In-Vehicle Information System Used in Complex and Low Traffic Situations: Impact on Driving Performance and Attitude

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Abstract. This paper describes a study where drivers' responses to an in-vehicle information system were tested in high and low density traffic. There were 17 participants in a study that was run using a driving simulator. Data was gathered for a comparison of how drivers react to an in-vehicle information system in low density traffic, complex traffic, and without system. Participants were also asked for their subjective evaluation of trust of the system and how they perceived it influenced their driving performance. Results show gender differences for both driving performance and attitude.

Keywords: Driving simulator, traffic density, in-vehicle system, cognitive load, trust, driving performance.

1 Introduction

Drivers use cognitive resources for attention, memory and decision making while driving. Complex traffic situations and unfamiliar road designs require additional resources. The measurement of cognitive resources in use while driving (cognitive workload) involves assessing how much mental effort an individual expends. This can be obtained by assessment techniques based on behavioral measures, performance measures, and self reported perception of mental effort load [1]. The concept of cognitive abilities and cognitive workload are important for the driving task, since even the smallest distraction or diversion of cognitive resources can have disastrous effects [2]. Interactions with in-car information systems (a secondary task) require cognitive resources and can distract from the primary task of driving task regardless of the intent of the system[2, 3].

Cognition is the processing of information from around us and includes perception, attention, pattern matching, memory, language processing, decision making, and problem solving. The conventional definition of cognitive load is the amount of mental resources needed to perform a given task [4-6]. User interfaces are no exception and all types, speech based, displayed based or tactile, make cognitive demands on their users. Confronted by a user interface, people must learn new

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concepts, retain information in short-term memory and learn the rules of the system. They must create and refine a mental model of the system and how to use it. In particular systems that use purely speech based interfaces places even more challenges on memory and attention. Information presented in speech is serial and non-persistent[7].

Successful speech based interface designs for vehicles must consider the limitations of human cognitive processing. An interface should not require users to hold too many items in short-term memory and they should not require users to learn a complex set of commands too quickly. In particular, there are three design challenges to consider for a speech based interface:

1. *Complexity*: How complex are the rules and commands and mental model that the user is required to learn? Is it familiar or a totally new concept?
2. *Memory load*: Are users required to hold information in their short-term memory? How much new commands and procedures do they have to learn?
3. *Attention*: The user's attention will be divided since the primary task is driving. If they are distracted, can they continue their interaction with the system when they are ready to do so? Is it easy for the user to attend to the most important information?

For the study described in this paper we consider attention, since this is the process of selecting what to focus on (if there are multiple possibilities available). The way that information is presented to users can have a significant effect on how they attend to the information[8, 9]. It is important to keep in mind the user's goals, priorities, and decision criteria. This makes it possible to optimize the presentation of information and not challenge the user's ability to attend to more important tasks.

All in-vehicle information systems require divided attention, and situations might arise that demand the driver's focused attention. In-vehicle systems must accommodate this need by providing the driver with control over the pacing of the interaction. Drivers might exert such control by using a pause/resume feature, or by a longer silence, after with the system clarifies the conversational context so that the driver can continue with the dialog. Rinalducci, Mouloua, and Smither [10] investigated the interaction between perceptual and cognitive abilities and driving. They studied three age groups, 19-34, 35-59, and 60 years and older. Their results show that young drivers have a reserve of cognitive resources to be tapped into when needed, and that this reserve diminishes over time. Older drivers have fewer resources to spare for other activities. Young drivers can deal with multiple pieces of information, whereas older drivers tend to focus on one source of information [11]. Rabbit [12] found that older drivers are more distracted by irrelevant information than young drivers.

To learn more about when, in what situations, and for which age-groups, an in-vehicle information system is most useful; we decided to design a study. In particular, we wanted to investigate the usefulness of in-vehicle information system during different traffic densities. This paper presents a study that compares how driving performance and attitude is affected by information from an in-vehicle information system in complex traffic and low traffic situations. It is interesting to see how information from an in-vehicle system is perceived during situations of complex traffic where one would hope the system would be most helpful. This is compared to how the system is perceived during low traffic situations. The experiment was conducted using a driving simulator to avoid potential dangerous situations while driving in real traffic.

2 Experimental Method

The study was designed to investigate how drivers react to spoken information and suggestions presented from in-car information systems during high traffic and during low traffic. In particular to track changes in behaviors and changes in driver state in relation to simple or complex traffic events. Would the system seem more helpful and useful in complex traffic situation or while driving in areas with little to no traffic?

The study also enabled us to investigate the effect of context, and constancy and how drivers react to information from the speech system during driving induced load (complex traffic situations), no load (simple to no traffic), and when the system simply omitted to provide any information.

2.1 Traffic Events and Driving Environment

To enable replication of the study in different locations, the study design took into consideration regional and cultural differences with respect to complex traffic events such as traffic circles and "right-of-way" regulations. This study would benefit from being run with different age groups, results from previous studies show that older adults react favorably to information from in-vehicle systems [13, 14]. It is important, especially when testing older age groups, to make sure to include a test battery of cognitive abilities and mobility in the pre-screening. For younger age groups this would be helpful, however, we did not consider it necessary since the participants were all University students.

We selected the following five traffic events to be used for the study since they are relatively unbounded:

1. Left Turns for right hand side driving and Right Turns for left hand side driving
2. Overtaking
3. Merging
4. Crossing busy intersection

These traffic events were repeated and used in the driving course for the study.

2.2 Experimental Design

Within-subjects experiment design was used, where all participants experienced all conditions. All participants were randomly assigned from the age group 18-25 (10 male and 7 female). They were all university students, pre-screened to have a valid driver license.

A 60,000 ft driving course was especially designed for the study containing randomized placement of multiple instances of the four selected traffic events. The four traffic events were combined with complex traffic or low density traffic and form the study conditions. Please see table 1 for a description of the 8 conditions based on a 4x2 (traffic events x traffic density) table.

Table 1. Conditions for the study (Traffic event X traffic density)

Condition	Light Traffic	Heavy Traffic
A	Left Turn/Right Turn	
B		Left Turn/Right Turn
C	Overtaking	
D		Overtaking
E	Merging	
F		Merging
G	Crossing/Stop&Go	
H		Crossing/Stop&Go

With four repetitions of each condition, the driving course contained in total 32 traffic events. These were placed at randomized intervals throughout the driving course.

Table 2. Order of Repeated Traffic Events (Conditions)

F	D	G	E	B	A	H	C
C	A	D	B	G	F	E	H
B	H	C	A	F	E	D	G
A	G	B	H	E	D	C	F

The in-vehicle information system was designed to give information about the upcoming traffic situation for half of the traffic events, balanced across conditions. The locations for the omitted prompts were randomly selected. The result was an in-vehicle system that contained 16 information prompts, 2 for each condition.

The driving simulator used in the experiment was STiSIM from Systems Technology Inc. Participants were driving for approximately 25 minutes, and they sat in a real car seat and 'drove' using a Microsoft Sidewinder steering wheel and pedals consisting of accelerator and brake. The simulated journey was projected on a wall in front of participants and was set to daylight and sunshine. The simulator was instrumented to automatically record driving performance parameters. While driving, the in-vehicle information system offered advice and suggestions at selected traffic situations as described above. The informational prompts of the system were recorded by a female voice talent in a calm and non-emotional voice. Typical prompts used by the system were "There is road work head, merge left", "Right lane is closed ahead, merge left", and "There is a busy intersection ahead".

The design of the study enabled us to collect data for comparisons of driver reactions in three different situations:

1. Responses in Light and Heavy Traffic
2. Responses when assisted by the in-vehicle system
3. Responses in Light and Heavy Traffic when assisted by the in-vehicle system.

2.3 Measures

There were three sets of measures derived from the collected data; prior driving experience, driving performance and attitudinals. All attitudinal measures are indices derived from questionnaire data by using factor analysis. The reliability of the derived indices are then verified by Cronbachs alpha.

Prior driving experience: Information about participants' real life driving experience was collected as part of the first questionnaire. Participants were asked to self report how many years they had been driving, the number of miles they typically drive per week, the number of accidents they had had, and the number of citations they had received.

Driving Performance: The simulator, STISIM Drive, automatically generated and gathered a large variety of data on driving behavior. In this study, we focus on five measures for the most dangerous behaviors: number of collisions, number of off-road accidents, swerving, and obedience to the most important traffic laws (adherence to traffic lights, stop signs and speed limits). The three measures were uncorrelated.

All of these negative behaviors are much more common in a driving simulator than in actual driving; indeed, we would be startled to find even two occurrences of these behaviors if the experiment involved real drivers. One key reason for dramatically higher rates in simulator studies is that we create extremely difficult courses so that we can find variance in driving performance: A simple course would fail to generate any variance in poor driving behavior.

State when driving with the In-vehicle Information System: The self-report of state when driving with the in-vehicle information system was an index based on terms that were rated using 10-point Likert scale [15] (1 = Describes Very Poorly to 10 = Describes Very Well). Participants were asked "How well do the following words describe how you felt when driving with the in-car information system?" We created an index based on factor analysis that included the following terms: I felt calm driving, I was at ease driving, I felt content driving, I felt comfortable driving, I felt confident driving, I was relaxed driving, I felt secure driving and I felt indecisive driving reverse coded. The index was very reliable (alpha = .95)

Trust of the in-car information system: In general, one can distinguish trust and credibility even though these two concepts are linked. When a source is considered trustworthy, or better when an individual trusts a particular source, it is more probable that this individual will accept pieces of knowledge (beliefs) coming from that source. Trustworthiness is a property of a source while credibility should be considered a property of a piece of information.

The questionnaire focused on trust and contained items from the Individualized Trust Scale [16]. All of these scales are based on pairs of adjectives which anchor seven-point Likert scales. The pairs of adjectives are antonyms. We created an index based on factor analysis with the following items: dangerous-safe, distrustful-trustful, trustworthy-untrustworthy, not deceitful-deceitful, reliable-unreliable, honest-dishonest. The index was very reliable (alpha = .73).

Perceived influence of the In-vehicle Information System: The perceived influence of the in-vehicle information system was an index of terms rated using 10-point Likert scales (1 = Describes Very Poorly to 10 = Describes Very Well). Participants were asked "How well do the following statements describe the in-car information systems influence on your driving?" We created an index based on factor analysis with the following terms: I was a more alert driver, I drove more carefully, I was a safer driver, I was a more confident driver. The index was very reliable (alpha = .79)

Perceived Usefulness of In-Vehicle System: Participants were asked two post – experiment questions before debriefing 1) did they think that the system was most useful in complex traffic situations, in low traffic situations, or in both, 2) did they want the system turned on or off.

3 Results

The effects of the in-vehicle information system, when used in a driving simulator, on attitude and driving performance were evaluated by a one-way ANOVA with gender as the between-participant factor. Significant results are indicated in ***bold and italics***.

3.1 Prior Driving Experience

Data shows that there were no major differences between the participants' prior driving experience, except that female drivers often drove with passengers in the car as opposed to male drivers that more often drove alone (see table 3). When asked where they normally drive, most participants listed Motorway and Urban, as their normal drive scene.

Table 3. Prior Driving Performance

	Gender	Mean	Std Dev	F	Sig.
Age	Male	24.90	2.64	1.59	.23
	Female	28.29	7.97		
Years of Driving	Male	5.5	1.72	1.38	.26
	Female	4.29	2.56		
Accidents	Male	1.3	1.57	1.27	.28
	Female	.57	.79		
Tickets	Male	.60	.97	1.39	.26
	Female	.14	.39		
Passenger	***Male***	***2***	***.47***	***5.4***	***.03***
	Female	***2.6***	***.54***		

3.2 Driving Performance

For overall driving: that is the average for the entire driving course, a factor analysis of all driving performance parameters found one reliable index, **bad driving**. This index consisted of “collisions”, “stop sign tickets”, “centerline crossings”, “road edge excursion”, and “speed exceedances” reverse coded. It is interesting to note that female drivers showed worse overall driving performance for the “bad driving” index than male drivers, see table 4.

Table 4. Driving Performance

		Mean	SD	F	Sig.
Bad Driving	***Male***	***32.1***	***8.57***	***4.63***	***.05***
	Female	***43.0***	***12.31***		
Bad Driving High Traffic	Male	15.20	6.42	2.59	.13
	Female	19.86	4.91		
Bad Driving Low Traffic	Male	7.9	2.93	3.58	.08
	Female	12.6	7.1		
Bad Driving With System	Male	10.2	2.25	.140	.71
	Female	10.6	2.05		
Bad Driving Without System	***Male***	***11.5***	***5.33***	***7.22***	***.02***
	Female	***18.14***	***4.48***		

For driving performance in both complex and low traffic situations, the data shows no significant differences between male and female drivers on the ‘bad driving” index, see table 4.

Looking at the data on driving with the in-vehicle system and driving without the system, there are significant differences. Female drivers once again show significantly worse driving performance driving without the system. There are no differences between female and male drivers in the “bad driving” index when driving with the system. It is however interesting to note that the difference in “bad driving” disappears when driving with the system, see table 4.

There are no significant differences between female and male drivers listening to the system in complex traffic situations. Once again the data show almost no difference in “bad driving”, see table 5. Similarly, there are no significant differences between male and female drivers when driving in low traffic and non-complex situations with the system. There is however a trend in the data that shows female drivers as worse drivers.

It is interesting to note that while there is virtually no difference in complex traffic situations, female drivers perform much worse than male drivers in low traffic situations with the system, see table 5.

The data show that there are no significant differences between male and female drivers on the “bad driving” index when driving without the system in complex traffic situations, see table 5. On the other hand, when driving in low density traffic, there is a significant difference in driving performance between male and female drivers. Female drivers once again show much worse driving performance in low density traffic, this time driving without the system see table 5.

Table 5. Driving Performance Traffic Density X Speech System

		Mean	SD	F	Sig.
Bad Driving High Traffic With System	Male	7.1	3.38	1.01	.330
	Female	8.86	3.76		
Bad Driving Low Traffic With System	Male	7.3	2.36	3.95	.07
	Female	9.5	1.98		
Bad Driving High Traffic Without System	Male	6.9	3.3	2.78	.12
	Female	9.3	2.1		
Bad Driving Low Traffic Without System	***Male***	***6.8***	***2.25***	***6.01***	***.03***
	Female	***10.4***	***3.15***		

Interesting trends to note in the data are: female drivers definitely drive worse overall, and especially when driving without the system. These differences seem to be exaggerated when driving in low density traffic, see tables 4 and 5.

3.3 Drivers Perception of the In-Vehicle System

Participants self-reported on how they felt while driving with the in-vehicle system. The index for "Calm and Relaxed while Driving" and the data show that female drivers felt significantly calmer and more relaxed driving with the system, see table 6.

Table 6. Influence of In-Vehicle System

		Mean	SD	F	Sig.
Calm and Relaxed	***Male***	***42.89***	***13.48***	***5.35***	***.04***
	Female	***57.97***	***12.86***		
Trust of System	***Male***	***28.86***	***8.87***	***7.31***	***.02***
	Female	***40.81***	***9.11***		
Positive Influence of System	***Male***	***13.37***	***6.68***	***5.89***	***.03***
	Female	***21.76***	***7.49***		

The index for "trust of the in-car information system" clearly shows that female drivers trusted the system more than male drivers, see table 6. This is a finding that confirms previous simulator studies with in-vehicle systems [14, 17-19], female drivers tend to appreciate speech systems in cars more then male drivers.

Participants were also asked to rate the influence of the in-vehicle system on their driving performance and driving experience. The data shows that female drivers perceived the system to have a more positive influence on their driving performance, than male drivers, see table 6.

Finally, we asked participants if they thought the system more helpful in low or high density traffic and if they would have the system turned on in their cars. Male drivers wanted the system to be mainly turned off, but could see potential of having the system turned on in low traffic situations to alert them of upcoming traffic events. They did not like the system in high traffic situations, and thought that it distracted them from focusing on the driving task. Female drivers, on the other hand, wanted the system turned on and found the system useful in both high and low traffic situations.

4 Conclusion

Data shows clearly that the in-vehicle information system, tested in this experiment, was perceived to be more helpful in low traffic situations than in high traffic. This is confirmed by both driving performance data and questionnaire data. It is also clear that female drivers would benefit the most from this type system. The data shows a significant improvement in driving performance when the system is in use, and female drivers felt more calm and relaxed when driving with the system than did male drivers. This confirms previous studies that show the same; female drivers tend to like in-vehicle information systems more than male drivers [14, 17-19]. Female drivers also perceived that this system had a positive influence on their driving performance.

There are still many open questions related to this research; How would other age groups react to this type of in-vehicle system? Would there be a different reaction using a male voice? What other linguistic and para-linguistic cues might influence perception and performance? What would be the reaction to a dialogue system, interactive system? What is the long term reaction to this type of system? What is needed for the system to build trust instead of becoming annoying? These and many more questions need to be investigated for a better understanding of how in-vehicle systems impacts driving performance.

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