value
Simple maneuver	1:3,000 x 1:6,000	756	570	-0.874	0.382
Complex maneuver	1:3,000 x 1:6,000	Paired-Samples T test			
		Mean	SD	t	p-Value
		3.22 x 2.67	0.955 x 0.871	4.437	<0.0001*
	Comparison between: First x second	Minimum duration of glances			
		First	Second	Z	p-Value
Simple maneuver	1:3,000 x 1:6,000	662.5	715.5	-0.241	0.809
Complex maneuver	1:3,000 x 1:6,000	1141	237	-4,117	<0.0001*
	Comparison between: First x second	Mean duration of glances			
		First	Second	Z	p-Value
Simple maneuver	1:3,000 x 1:6,000	657.5	720.5	-0.287	0.774
Complex maneuver	1:3,000 x 1:6,000	742.5	583.5	-0.745	0.456

Table 2. Summary of the analyses for dependent variables. *Significant at $\alpha = 0.01$.

The results presented in Table 3 revealed that there is a significant relationship between drivers' gender and their performance on tactical task. We noted that women have to look at maps more frequently than men to perform the tactical task in simple maneuver, independently the map scale used, if 1:3,000 (p=0.008) or 1:6,000 (p=0.071).

	Map scale	Visual demand variable	Mann-Whitney test (ranks mean)			
			Gender		Z	p-Value
			Male	Female		
Simple maneuver	1:3,000	Minimum duration of glances	29.71	23.29	-1.533	0.125
		Mean duration of glances	29.27	23.73	-1.318	0.187
		Number of glances	20.94	32.06	-2.656	0.008*
Complex maneuver		Minimum duration of glances	24.46	28.54	-0.971	0.331
		Mean duration of glances	27.77	25.23	-0.604	0.546
		Number of glances	Independent-Samples T test			
			Mean	SD	t	p-Value
			3.09 x 3.35	1.075 x 0.820	-0.965	0.339
	1:6,000	Visual demand variable	Mann-Whitney test (ranks mean)			
			Gender		Z	p-Value
			Male	Female		
Simple maneuver		Minimum duration of glances	27.75	25.25	-0.596	0.551
		Mean duration of glances	27.38	25.62	-0.421	0.674
		Number of glances	22.79	30.21	-1.807	0.071*
Complex maneuver		Minimum duration of glances	24.71	28.29	-0.852	0.694
		Mean duration of glances	28.13	24.87	-0.778	0.437
		Number of glances	Independent-Samples T test			
			Mean	SD	t	p-Value
			2.67 x 2.67	0.939 x 0.817	0.250	0.980

Table 3. Summary of the analyses related to drivers' gender. *Significant at $\alpha = 0.01$.

4. Discussion

This section discusses the results obtained with a group of drivers from an experiment in a low-cost and fixed-base driving simulator. The results showed that drivers had better performance in complex maneuver when they were instructed by more generalized map. Probably this occurred due to the maps at 1:6,000 scale can support drivers to identify not only the direction of next maneuver clearly, but also to get surrounding information of the route (example Figure 1b).

According to Burnett (1998), navigation task is composed by a number of different stages, such as preview, identification, confirmation, trust and orientation, and the literature (Ross & Burnett 2001, Lee et al. 2008, Marques et al. 2012, Ramos et al. 2014c) has suggested that an efficient navigation map is that which supports drivers in each stages. The preview and identification stages are directly related to tactical task, while confirmation, trust and orientation stages are related to navigation task as a whole.

Based on Figure 1a and Figure 1c, for example, we can assumed that maps at 1:3,000 can also help the drivers to identify the direction of next maneuver in details. However, this map scale, when displayed in seven-inch monitor, allows drivers to visualize two and a half blocks only. This reduces the surrounding information of route, and it may negatively affect the trust and orientation stages. We assumed that navigate using cartographic representations which establish a proper relation between spatial information about route and details of the next maneuver seem to favor drivers to be more confident to comprehend map information and this, consequently, contributes to reduce the drivers' visual demand.

5. Conclusion

This section presents some conclusion from the obtained findings, some recommendations regarding the interface design for in-vehicle route guidance and navigation system and also some suggestions to future studies.

We conclude that cartographic communication performance of navigation maps depends on the scale selected, especially when they have to support drivers in complex maneuvers. In the study case, because the more generalized map requires low visual demand, it seems to be more appropriate to support the tactical task related to complex maneuver. We also conclude that gender is an important issue to be considered at map scale selection.

To improve usability of RGNS in terms of drivers' distraction, it is recommended that map scale should be set up considering a proper balance between spatial information about route and amount of information required for the next maneuver. Moreover, it is recommended to adopt scale according to complexity of maneuver.

We suggest that future studies explore deeper the relationship between drivers’ performance and their gender, since this group characteristic has influenced the amount of time that drivers spend with their eyes off-road to receive information from RGNS interfaces. We also suggested to associate visual demand with other objective measures, such as navigational errors, as well as with subjective measures such as drivers' satisfaction. These will help to estimate more accurately the drivers' mental workload related to driving and using in-vehicle route guidance and navigation system

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