The Impact of an Adaptive User Interface on Reducing Driver Distraction

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ABSTRACT

This paper discusses the impact of an adaptive prototype in-car communication system (ICCS), called MIMI (Multimodal Interface for Mobile Info-communication), on driver distraction. Existing ICCSs attempt to minimise the visual and manual distraction, but more research needs to be done to reduce cognitive distraction. MIMI was designed to address usability and safety issues with existing ICCSs. Few ICCSs available today consider the driver's context in the design of the user interface. An adaptive user interface (AUI) was designed and integrated into a conventional dialogue system in order to prevent the driver from receiving calls and sending text messages under high distraction conditions. The current distraction level is detected by a neural network using the driving speed and steering wheel angle of the car as inputs. An adaptive version of MIMI was compared to a non-adaptive version in a user study conducted using a simple driving simulator. The results obtained showed that the adaptive version provided several usability and safety benefits, including reducing the cognitive load, and that the users preferred the adaptive version.

Categories and Subject Descriptors

H.5.2 **[Information Systems]:** Information interfaces and presentation – user interfaces, evaluation/methodology.

General Terms

Measurement, Performance, Design, Experimentation, Human Factors.

Keywords

Adaptive user interface, driver distraction, in-car communication systems, neural networks, workload manager.

1. INTRODUCTION

In-car communication systems (ICCSs) form a part of embedded systems, called in-vehicle information (or infotainment) systems. In-vehicle information systems provide secondary services in parallel with driving, which is the primary task. Drivers and passengers often listen to music, use maps or navigation devices and use their phones to make and receive calls and send text messages. ICCSs deal only with communication services, such as making calls and sending text messages. Today, ICCSs are becoming a common feature in many cars.

Driver distraction may occur when the driver is engaged in secondary tasks such as texting or calling whilst driving. The legislation of several countries forbids the use of a mobile phone whilst driving. However, the use of hands-free systems, such as ICCSs, is legal [3].

Spoken Dialogue Systems (SDSs) are often used to facilitate the interaction with ubiquitous applications, especially in a car. These systems are sometimes criticised in terms of the high rate of speech recognition errors due to ambient noise and privacy issues. This can lead to an increase in the driver workload. ICCSs using multimodal interfaces (e.g. speech and steering wheel buttons) have attempted to address this issue by preventing or recovering from recognition errors as one modality can compensate for errors from another modality.

Current ICCSs do not take into account difficult driving situations such as changing lanes, overtaking or taking a corner. Adaptive interfaces, which adapt according to the current driving situation, can be useful to minimise the driver distraction [6].

The aim of this paper is to discuss the design and evaluation of an adaptive user interface for an ICCS, called MIMI [18]. The paper proposes a model to infer difficult driving situations, which can be used as a guideline to design safer ICCSs. MIMI supports speech and steering wheel input to make calls and send text messages, using speech output. The aim of this paper is to investigate the impact of the adaptive interface on reducing driver distraction when using an ICCS. A user study was conducted to compare a non-adaptive version of MIMI to an adaptive version.

This paper is structured as follows: related work is discussed in Section 2, which includes ICCS, driver distraction and adaptive interfaces. Section 3 reviews the architecture and design of MIMI. Section 4 discusses the design of the user study that was used to compare the adaptive version of MIMI to the non-adaptive version. The results of the user study are presented in Section 5 and a discussion of these results is contained in Section 6.

2. RELATED WORK

The design of an interface for an ICCS was based on work done in several research areas. The following sections discuss ICCS, driver distraction and adaptive interfaces.

2.1 In-Car Communication Systems

ICCSs are software systems developed to handle all communication-related tasks in vehicles. They are included in broader in-car software systems called in-car infotainment systems. Infotainment systems often include the following sub-systems [17]:

- *Navigation system*: Provide directions and points of interest on a map. Free-standing navigation systems

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often use a different microphone and speaker which can interfere with the entertainment system or vice versa;

- *Car information*: Information, such as petrol level, traffic conditions, weather, stock, and petrol prices can be shown;
- *Safety information*: Emergency messages can be sent in case of an accident (e.g. General Motors' OnStar [4]);
- *Communication*: Address book information is retrieved and used to build a proper grammar for the speech recognition engine. This allows the driver to efficiently make calls and send text messages whilst driving; and
- *Entertainment* (CD and radio): Media data (title, artist, album, genre and track) is retrieved from the CD or the music device connected to the system. The radio can be tuned by selecting a radio name or a frequency.

Several types of interfaces are often used when designing ICCSs namely graphical user interfaces (GUIs), speech user interfaces (SUIs) and multimodal user interfaces (MMIs).

2.2 Driver Distraction

Driver distraction occurs when the driver's attention is diverted away from the driving task by an event or an object to the extent that the driver is no longer able to perform the driving task adequately or safely [21]. An external event could be an incoming call or text message. Studies on driver distraction distinguish three main types of distraction, namely visual, manual and cognitive distraction:

- **Visual distraction** occurs when the driver neglects to look at the road and rather focuses on another visual target for an extended period of time [22].

- **Cognitive distraction** includes any thoughts that absorb the attention of the driver [22]. This can prevent the driver from being able to navigate safely through the road network and reaction time may be reduced.

- **Biomechanical or manual distraction** occurs when a driver removes one or both hands from the steering wheel to physically manipulate an object instead of focusing on the primary task which is driving safely. Effects of manual distraction include steering in the wrong direction or not changing gears. Tasks such as sending a text message are a major source of manual distraction.

A study carried out by the Monash University Accident Research Centre [5] shows that sending an SMS is more distracting than simply talking on a mobile phone. When using a mobile phone whilst driving, drivers experience divided attention. Their performance in driving and using the mobile phone depends on the difficulty of the task. This explains why sending a text message seriously affects the ability to drive safely. Drivers intuitively adopt an adaptive behaviour in order to perform a secondary task whilst driving. A similar approach can be used to address cognitive distraction when designing an ICCS. Existing ICCSs also have some usability issues which make them difficult to use. A natural dialogue structure and sufficient feedback can help to minimise most usability issues found in existing ICCS [17].

Several variables can be used to measure driver distraction. These variables include lateral deviation, driving errors, cognitive load and the ability to effectively perform the secondary task (e.g. sending a text message). The ICCS's usability can also influence the driver distraction. Tasks such as sending a text message require the driver's full attention and can cause manual, visual and cognitive distraction.

2.3 Adaptive User Interfaces

Adaptive user interfaces (AUIs) are interfaces that are able to adapt to a specific user, provide feedback about the user's knowledge and predict the user's future behaviour, such as answers, goals, preferences and actions [8]. Adaptive systems also include systems that detect common user tasks and make these tasks more accessible. Making lists of recently-opened files is a simple example of this. The adaptation does not only depend on the user, it can also depend on the context of use, the task to be performed and the device [12].

Cognitive workload, user performance and situation awareness can be used to trigger an adaptation effect. User performance can help to establish a profile, e.g. whether the driver is a novice or an expert. This profile can be determined using variables such as the reaction time, lateral acceleration and lateral position.

Cognitive workload and situation awareness are correlated since difficult driving situations imply more attention from the driver and therefore an increase in cognitive workload.

In a mobile scenario, such as a car, these adaptation factors can be inaccurate. Artificial neural networks can be used to infer the distraction level, because they are able to handle noisy data with success. Fuzzy logic could also give accurate results as an inference mechanism for ICCSs. Models based on neural network (NN) have been successfully used to predict intersection crashes [1].

Several adaptation effects have been used for adaptive interfaces in cars. These include postponing, resuming, cancelling calls and text message notifications [9], sending messages to callers and putting the calls on hold [6].

3. MIMI: AN ADAPTIVE ICCS

The design of MIMI excluding the adaptive module was discussed in [18]. In the adaptive version, an adaptive module was added in order to detect dangerous driving situations. The design and implementation of MIMI are briefly reviewed here together with a discussion of the adaptive module and the neural network used to infer the current driving situation..

3.1 Architecture and Design of MIMI

The architecture of MIMI consists of four modules which are seamlessly interconnected (Figure 1). The input module (A) contains the speech engine which receives and processes spoken utterances from the driver. The recognised words or phrases are sent to the natural language understanding module in order to attach a meaning to them. The result is then sent to the multimodal fusion sub-module. The steering wheel button events are captured and sent to the multimodal fusion sub-module. Then inputs from the two channels are combined using a frame-based fusion technique [11].

The dialogue management module (C) is comprised of the dialogue engine and the adaptive module (see Section 3.2). The dialogue engine manages the flow of the dialogue between MIMI and the driver. This process consists of turn-taking, grounding and clarification. The turn-taking decides whether MIMI or the driver should take the lead in the dialogue while the grounding ensures that the information received by MIMI matches the information given by the driver. Finally, questions are asked to clarify information in the case of ambiguity. A frame-based approach was used to implement the dialogue engine. The mobile phone interface (B) manages all interaction with the actual phone. Attentional commands are sent to initiate calls and send text messages while incoming events are captured by the mobile phone interface's module.

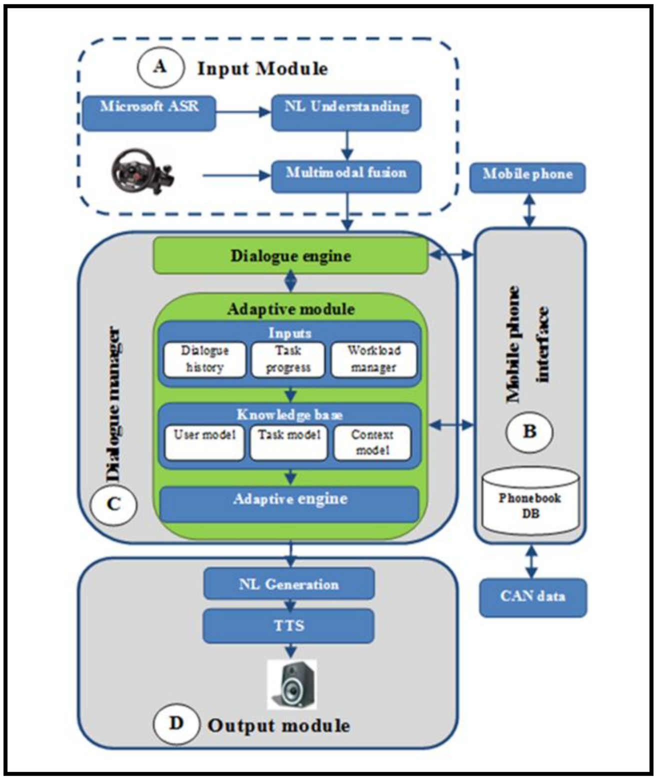

Figure 1. Architecture of MIMI [5].

The output module (D) is comprised of two sub-modules: the natural language generation (NLG) and the text-to-speech (TTS) [16] synthesiser. The NLG rearranges and prepares the data to be presented to the TTS for output.

3.2 Adaptive Module

In Figure 1, the module responsible for the adaptation is the adaptive module. The following subsections discuss how the distraction level is determined, how the system was trained and what adaptation effects are provided.

3.2.1 Determining Distraction

An artificial neural network (NN) is used to determine the current level of distraction. The accuracy of a neural network depends on a number of factors: inputs, outputs, the neural network architecture, the training technique and the choice of training data. As shown by Figure 2, the inputs of the NN are speed, speed variation, the steering wheel angle and its variation. Several studies have shown that a large number of vehicle accidents occur due to driving at high speeds [15]. Moreover, critical driving situations such as lane changing, overtaking, reversing and turning are also affected by a change in speed. In this implementation, the speed can range from 0 to 300 kilometres per hour. The steering wheel angle ranges from -180 to 180 degrees. Both variables can be obtained in a real car through the controlled area network (CAN).

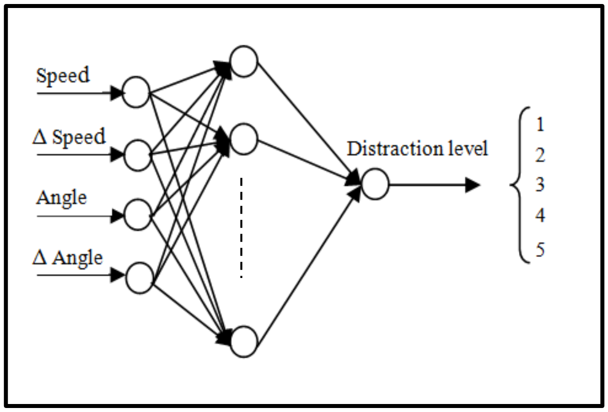

Figure 2. Neural network that determines the driver distraction.

The NN is designed as a Multi-Layer Perceptron: it has three layers of neurons, the input, the hidden and the output layer [2]. The output layer consists of a single neuron that represents the distraction level. The distraction level is ranked as very low (1), low (2), mid (3), high (4) or very high (5). The sigmoid function is used to compute each neuron output for both the hidden and the output layers.

3.2.2 Training

A supervised learning technique was used to train the workload manager. The back propagation algorithm [2] was used to compare the differences between the calculated output and the target in order to adapt its weights towards a minimal global error. The effectiveness of a neural network trained by back propagation strongly depends on the reliability of the training set. Possible signs of driver distraction including slowing down in speed, sudden braking, number of collisions or the ability to keep a lane [7], are recorded and associated with the corresponding distraction level.

The data collection was conducted in a laboratory environment using the Lane Change Task (LCT) driving simulator [13]. A data collection module was implemented to collect driving context variables together with the user's distraction level. A connection was established between the PC running the simulator and the laptop running the data collection module through the LAN (Figure 3). The data collection module captured and recorded the speed and the steering wheel angle associated with the distraction level each time the user was prompted to provide it.

Ten users participated in the data collection in which they were asked to drive and follow instructions to change lanes. A "beep" sound was generated every fifteen seconds to prompt the participant to provide the current distraction level. The users had to provide their perceived distraction level ranging from 1 to 5, where a distraction level of 1 represented a very low distraction, and 5 represented a very high distraction level.

A hundred observations were recorded for each participant. This resulted in one thousand observations in total. A supervised training technique was used to adjust the weights [2]. Random weights were generated and then a distraction level was calculated with these weights. The differences between the calculated weights and the targeted weights were used to adjust the weights. This process was repeated for all the items in the training set.

After the adjustment of weights in the neural network, a test was performed to validate the set of weights obtained. The validation consisted of using the neural network with the untrained data in the testing set. The workload manager was trained and tested several times until a score of 75% of well-recognised untrained data was obtained. The distraction level was grouped into three categories: low (1, 2), medium (3) and high (4, 5). This was to address potential classification errors from the neural network.

3.2.3 Adaptation Effects

The adaptive interface is intended to adapt to the current driving situations. The goal of the adaptive system is to avoid interrupting the driver in dangerous situations. The adaptation effects therefore do not include the conversation itself.

When the dialogue manager (DM) receives a call or a text message under a distraction level greater than 3 (medium), the incoming call is postponed. When the distraction level returns to 1 (very low), the DM resumes the dialogue. Given the errors that might occur when determining the distraction level, it was safer to wait for the distraction level to return to 1 before notifying the driver of any incoming event. Warning sounds were produced when outgoing communication events were attempted under high distraction conditions. However, the driver was left the choice of whether to continue or stop the communication task.

4. USER STUDY

A user study was conducted to investigate the impact of the adaptive user interface on the driver distraction. The adaptive system was compared to the non-adaptive version of MIMI. The comparison was done in terms of usability and safety metrics. The experiment was designed using a within-subjects approach with counterbalancing whereby each participant had to use the two versions of MIMI in a different order. A low cost driving simulator [20] was setup and used. The aim and the design of the experiment are discussed in the following subsections.

4.1 Aim of the Study

The goal of the user study was to identify potential benefits obtained from using an ICCS with an adaptive interface. Similar to several automotive interface evaluations, the experiment was conducted with a driving simulator so as to better simulate a real driving context. Both incoming and outgoing tasks were performed by participants in order to compare different aspects of the two systems.

The following metrics were captured:

a) **Usability metrics:**
  - **Task success** (performance): whether the participant successfully achieved the task;
  - **Errors** (performance): number of errors while performing the secondary task;
  - **Effectiveness of tasks** (self-reported): whether the participant felt that the task was successfully completed;
  - **Time on task** (performance): the time spent while performing a task;

b) **Safety metrics:**
  - **Mean lateral deviation** (performance): the difference between the path that the driver was expected to follow and the actual path which was followed. The mean lateral deviation has been used in several similar studies to measure the driving distraction [14, 19];
  - **Cognitive load** (self-reported): the cognitive load represents the amount of effort that the driver experienced while performing tasks. The NASA TLX questionnaire was used to capture this metric;
  - **Cognitive assessment** (self-reported): the ability of participants to remember the callers' names and the topics of the text messages received. This uses the driver's attention and may be cause unsafe driving;
  - **Perceived safety** (self-reported): the feeling of being free from danger and risk; and
  - **Adaptation** (self-reported): whether the participants noticed the adaptation effects of MIMI.

4.2 Methodology

The methodology used in the experiment is discussed in the following sections. This includes the selection of the participants, the apparatus, the procedure, the tasks performed and the metrics used to compare the two versions of MIMI.

4.3 Selection of Participants

Thirty (30) volunteers were recruited and completed the user study. Half of the participants were male (15) and the other half were female (15). Most participants (83%) were between 18 and 24 years old and the remainder (17%) were between 25 and 39 years old. Knowing that younger drivers are more likely to use their phone whilst driving, focusing on this group will provide knowledge on the impact of the adaptive approach. Half of the participants (15) had English as their first language; 17% had Afrikaans as their first language; 10% had Xhosa as their first language; while the remaining 23% spoke another language.

Table 1. Distribution of participants according to driving, gaming and ICCS experience (n=30).

	n
Driving	
I have a driver's licence	**21**
• I drive for less than 5 hours a week	10
• I drive between 5 and 10 hours a week	9
• I drive between 11 and 20 hours a week	2
• I drive for more than 20 hours a week	0
Gaming	
I play computer games	**27**
• I play for less than 5 hours a week	22
• I play between 5 and 10 hours a week	4
• I play between 11 and 20 hours a week	1
• I play for more than 20 hours a week	0
ICCS experience	
I know what ICCSs are	**27**
• ICCS are safe	24
• I have used an ICCS before	3

Table 1 shows what previous knowledge participants had about driving, gaming and the use of ICCSs. Ninety percent (27) of participants had played a computer game before, although most of them played for less than 5 hours a week. Seventy percent (21) of participants had a valid driving licence, although most of them drove for less than 20 hours a week. Ninety percent of participants knew what an ICCS was and eighty percent (24) thought they were safe when used together with driving. Only ten percent (3) of participants had used an ICCS before the experiment.

4.4 Apparatus and Procedure

A literature survey identified several methods used to evaluate ICCSs ranging from laboratory testing to naturalistic driving. To conduct the user testing, we developed a low-cost driving simulator whose level of fidelity can be compared to a custombuilt research simulator [20]. The software used to simulate the driving and record data for this experiment was the Lane Change Task (LCT) test [13]. This simulation software has been used in several research projects [19] to evaluate driver distraction. A Logitech steering wheel and pedals were connected to a PC running the driving simulator (Figure 3). A laptop running the two versions of MIMI was connected to the PC via a LAN. This LAN connection was established in order to transfer the driving speed and the steering wheel angle of the simulated car which was captured by an application running with the LCT.

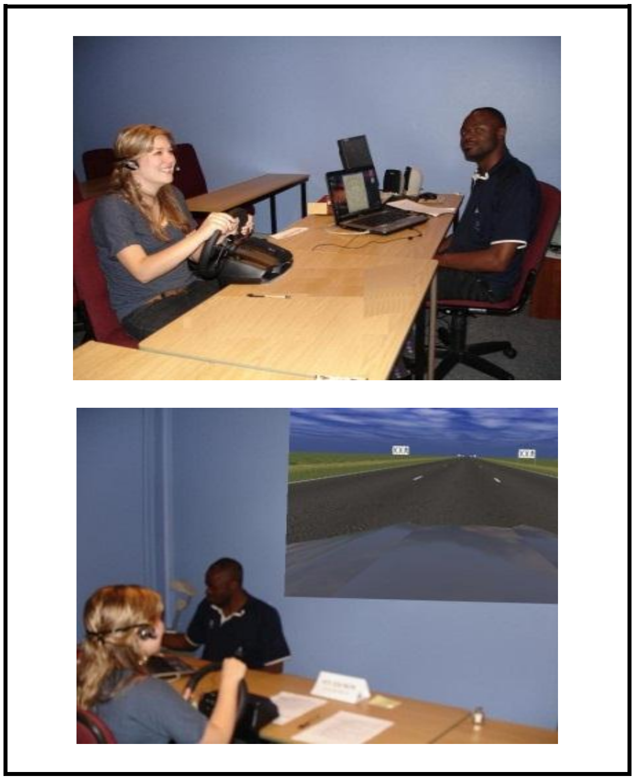

Figure. 3. Apparatus used for the user study.

A microphone (earphone) connected to the laptop was used to capture the speech. Speakers connected to the PC were used for the sound of the engine. A video projector was used to display the content of the screen on the wall; in order to create a more realistic test environment.

Prior to the beginning of a test session, the participant was welcomed in the laboratory and the purpose of the study was presented. Each participant was required to sign a consent form and completed a biographical information form. A demonstration on how to use the simulator and follow instructions to change lanes was presented to the participant. A second demonstration on how to use the steering wheel buttons and the microphone to make calls and send text messages was presented. The participant then started by driving on a full track without performing any tasks (single-task baseline). Then the participant started performing the tasks using the first system (dual-task). After the tenth task, the participant was asked to complete a post-task questionnaire. Then an equivalent set of tasks using the second system was performed and another post-task questionnaire was completed at the end. Lastly, the participant completed a post-test questionnaire comparing MIMI 1 (non-adaptive) and MIMI 2 (adaptive) on five different aspects (adaptation, preference, context awareness, ease of use and safety). To add difficulty to the driving task, each task was performed on a different track which started on a left or a right bend. Each testing session lasted approximately one hour. Each participant received a gift voucher from a local entertainment centre.

4.5 Task List

All participants had to perform several tasks using both systems. The set of tasks performed for the two systems was equivalent but slightly different as the names and telephone numbers were different.

Table 2. List of tasks performed during the user study.

LIST OF TASKS	
T01	Please call John by saying “**Call John**”;
T02	Please answer the incoming call; - Press the “**CALL**” button **or** - Call back the caller;
T03	Please call the number 071 234 5678 - Say “**Call number**”; - Dictate the number and press the “**CALL**” button; - Say “**Yes**” to confirm the number;
T04	Please accept and read the incoming text message; - Say “**Yes**” to confirm;
T05	Please call the last outgoing number by saying: - **Redial** - Say “**Yes**” to confirm;
T06	Please answer the incoming call; - Press the “**CALL**” button **or** - Call back the caller;
T07	Please send the text message “Appointment postponed” to “John” by saying **“SMS John”**; - Say “**Yes**” to confirm the command; - Say “**Two**” to choose the second option;
T08	Please accept and read the incoming text message; - Say “**Yes**” to confirm;
T09	Please call the last incoming number or contact by saying: - **Call back**; - Say “**Yes**” to confirm the command;
T10	Please accept and read the incoming text message; - Say “**Yes**” to confirm;

Table 2 lists the tasks that were performed by each participant. These tasks were grouped into user-initiated tasks and system-initiated tasks. User-initiated tasks are outgoing communication events, that is, tasks where the user decides to issue a command and includes tasks such as making calls and sending text messages. System-initiated tasks are incoming events, that is, tasks that are not triggered by the user. Receiving calls and text messages are examples of system-initiated tasks. Both categories are useful to assess the ability of the adaptive module to perform the expected adaptations.

All system-initiated tasks were presented to the user while they were taking a corner. User-initiated tasks were performed after the start sign, on a straight road. This was done to add a complexity to system-initiated tasks in order to better assess the adaptation effects.

Users had the ability to use the “repeat” command to replay any system’s utterance that they did not hear properly. When dictating telephone numbers, users heard a “beep” sound after every sequence of digits well recognised.

4.6 Results

The results are presented in two sections, namely usability and safety. Graphs and tables showing the results are discussed.

4.6.1 Usability

In terms of usability, all categories received a positive rating (mean > 4.00) for the two versions. The adaptive version (MIMI 2) was rated slightly better than the non-adaptive version (Figure 4). The telephone number dictation task received the lowest mean ratings, due to speech recognition errors (4.47 for MIMI 1 and 5.07 for MIMI 2).

4.6.1.1 Errors and Success Rate

Some errors occurred when drivers attempted to dictate a telephone number. All tasks were completed successfully with few errors except for T03 (calling by dictating a telephone number). For this particular task, the mean of number of errors committed when using MIMI 2 was 7 while MIMI 1 scored 30. MIMI 2 had also an advantage in term of success rate which was 86.66% while MIMI 1 only scored 63.33%. When using MIMI 2, participants managed to successfully dictate a telephone number 27% more often than when using MIMI 1. When using MIMI 2, participants were 77% more accurate when dictating a telephone number.

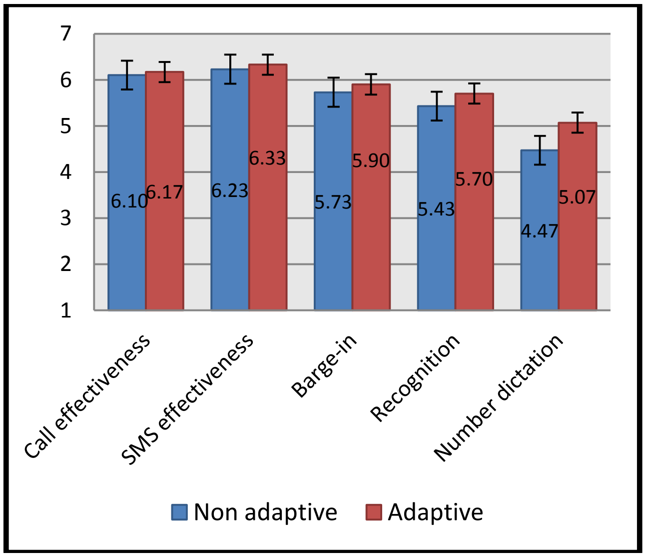

Figure 4. Comparison of the usability of the non-adaptive and the adaptive versions of MIMI (n=30).

4.6.1.2 Time on Task

A t-test analysis of the time on task, with a 95% confidence interval, revealed a significant difference between MIMI 1 and MIMI 2 for all system-initiated tasks (T02, T04, T06 and T08), except T10 (Table 3). Using MIMI 1 was faster that using MIMI 2 for these tasks. The reason for this was the postponement of the incoming calls or the text messages. For user-initiated tasks, although there was no significant difference between MIMI 1 and MIMI 2, the adaptive version (MIMI 2) performed better than the non-adaptive version during high distraction levels. Overall, the time on task for each task was low. Calling a number and sending a text message (T03 and T07) took more time than the other tasks. MIMI 2, on average, performed 15.65% faster than MIMI 1 when calling a number and 3% faster than MIMI 1 when sending a text message.

Table 3. Comparing the mean time-on-task (in seconds) for MIMI 1 and MIMI 2 (n=30).

	MIMI 1		MIMI 2		T-test
	Mean	**StdDev**	**Mean**	**StdDev**	**p value**
T01	11	19.02	14.5	19.98	0.16
T02	10	5.22	21.5	7.34	**0.00**
T03	36	34.8	40.5	34.47	0.78
T04	11	6.28	20.5	7.56	**0.00**
T05	11	12.75	10.5	8.79	0.88
T06	10	4.29	18	7.45	**0.00**
T07	23	12.09	22	12.57	0.78
T08	11	9.95	20.5	18.64	**0.05**
T09	7	10.91	7	11.01	0.97
T10	10	5.34	16.5	38.75	0.08

4.6.2 Safety

Safety metrics were obtained via the LCT Analysis software (mean lateral deviation) and a log file that recorded everything said by the driver and captured by MIMI (number of errors, number of tasks completed, time on task and success rate). The CSUQ questionnaire [10] was also used to obtain the perceived usability metrics.

4.6.2.1 Mean Lateral Deviation

The LCT simulator logged all data related to the movement of the car, including the time, speed, steering wheel angle, track, marker and gear. This data was saved on the hard drive at the end of the simulation.

Table 4. Comparing the mean lateral deviation (in meters) for MIMI 1 and MIMI 2 (n=30).

	MIMI 1		MIMI 2		T-test
	Mean	**StdDev**	**Mean**	**StdDev**	**p value**
T01	1.16	0.7	0.98	0.69	0.21
T02	0.94	0.49	0.87	0.43	0.18
T03	1.86	0.58	1.77	0.51	0.33
T04	0.99	0.45	0.95	0.43	0.68
T05	1.25	0.49	1.24	0.45	0.78
T06	1.05	0.56	0.84	0.53	0.52
T07	1.62	0.56	1.43	0.64	0.14
T08	1.13	0.5	1.02	0.4	0.28
T09	1.05	0.71	1.1	0.51	0.65
T10	0.96	0.63	0.79	0.48	0.47

Baseline data was captured for all participants during the single-task which consisted of driving the car while following the instructions on the road. For a distance of 3000m, a small lateral deviation (mean=2.50 m, median=2.15 m) was calculated.

The mean lateral deviation was calculated when performing tasks with MIMI 1 and MIMI 2 (Table 4). Although the p-values obtained when performing a one-tailed t-test with a 95% confidence interval on each task did not show a significant difference between MIMI 1 and MIMI 2, MIMI 2 generally performed better than MIMI 1. Participants managed to follow lane change instructions better when using the adaptive version of MIMI, as seen by the consistently lower lateral deviation values of MIMI 2 compared to MIMI 1.

4.6.2.2 Cognitive Load

The NASA TLX questionnaire was used to measure the participants' cognitive load. All the variables received a positive rating. For MIMI 2, the mental, physical and temporal demands were lower than MIMI 1 (Figure 5). In both cases, participants reported that it required some effort to accomplish their level of performance (mean = 3.63 for MIMI 2 and mean = 3.47 for MIMI 1). MIMI 2 (mean = 5.10) was found to be slightly less frustrating than MIMI 1 (mean = 4.93). Participants reported higher performance using MIMI 2 (mean = 5.67) than using MIMI 1 (mean = 5.47).

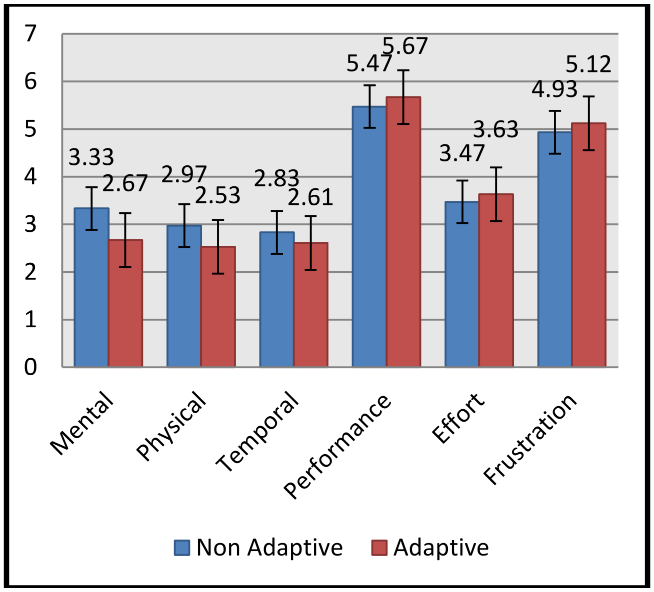

Figure 5. Mean of cognitive load (n=30).

Overall, in terms of cognitive load, using the adaptive version (MIMI 2) was found to be better than using the non-adaptive version (MIMI 1).

4.6.2.3 Cognitive Assessment

Participants were asked questions about the content of the messages that they received and the names of their senders. Most participants using both systems couldn't provide correct answers for half of these questions.

4.6.2.4 Perceived Safety

Participants rated the safety highly for both versions of MIMI (Figure 6). For all categories, the adaptive system (MIMI 2) received higher scores.

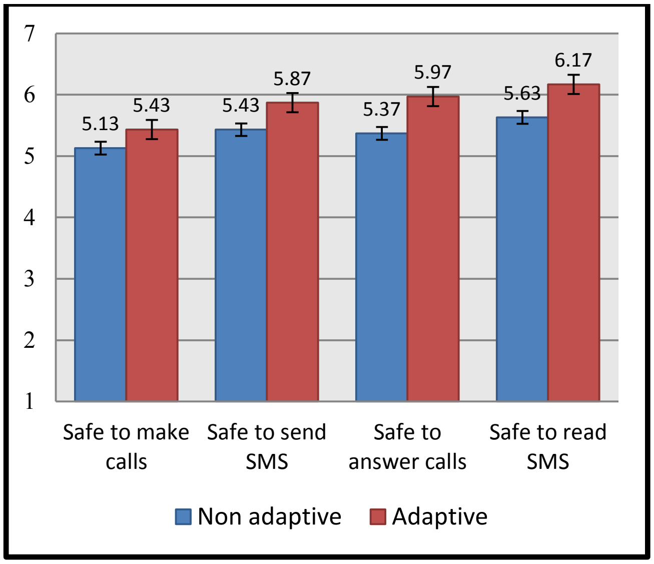

Figure 6. Comparison of the safety ratings of non-adaptive versus the adaptive version of MIMI (n=30).

4.6.2.5 Adaptation

Self-reported data were collected in several categories. This includes the noticeability of the adaptation effects and the overall post-test ratings.

Table 5. Comparing the adaptation of MIMI 1 and MIMI 2 (n=30).

	Postponing		**Warning sound**	
	MIMI 1	**MIMI 2**	**MIMI 1**	**MIMI 2**
Mean	4.76	5.80	4.80	4.80
Median	5.00	6.00	4.00	5.00
Mode	4.00	6.00	4.00	4.00
StdDev	1.87	1.45	1.56	1.65
p-value	**0.01**		1.00	

A t-test with a 95% confidence interval showed a significant difference (t (29), p=0.01) in favour of the adaptive version of MIMI (MIMI 2) in terms of event postponement (Table 5). Most system-initiated tasks were triggered when the driver was taking a corner (high distraction condition). The adaptive version delayed the call notification while the non-adaptive version notified the driver immediately.

5. DISCUSSION

Overall the results showed that participants preferred using the adaptive version of MIMI (MIMI 2). They felt more confident because they were not interrupted by the system at inappropriate times. The adaptation effect worked well for incoming events. However, most participants did not notice the warning sound that alerted them when they tried to make a call under high distraction conditions. This happened because participants were not told that such a feature existed. Another reason why the warning sound was not noticed is that several other sounds are generated by MIMI, including the "beep" sound which indicates successful recognition of a spoken command and this created confusion. Other high distraction conditions were not accurately recognised by the workload manager. For example, when participants changed lanes, the distraction level sometimes remained low. This was because the simulator used to train the workload manager does not support different driving scenarios. It was therefore difficult to improve the accuracy of the neural network. Better simulation software could help to improve the quality of the workload manager.

It is important to note that although the time required to perform system-initiated tasks, such as receiving incoming calls, was longer for MIMI 2 than for MIMI 1, the participants preferred using MIMI 2. This shows that the participants prioritised safety rather than performance.

6. CONCLUSION AND FUTURE WORK

The use of an ICCS in a driving context can be negatively affected by usability and safety issues. This paper has highlighted the impact of an adaptive interface on reducing driver distraction. MIMI assists the driver in making calls and sending text messages using speech input and output. A user study was conducted in order to identify the potential benefits of an adaptive interface for ICCSs. An adaptive version of MIMI was compared to a non-adaptive version in terms of safety, driver distraction and usability. The adaptive version of MIMI had better results than the non-adaptive version in terms of perceived safety and usability. The usability of both systems was rated positively, implying that the adaptive interface did not negatively affect the usability of the ICCS. Overall the adaptive version performed better than the non-adaptive version regarding lateral deviation and cognition.

Inferring the current driving situation was done using a neural network. The speed of the car and the steering wheel angle provided a good indication of the movement of the car. However, other difficult situations such as lane changing were not always recognised. Given the limitations of the driving simulator, the neural network could not be trained for different driving scenarios.

The distraction level was successfully determined using a neural network. The results of the user study showed that an adaptive interface can have a positive impact in a safety-critical application such as an ICCS.

Other adaptation effects will be investigated in future. Alternative strategies to warn the driver when talking on the phone is potentially dangerous are going to be investigated. Several other input variables will also be used to improve the accuracy of determining the distraction level. Real-time sensor fusion techniques will be used for this purpose.

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