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WORKING PAPER

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Internal working paper no 15-03

July 2015

Gesturing on the Steering Wheel, a Comparison with Speech and Touch Interaction Modalities

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ABSTRACT

This paper compares an emergent interaction modality for the In-Vehicle Infotainment System (IVIS), i.e., gesturing on the steering wheel, with two more popular modalities in modern cars: touch and speech. We conducted a between-subjects experiment with 20 participants for each modality to assess the interaction performance with the IVIS and the impact on the driving performance. Moreover, we compared the three modalities in terms of usability, subjective workload and emotional response. The results showed no statically significant differences between the three interaction modalities regarding the various indicators for the driving task performance, while significant differences were found in measures of IVIS interaction performance: users performed less interactions to complete the secondary tasks with the speech modality, while, in average, a lower task completion time was registered with the touch modality. The three interfaces were comparable in all the subjective metrics.

Author Keywords

Gestures; touch; speech; HUD; IVIS comparison.

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous;

INTRODUCTION

Increasing the driver experience while maintaining a high safety level is one of the hardest challenges for modern car designers. Many companies are moving through a semi-autonomous driving approach, where the driver has the possibility to distract from the primary task that is taken in charge by the autonomous driving system of the car. Nevertheless, taking back the driver in the loop in emergency situations could imply much slower reaction times than a driver that is focused on the primary task [7]. An alternative approach for increasing the driving experience and safety is leaving the driver engaged in the primary task and optimize the interface for the secondary task in terms of driver distraction and user experience. Several researchers and In-Vehicle Infotainment System (IVIS) designers [2,8,12] embraced the "eyes on the road, hands on the steering wheel" approach [8], in order to decrease driver distraction and, hopefully, increase safety. Speech and gesture are often used as interaction modalities that can support this approach, especially if combined to a Head-Up Display (HUD) [1,12]. In order to understand the impact of the different interaction modalities on driving performances and on the user experience, we compared three different interfaces for the IVIS, each based on a different interaction modality: speech, gesture and touch. The speech interface was designed to comply with the eyes on the road, hand on the steering wheel approach, combined with a HUD. The gestural interface adopted the same approach and investigated a novel trend, i.e., gesturing on the steering wheel. Nevertheless, in order to increase the user experience, we chose to adopt user-elicited gestures, which required leaving one hand from the steering wheel, thus, losing partially the "hands on the steering wheel" safety constraint. The third interface used a popular interaction modality in modern cars, i.e., a touch interface on the dashboard, which does not comply at all with the "eyes on the road, hands on the steering wheel approach". Following these considerations, we could expect a negative impact of the touch interface on driving performance. Obviously, besides driving performances, we are interested in investigating the user experience of the driver; therefore, subjective evaluations on the usability, emotional response and perceived workload were conducted.

In the next section, we present previous studies assessing and comparing the three different interaction modalities for the IVIS, with a particular focus on gestural interfaces on the steering wheel. Then, we describe the three interfaces designed for this experiment and the test methodology. Finally, we present and discuss the results.

RELATED WORK

Many researchers explored gestures performed on the steering wheel, either on its surface [2,8,12], in the surrounding space [6] or on a central touchscreen [5,20]. These gestures are performed either while firmly holding the steering wheel [1,5,6,8,12], or after shifting the hand position [1,12,14]. Döring et al. used a user elicitation approach for the design of a gestural interface on a touchscreen integrated in the steering wheel, but they restricted the possible interaction areas to two input fields close to left and right edges of the steering wheel [5]. As a result, the most common gestures elicited by participants were always performed with their thumbs without leaving the hands from the steering wheel. Recently, Angelini et al. presented a user-elicited taxonomy of gestures performed on the entire surface of a traditional steering wheel [1]. A larger variety of different gestures were proposed by the users and two different trends were evidenced: some people suggested gestures to be performed without taking the hands off the steering wheel, while others suggested gestures that required taking at least one hand off the steering wheel. We decided to use the results of this user elicitation to design a gestural interface that could be perceived as intuitive by the users, following the insights of Morris et al. [18]

Although several researchers presented an interface with gestures performed on the steering wheel [2,5,6,12,14], among them, only Döring et al. compared gestures to different interaction modalities [5]. Indeed, the authors compared their interface to two traditional interfaces, a radio with buttons in the central dashboard for the music control task and a conventional car navigation system for the navigation task. While they did not find significant differences on the driving performances, they found a significant decrease on the amount of glances and the time spent looking away from the road when using the gestural interfaces compared to the traditional ones. Generally, users rated the gestural interface higher compared to the traditional interfaces in terms of general preference, distraction, and easiness of use. Bach et al. compared gestures on a touchscreen to a touch interface with graphical buttons and a traditional car radio with tangible buttons noticing a decreased lateral deviation for the gestural interface compared to the central dashboard with buttons [3]. In terms of interaction time, users were faster using the touch interface compared to gestures and buttons. Also in this study the gestural interface was largely preferred to traditional interfaces. In our study, we compared the gestural interaction modality to two state of the art interaction modalities: speech interaction (combined to a HUD) and touch interaction on a large Android touchscreen.

Several studies investigated the implications and risks of using speech-based interfaces in the car [10,14,15]. Maciej and Vollrath compared a touchscreen interface in the dashboard and a speech based interface during the execution of four IVIS tasks (audio, phone number selection, navigation system with address entry and point-of-interest selection), obtaining better driving performances with the speech based interface for all the tasks except the point of interest selection, which required higher visual attention on the lateral screen [15]. Nevertheless, the authors stressed that the driving performances while using the speech interface were significantly worse than the baseline, especially with a more demanding primary task (in their case, the "Lane Change Task"). Similar conclusions were drawn by He et al. for speech-based text entry compared to a handheld touch device [10]. In our experiment we focused the comparison only on menu-based tasks, avoiding more complex tasks such as text entry or navigation to an address, with the aim of comparing the three different interaction modalities on a same structured menu interface.

SYSTEM DESIGN

This section describes the three interfaces that we designed to compare three different interaction modalities (gesture, speech and touch):

- Gestural interface on the steering wheel and visual feedback on the HUD
- Speech-based interface and visual feedback on the HUD
- Touch interface on the dashboard

Since the aim of this study is comparing the interaction modalities, not the interfaces, we designed the rationale behind the interface to be exactly the same. We adopted a hierarchical menu interface where the elements showed within the HUD for the first two modalities and the elements showed within screen of the tablet were the same, even if displayed in a slightly different manner to adapt to the requirements and possibilities of the two interfaces. In particular, the goal of the interaction scenario was to navigate the menu in order to accomplish some predetermined tasks. The structure of the menu was the same for all the interaction modalities and the number of interactions required to complete the proposed tasks was exactly the same in the three cases. The first level of the menu contains three items (Music, Contacts and Reminders), which correspond to the three functions implemented in the IVIS (Music Player, Phone Calls and Vocal Assistant). The second level displays the content of each menu. Each content list has a circular structure (the last item is linked with the first one).

In the HUD system, we implemented a menu layout similar to the Cover Wheel Layout (but with no 3D effect) [17], as shown in Figure 1. As shown by Mitsopoulos-Rubens et al. [17], this layout structure should not have an impact on performance compared to a list layout, often used in other HUD interfaces. The items of the list are displayed horizontally, with the selected item in the center, highlighted. The HUD was implemented only for the gesture and speech modalities; for the touch modality, the user relied only on the touchscreen visual feedback, which is the typical configuration available in commercial vehicles. We provided the same audio feedback (music, traffic alerts or simulated phone calls) for the three interfaces through stereo speakers.

The commands that allowed the navigation through the menu items were the following: VOLUME UP, VOLUME DOWN, NEXT, PREVIOUS, SELECT and BACK. The first two commands allowed to set the desired volume (in ten steps), the NEXT and PREVIOUS commands allowed going to next and previous elements in the list, while SELECT and BACK were used respectively to select or play an item and go back to the parent item. Each interface implemented the commands exploiting the corresponding interaction modality, as described in the following subsections.

Figure 1. Head-Up Display Interface in a music player item

Gestural Interface (WheelSense)

In a precedent study [1], 20 users were asked to elicit pairs of gestures to operate a HUD with the six aforementioned commands (Volume UP/DOWN, NEXT/PREVIOUS, SELECT/BACK). Users were allowed to suggest any type of gesture that implied a contact with any part of the steering wheel.

The gestures preferred (i.e., elicited more often) by the participants were adopted for designing the interface of this study. The selected gestures were the followings:

- Volume UP: hand swipe (toward the top) on the external part of the right side of the steering wheel;
- Volume DOWN: hand swipe (toward the bottom) on the external part of the left side of the steering wheel;
- PREVIOUS: hand tap on the external part of the left side of the steering wheel;
- NEXT: hand tap on the external part of the right side of the steering wheel;
- SELECT: hand tap on the frontal part of the top of the steering wheel;
- BACK: hand tap on the frontal part of the bottom of the steering wheel;

All the six gestures required to temporarily remove one hand from the steering will. The gestures on the left/right side of the steering wheel were performed with the corresponding hand. For the gestures on the top and the bottom, the user could use her preferred hand according to the situation and personal preferences.

Figure 2 shows the six gestures performed on the related steering wheel region.

In order to recognize gestures, we implemented a system, called WheelSense, based on capacitive sensors integrated in a Logitech G27 steering wheel (depicted in Figure 2). The system is based on a Freescale MPR121 capacitive sensor connected to an Arduino Uno board. We built electrodes sticking strips of copper tape on the steering wheel. To avoid encumbering cables, the sensor data were sent through a

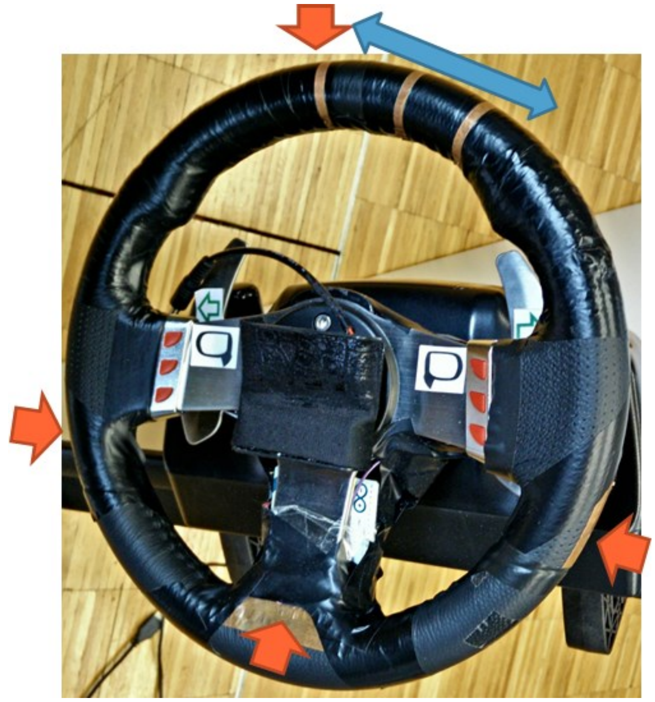

Figure 2. Logitech G27 Steering Wheel equipped with capacitive sensors, also called WheelSense. Red arrows depict hand-taps and blue arrow the hand-swipe.

Bluetooth connection to the PC where a C# application recognized gestures through a simple threshold-based algorithm. Therefore, the system did not required to be trained with each user. The system did not require manual gesture segmentation. To avoid undesirable false positives, the gesture recognizer was disabled while steering right or left and while no task was assigned to the user.

Speech Interface

For the vocal interface, we chose to simplify as much as possible the corresponding vocal commands. The following list reports the six vocal commands:

- Volume UP: “Up”
- Volume DOWN: “Down”
- PREVIOUS: “Left”
- NEXT: “Right”
- SELECT: “Select”
- BACK: “Back”

During the experiment, the vocal commands were recognized through a Wizard of Oz approach [11]. This method allowed creating the sense of a natural interface where the time between the user’s command and the system execution was similar to the dialog between humans. To keep the interface as natural as possible, we considered that the vocal system did not require any manual or keyword segmentation for the vocal commands.

Touch Interface

The touch interface was designed for an Android Tablet with a screen size of 10.1 inches.

We exploited the size of this screen to make the items of the menu as big as possible, in order to facilitate the touch interaction and the readability of the information. Each button represented a command. We used simple icons that were easy to interpret for the participants. Although the menu content was the same than in the two HUD interfaces used in the previous interactions, we exploited the whole surface of the screen to make some information more noticeable. Figure 3 shows the placement of tablet and provides a hint of the user interface.

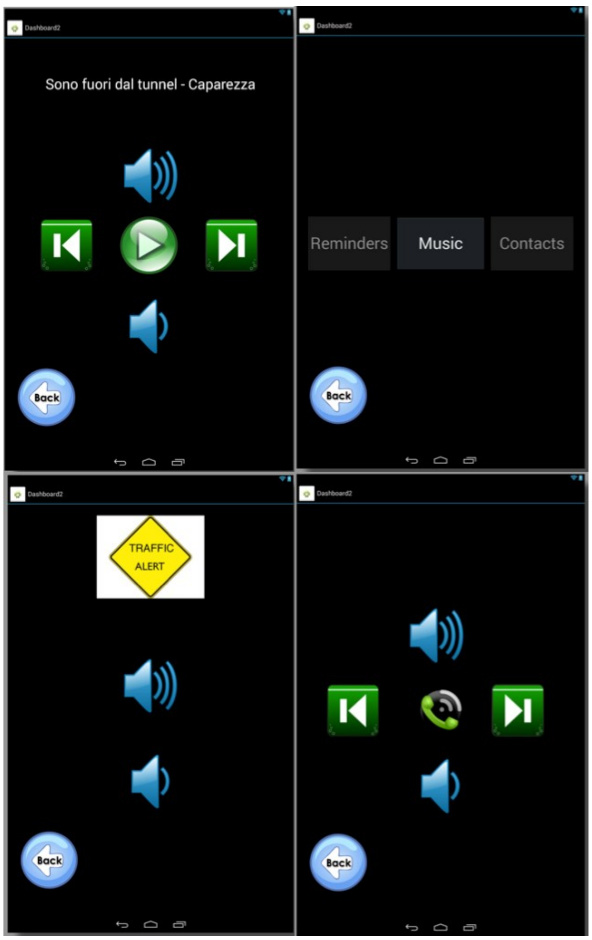

Figure 3. Four views of the touch interface.

TEST METHODOLOGY

Participants

The sample of this study consists of 60 participants (83.33% female). All of them were members of the University of Fribourg (Switzerland), and in possession of a valid driving license, and aged between 18 and 40 years (M = 23.22).

Self-reports showed that the participants rated themselves as average drivers (M = 4.37 on a seven-point Likert scale from "beginner" to "expert"). With regard to simulator experience, they rather rated themselves as beginners (M = 2.30).

When asked about the frequency of usage of different interaction modalities in the car in a 7 point Likert scale, buttons were by far the most used interface (M=4.6 SD=1.9) followed by touchscreen (M=2.0 SD =1.6) and speech interaction (M=1.2 SD=0.7). Concerning the interaction modality that users considered as easier to use to interact with an IVIS, 5 participants answered the speech interaction, 1 the touch interaction and 54 an interface with buttons. Since there are no commercial cars equipped with a gestural interface, it was not included as an option in the questionnaire.

Experimental Design

In this study we decided to use a driving simulation scenario that could be as close as possible to a real driving scenario. This choice was made to ensure obtaining a measurement of perceived cognitive workload and of the emotional response as close as possible to a real driving simulation. For this reason, we did not use the standard measurement tools for assessing driving performances, such as the Line Change Task [16] or for assessing the cognitive workload, such as the Detection Response Task (ISO/CD 17488).

In a one-factorial design, IVIS interface was used as a between-subjects variable, being varied on three levels: participants used either a touch interface, or a speech-based interface or a gestural interface.

Participants had to complete different tasks in a driving simulation. The dual task paradigm was applied. The primary task was to drive a defined route in the driving simulation. Participants were asked to respect traffic rules and to drive as safe as possible without stopping on the route. To follow the right itinerary participants were guided via verbal instructions by the investigator.

The secondary tasks consisted of different interactions with the IVIS that had to be executed while driving. They were inspired by real tasks typical in IVIS usage. On defined positions of the itinerary, pre-recorded verbal instructions were presented to the participants, describing what they had to do. The following tasks had to be completed during the drive:

- Lower the volume of an incoming traffic alert
- Search for a specific person in the contacts list and start a phone call
- Five tasks asked the participants to do some changes in a media player, such as playing a specific song or adjusting the volume

Measures

Performance

For primary task performance, three measures were recorded: (1) driving time: the time participants needed to drive the route, (2) violations: the number of infractions of the traffic rules, (3) accidents: number of collisions while driving the route.

Regarding secondary task performance, the number of interactions and the completion time for each task was recorded.

Subjective workload

To assess the subjective workload while driving, the Driving Activity Load Index (DALI) was applied [19]. The DALI is a modified version of the National Aeronautics and Space Administration-Task Load Index (NASA-TLX), which has been especially adapted to the driving context [9]. On a seven-point Likert scale (1 = low; 7 = high) participants rated their perceived workload on seven factors (visual demand, auditory demand, tactile demand, temporal demand, interference, attention and situational stress).

Perceived usability and learnability

As a measure of the perceived usability, the System Usability Scale (SUS) [4] was applied after product usage. The SUS consists of 10 items and is well suited for a quick comparison between systems in regard of usability. Items were rated on a seven-point Likert scale (1 = strongly agree; 7 = strongly disagree), which results in a score between 0 and 100. The overall internal consistency of the questionnaire (Cronbach's $\alpha > .91$) is high. The leanbility factor has been measured using two items of the SUS questionnaire as explained by Lewis and Sauro in [13].

Emotions

To measure different aspects of emotion, the PANAVA-KS (short scale for the assessment of positive affect, negative affect and valence) [21] was applied. It consists of 10 bipolar adjectives that describe different affective states. Items were rated on a seven-point Likert scale with the two extreme points (e.g. happy: very happy, very unhappy). The psychometric properties of the questionnaire are sufficient (Cronbach's α =.83 for positive affect, .76 for negative affect and .74 for Valence).

Material

A realistic driving simulator was running on an Intel Core i7 Windows PC and displayed on three 19" 1280x1024 LCD screens. Car and IVIS audio feedback was provided through a pair of stereo speakers positioned in front of the user. A Logitech G27 set, including the steering wheel, pedals and the gear stick, was used to control the vehicle in driving simulator. We used a Samsung Nexus 10 Tablet positioned on a reclined portrait stand for the touch interface. We placed the tablet in a position where it was easy to read and easy to reach. However, in order to interact with the system the participants had to glance at the screen, remove one hand from the steering wheel and touch the desired button. The HUD was implemented through a software overlay on top of the driving simulator. The experimental setup is shown in Figure 4. All the interactions with the IVIS were logged by the system.

Statistical Analysis

For measures of user performance and subjective user ratings, a one-factorial analysis of variance (ANOVA) was carried out, followed by explorative post-hoc comparisons, for which a Bonferroni correction was applied. For the analysis of the data on participants' affective states, a one-factorial analysis of covariance (ANCOVA) was carried out, with the initial baseline measure (taken prior to task completion) used as covariate.

Figure 4. Experimental setup

RESULTS

Driving performance

The data of the driving performance are presented in Table 1. Data analysis indicated no significant difference between the different interaction modalities [SA1] for driving time, driving errors and accidents (all Fs < 1).

	Touch control	Voice control	WheelSense
	M (SD)	M (SD)	M (SD)
Time (s)	917 (124)	935 (154)	902 (101)
Driving errors	34 (10)	34 (13)	36 (11)
Accidents	2.8 (2.3)	3.6 (3.1)	3.0 (2.7)

Table 1: Performance values on the driving task as a function of the interaction modality

Secondary task performance (IVIS interaction)

Task completion time. The analysis of the data of task completion time (see Table 2) revealed a significant effect between the different interaction modalities (F = 5.3; df = 2, 57; p < .01), with post-hoc analysis indicating that task completion time in the touch modality was lower (i.e., higher performance) compared to the WheelSense modality. The other post-hoc comparisons did not reach significance level.

Interaction efficiency. The data about the number of user interactions are also presented in Table 2. Statistical analysis (F = 16.8; df = 2, 57; p < .001) revealed a lower number of user interactions (i.e., higher performance) for the speech control condition compared to the other two conditions (large effects with r between .63 and .68). Since the menu structure for the three IVIS was the same, those findings indicate that participants committed fewer errors in the speech condition.

	Touch control	Voice control	WheelSense		
	M (SD)	M (SD)	M (SD)	*p*	*r*
Task completion time	34.8 (8.3)	39.5 (9.6)	43.5 (7.3)		
				< .01	.49
Interaction efficiency	15.4 (2.0)	12.9 (0.9)	15.1 (1.4)		
				< .000	.63
				< .000	.68

Table 2: Performance values on the secondary tasks and results of post-hoc tests (Bonferroni corrected) as a function of interaction modality.

Subjective evaluation of the IVIS systems

The data of mental workload, perceived usability and learnability are presented in Table 3. The calculated ANOVAs showed no significant effect of interaction modality on the different subjective evaluations of the IVIS systems (both Fs < 1).

	Touch control	Voice control	WheelSense
	M (SD)	M (SD)	M (SD)
Mental workload	5.3 (.56)	5.0 (.71)	5.1 (.98)
Perceived usability	72.7 (16.0)	72.1 (16.5)	66.2 (15.4)
Learnability	86.6 (15.6)	80.0 (23.3)	73.7 (28.9)

Table 3: Subjective evaluation of the IVIS systems as a function of the interaction modality.

Affective state of the user

The data of valence, positive affect (PA) and negative affect (NA) are presented in table 4. Statistical analysis revealed no significant influence of interaction modality on any measure of user affect ($F_{Valence}$ = 2.3; df = 2, 54; p > .05; F_{PA} < 1; F_{NA} = 2.8; df = 2, 54; p = .07). The covariates *initial PA* showed a significant effect on users' PA ratings after task completion (F = 8.0; df = 1, 54; p < .01) as well as the covariate *initial NA* was linked with participants' NA ratings (F = 15.3; df = 1, 54; p < .001). No other effect of a covariate reached significance level.

	Touch control	Voice control	WheelSense
	M (SD)	M (SD)	M (SD)
Valence	10.4 (2.2)	9.1 (1.8)	10.1 (2.0)
Positive Affect	19.2 (3.0)	18.8 (2.5)	18.7 (3.6)
Negative Affect	17.0 (3.4)	17.2 (2.8)	15.3 (3.4)

Table 4: Ratings of users' affective states after task completion as a function of the interaction modality.

DISCUSSION

The main goal of the present study was to evaluate three different interaction modalities of in-vehicle information systems in the context of a driving simulation study. Measures of driving performance, interaction performance, workload, perceived usability and user affect were recorded. The main results showed some advantages of the speech control (with regard to interaction efficiency) and touch control (regarding task completion time) for performance on the secondary task. This could be explained because user could rapidly execute the same command on a touch interface, especially if they have to press the same button. Since the interaction with the touchscreen is visually demanding, users were sometimes imprecise, making mistakes, for example going too far in the item list in respect to the desired item. The same considerations could not be done for the gestural interface on the steering wheel, probably because the users were not acquainted with this interaction modality.

The interaction modality of the IVIS had no effect on all the other measures assessed in this study (e.g. driving performance, subjective evaluation of the IVIS system as well as on the users' affective state). This results is rather surprising since it was expected that the use of interaction modalities allowing the driver to keep her eyes on the road (i.e., speech and gestures) would result in increased driving performance (e.g., decreasing driving errors and accidents) compared to the use of the touch modality, for which the driver needs to shift her attention from the road towards the central dashboard.

Gestures and speech are very innovative and uncommon systems. Users did not have previous experience with similar systems; therefore, it is surprising and satisfactory that ratings of their usability did not differ from the ratings of the better known touch system. Indeed, there was a remarkable difference between the learnability score of the touch and gesture systems, although not statistically significant ($p=0.084$).

Concerning the absence of difference in driving performance and subjective workload, it can be argued that the novelty of speech control and gestural control might have had some negative influence on performance and perceived workload. Since the interaction with these new systems was uncommon and novel, this might have been the reason for a decrease in driving performance and an increase in subjective workload. The advantages of those systems in comparison with the touch system due to the eyes on the road-principle might hence have been compensated by their disadvantages due their novelty.

LIMITATION

This study focused on the comparison between interactions *modalities*. For this reason, we used the same hierarchical organization of the menu for the three modalities and we adopted the same commands (i.e., UP, DOWN, RIGHT, LEFT, SELECT, and BACK).

Obviously, each interaction modality could offer several advantages that were not exploited in the designed interface for the sake of a "fair" comparison. For example, considering a speech interface, it could be possible to directly issue an order (e.g., "System, call Home" or "System, play The Man Who Sold The World"). This will reduce the time in which the driver's focus switches from the primary to the secondary task, and will reduce the overall time spent interacting with the IVIS. Nevertheless, a segmentation approach is generally required for most speech recognizers: the current commercial systems require the user to press a button or to use a keyword to activate the vocal interface (such as the word "System" in our example or "Ok, Google" and "Hey Siri" in other systems based on speech recognition). In our study, we overlook this aspect, using a "Wizard of the Oz" approach, considering the system as able of automatically segment the vocal commands. Finally, the design of interaction-specific solutions can be extremely varied. It means that we risked designing a system too dependent on the design of the interaction, biasing the modality comparison.

Concerning the gestural interaction, the chosen gesture vocabulary could have an impact on the perceived usability and emotional response of the users, although the gesture elicitation approach should have optimized this aspect.

Finally, we did not count the number of errors made by the users. Since in our setup, it was difficult to discriminate user errors from errors of the recognition system.

CONCLUSION

We compared a novel interaction modality for the IVIS, gesturing on the steering wheel, with two classic modalities in modern cars: touch and speech. A between subject experience involving 20 participants per modality assessed that the gesture-based modality is comparable with the other two in terms of perceived usability, subjective workload and emotional response.

These results are particularly significant since they mean that the novel approach is perceived by the user as a novel realistic opportunity to perform secondary tasks in driving conditions even while compared with approaches that they already have the habit of using.

In future works it will be interesting to evaluate if a multimodal approach could help to overcome the well-known practical limitation related to each modality (e.g., speech interaction is not suitable in shared space, the touch interaction requires to remove the eyes from the road, and gesture interaction, as novel modality, has a fee to pay in terms of learnability).

Finally, because of the between subject approach, an extension of the comparison to other interaction modalities, for example buttons on the steering wheel, is also possible.

ACKNOWLEDGMENTS

This work has been supported by Hasler Foundation in the framework of “Living in Smart Environments” project.

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