You Can Touch, but You Can't Look: Interacting with In-Vehicle Systems

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ABSTRACT

Car drivers are nowadays offered a wide array of in-vehicle systems i.e. route guidance systems, climate controls, music players. Such in-vehicle systems often require the driver's visual attention, but visual workload has shown significant less eyes-on-the-road time and affects driving performance. In this paper, we illustrate and compare three different interaction techniques for in-vehicle systems. We refer to them as tactile, touch, and gesture interaction. The focus of the techniques is the effects on drivers while driving cars. We evaluated the interaction techniques with 16 subjects in two settings. Our results showed that gesture interaction has a significant effect on the number of driver eye glances especially eye fixations of more seconds. However, gesture interaction still required rapid eye glances for hand/eye coordination. On the other hand, touch interaction leads to fast and efficient task completion while tactile interaction seemed inferior to the two other interaction techniques.

Author Keywords

In-vehicle systems, visual attention, gesture interaction, touch interaction, tactile interaction, driving, eye glances

ACM Classification Keywords

H.5.2 [User Interfaces]: *Interaction styles*

INTRODUCTION

Designing for mobility is rather challenging as mobile users and mobile use are characterized by great diversity and done for different purposes. As designers we need to enable users to interact with technologies during travelling, trips, journeys, hikes, visits, or rides. An increasingly important area for human-computer interaction within mobility is the design of in-vehicle systems. With significant advances in technology, car drivers are nowadays offered a wide array of in-vehicle systems i.e. route guidance systems, climate controls, music players. As emerging vehicles constantly offer additional and more advanced in-vehicle systems, the side effects of in-vehicle systems become more significant. Several research studies illustrate that interacting with such in-vehicle systems while driving highly challenges drivers' attention on the primary task of driving [12, 16, 22].

Visual attention stands out as the most important attention property when driving vehicles. Not surprisingly, research on visual workload has shown significant less eyes-on-the-road time when drivers interact with in-vehicle systems with high visual demands and this directly affects driving performances [11, 24].

However, many vehicles are today shipped with a built in touch screens which highly depends on visual attention. Such touch-based screens are typically being employed to enable the driver to interact with novel functions as well as established functions. Consequently, simple control operations (e.g. using a fan speed dial) have become more complicated requiring a number of discrete steps interactions (e.g. mode selection, option choice, adjustment setting). Taking the immediate safety critical aspects of driving into account, Green recommends that we need to identify and investigate new interaction techniques that are more suited for in-vehicle systems [10].

This paper compares three different interaction techniques for in-vehicle systems. Inspired by previous research (i.e. [1, 2, 19, 24]), we identify and refer to tactile, touch, and gesture interaction for in-vehicle systems. The interaction techniques are illustrated and manifested through three different music players and are compared on their effects on primary and secondary driving tasks performances and on visual attention of the driver. The paper is organized as follows. First, we illustrate related work on in-vehicle systems interaction. Secondly, we illustrate the interaction techniques. Thirdly, we outline an experiment where the techniques are compared against each other and findings are presented and illustrated. Finally, we discuss our results.

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RELATED WORK

Most in-vehicle systems research focus on how to minimize driver workload and how to reduce visual attention on such systems [2]. As touch sensitive interfaces are finding their way into more vehicles (i.e. where drivers typically can control media centres, climate controls etc.), a characteristic assumption is that we need to look past the capabilities of tactile feedback and search for new techniques that require no (or very limited) visual attention. Traditionally, the car requires little visual attention to master i.e. gear selection, throttle control, or steering wheels.

Touch-based and tactile-based interaction techniques have been investigated on their abilities to support drivers when interacting with in-vehicle systems. Several studies explore opportunities and limitations of these techniques [5, 17, 24]. Bellotti et al. compared a haptic-based force-feedback knobble against a touch-based interface on a configurable touch screen. They found that the tactile interface performed better on visual demanding tasks and also in relation to eyes-off-the-road frequency and duration [5]. Tsimhoni and Green identified a similar result where touch-based interaction required higher visual attention, but it also involved lowered driving performance [24]. They noticed that drivers wandered more in their lane and departed from their lane more frequently. Also, drivers made shorter glances at the interface, had a higher number of glances, but waited longer between glances. If driving conditions got difficult and thus visual demands for driving were high, task completion times increased. Finally, Noy et al. found that manipulation tasks performed on a touch screen were significantly more mentally demanding than radio tuning tasks simply because it required significant visual attention as a consequence of the lack of tactile and kinaesthetic feedback [17].

While touch-based and tactile-based techniques seem to suffer from a number of inherent limitations in terms of reducing visual attention, two other techniques potentially provide attention low interaction – i.e. speech recognition and gesture-based interaction. Speech recognition stands out as a potentially useful technique for in-vehicle systems interaction as it provides both hands-free and eye attention free interaction (at least in theory). Barón and Green [4] state, however, that speech recognition is highly cognitive demanding and it has been characterized as both impractical and flawed in regard to in-vehicle interaction [8].

Gesture-based interaction, on the other hand, could provide a suitable alternative to speech recognition as it overcomes some of the inherent impracticalities of spoken language while driving. Alpen and Minardo explored gesture-based interaction with in-vehicle systems [1]. In an experiment using driving simulators, subjects performed entertainment tasks, (e.g. find a song, search presets, adjust volume) with both a gesture interface on the windshield and a conventional radio. Subjects in the gesture condition made fewer driving errors than radio interface subjects, however not significantly fewer errors. Further, subjects preferred the gesture interface to the radio, because it allowed them to keep eyes and attention on the driving. Subjects did not have to reach and touch anything and gesture interaction allowed them to be less accurate while being successful.

Pirhonen et al. compared a gesture-based interface to a touch-based interface for an on-the-go MP3 music player [19]. They stressed the importance for mobile users to focus their visual attention on the world around them and not on the device (drivers are typically in a similar situation). They found that overall workload was significantly reduced as well as overall task completion time for the gesture-based interface. Further, gesture interaction facilitated the primary task (of walking) as the walking speed was closer to the participants' preferred walking speed. No difference was found in the number of errors made between the two types of interfaces.

IN-VEHICLE SYSTEM INTERACTION

Based on previous research on interaction techniques for in-vehicle systems and inspired by Pirhonen et al. [19], we present tactile, touch, and gesture interaction as alternatives to in-vehicle interaction techniques. The three techniques (tactile, touch and gesture) are represented by individual systems in order to demonstrate and compare the qualities and problems regarding attention.

One type of well-established in-vehicle systems is common car stereos or music players. For this experiment, we opted to use music players as case systems to represent the three interaction techniques (i.e. [1, 19]). The different types of interaction are not unique to the domain of music players and were chosen as case systems to allow direct comparison of the interaction techniques. The terms *tactile interaction*, *touch interaction* and *gesture interaction* will be used when discussing the three music players that manifest the respective interaction techniques.

Tactile Interaction

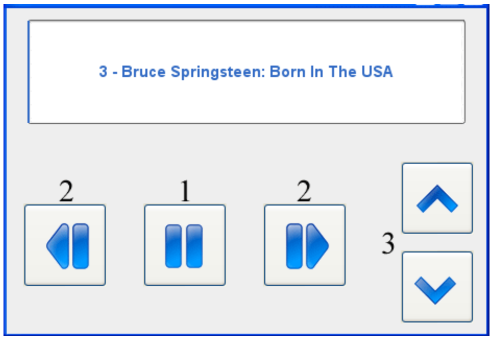
The tactile interaction was represented by an off-the-shelf car stereo with CD functionality. The product was a xZound CDX5 and is illustrated in figure 1.

Figure 1. The conventional car stereo (Xzound CDX5) used for the tactile interaction. Play/pause is located at the lower middle part (1), skip forward/back is located in the lower right (2), and the volume is controlled via the knob to the left (3).

Prior to selecting the specific model standard functionalities were investigated in car stereos to ensure that any model we would select was both representative and intuitive. The car stereo was selected due to its traditional looks and its conventional interface. The car stereo operates via tactile interaction with either the buttons at the lower part of the unit or via turning the volume controller knob seen on the left. Thus, the user of the car stereo usually experience tactile feedback when pressing buttons or turning knobs. The display presents information regarding playing mode, track number, and volume level.

Touch Interaction

The touch interaction technique was manifested in a touch screen with a touch-to-push interface (see figure 2).



3 - Bruce Springsteen: Born In The USA

Figure 2. Overview of the touch screen based music player manifesting touch interaction. Play/pause is located in the middle (1), skip forward/skip back is located on the sides (2), and volume control is located to the right (3). The figure shows the system in playing mode – if the pause button is touched, the icon changes to a "play icon" and the music stops. Diagonal size is approximately 7".

By touching the buttons on the interfaces, the user controls the basic functionality of the system. Buttons are triggered by button release only, i.e. nothing happens if buttons are pressed and held or if buttons are missed. The player features only basic functionality of the kind also found on the car stereo, i.e. play/pause, skip back/forward, and adjust volume up/down. The interface also displays the artist and song number for the track currently being played.

Gesture Interaction

The gesture interaction was implemented through a touch screen based "drawing canvas" as illustrated in figure 3.

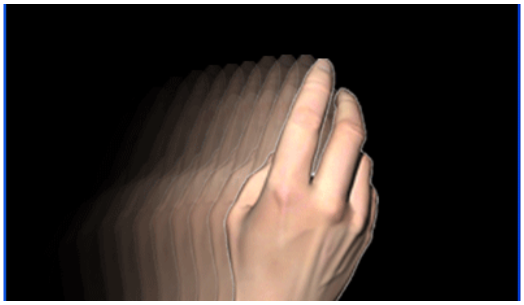


Figure 3. A touch screen serves as the canvas for gesture interaction. The hand is drawing a line from left to right indicating a skip forward operation.

The user controls the player by using a finger to draw gestures anywhere on the canvas. The input is then matched against a set of predefined gestures and any command assigned to that specific gesture is executed. The system features the same basic functionality as the two other systems, i.e. play/pause, skip back/forward, and adjust volume up/down. Track numbers are read out loud is included dubbed "Get Song Number". In addition a set of earcons provide auditory feedback, for instance when a gesture could not be recognized. Figure 4 presents the implemented gestures, which are inspired by Pirhonen et al. [19], and their respective function.

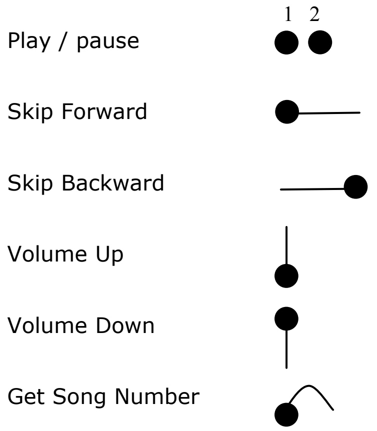


Figure 4. The set of input gestures for the gesture interaction based music player. A dot indicates a gesture start, e.g. play or pause is executed by tapping the canvas twice.

EXPERIMENT

The main objective for the experiment was to compare the three interaction techniques as illustrated above. In this section, we outline the rationale behind the experiment and illustrate key elements of the experiment.

Subjects

16 people (1 female, *M*=28, *SD*=5.7) participated in our experiment. All subjects carried valid driver's licenses and their driving experience ranged from app. 100 km per year to 20,000 km per year (*M*=4,732 km, *SD*=5,966 km). All subjects stated that they were in a fair health condition including having normal or corrected-to-normal vision. 7 of the 8 subjects in the controlled track sessions had been to a similar facility while training for their driver's licenses whereas 6 of 8 subjects in the simulated driving sessions indicated that they had previously used steering wheel and pedals for computer games and had tried the selected game.

Design

We utilized a combined within-subject and between-subject design using interface type (tactile, touch, and gesture) as within independent variable and driving setting (controlled and simulated) as between independent variable. Subjects were randomly assigned to exactly one of the two driving settings where they each participated in three sessions; one for each of the interface types. The order of interface types was counter-balanced between subjects to minimize carry-over effects. Thus, in total we conducted 48 (3×2×8) testing sessions (3=interaction techniques, 2=settings, 8=subjects).

The primary dependent measures were primary driving task performances (longitudinal and lateral control), secondary driving task performances (interaction errors and task completion times), and eye glance behavior. Additionally, satisfaction was measured as a secondary measure. The dependent measures are further elaborated and discussed in the data analysis section.

Driving Settings

We integrated two different driving settings for the testing of the interaction techniques. We refer to them as controlled driving and simulated driving (i.e. [2]). This allowed us to identify and explore similarities and differences between the different driving situations and to address problems that might be associated with either the controlled driving or the simulated driving. This paper primarily addresses the three interaction techniques; specific findings and discussion of the driving settings can be found in [3].

Controlled Driving

The controlled driving took place at a driving facility in Aalborg, Denmark normally used for training purposes (see figure 5). Subjects drove on a 3.2 km test track and there were no other road users on the facility at the time of the experiment. The track was equipped with various driving features to mimic low-density rural driving conditions i.e. simple curve exercises and simple slalom areas. Also, the track had a speeding camera and traffic lights. The vehicle used for the experiment was a 3-door Opel Astra.

Figure 5. Vehicle setup with the touch interaction and gesture interaction players running off a touch screen (left). The car stereo (tactile interaction) is placed just below. Subject driving the vehicle used in the experiment (right).

Besides swapping the original car stereo with the one needed for the experiment, a 17" flat touch screen (of which only a 7" section was used) was attached to the centre console. The tactile car stereo was placed in the middle of the centre console and the touch screen was mounted on the top part of the same console.

Simulated Driving

The simulated driving took place in the HCI laboratory at Aalborg University decorated as a medium-fidelity driving simulator. The driving simulator consisted of a set of force feedback steering wheel and pedals to control a vehicle in a PlayStation based simulation (Gran Turismo 3).

Figure 6. Frame from the laboratory video feed showing a participant driving the simulator while using gesture interaction (left). Setup in the driving simulator with force-feedback steering wheel and car seats (right).

A similar car and circuit was selected for the simulation. To enhance the driving experience, the windshield image was projected onto a 2 × 2-meter canvas directly in front of the driver. Driver and passenger car seats were integrated to promote a more realistic driving environment. The touch screen and car stereo were placed in the same position as in they were in the controlled driving setting.

Tasks

Thirty smaller assignments were used in all 48 sessions. The tasks were introduced to the subjects verbally readout by the test manager. All tasks could be completed by using the basic functionality offered by each of the interaction technique.

Procedure

The procedures for the two experiment settings were made as identical as possible. All participants were introduced to the three systems prior to the testing sessions. This involved an introduction to the basic functionality of the systems and the gestures for the gesture-based interaction. Moreover, the subjects were asked to complete some smaller exercises to ensure that the functionality was understood correctly.

The controlled driving subjects were introduced to the vehicle and the driving facility. They were asked to drive around the course a few times to familiarize themselves with both the facility and the car. During this practice, the test manager would introduce the track and explain the procedure and give general driving instructions. Subjects were asked to drive casually around the circuit at a speed of app. 50 km/h. In addition, they were told to drive as they would normally do and to adhere to a few simple driving tasks that were scattered around the circuit, i.e. the traffic lights and the speeding camera where they were asked to get as close to 60 km/h as they could. These tasks were presented in an attempt to create a higher sense of realism. The vehicle was equipped with two cameras to capture eye movements and interaction of the subjects. A GPS device was positioned in the car to provide information about the vehicle speed. The GPS data combined with the laptop data log would also prove useful as a statistical analysis tool concerning the vehicle speed and position on the circuit for each interaction event.

We used a similar approach in simulated driving where the subjects were given time to adjust to the steering sensitivity and the simulator driving sensation. For the evaluation, the subjects were told to drive between 50 and 70 km/h and to stay in the middle of the road. The driving simulator used four cameras to capture eye movements and interaction of the subjects.

Data Analysis

We chose to integrate several parameters for the assessment of the interaction techniques. From a literature review on in-vehicle systems research, we identified and illustrated a number of relevant dependent measures for assessing the quality of the three interaction techniques and their effects on the driver and the driving [2]. The included measures in the experiment were:

1. Primary driving task performance
2. Secondary driving task performance
3. Eye glance behaviour

Further, we measured subjective attitudes of the subjects towards the interaction techniques.

1) We measured primary driving task performance through lateral and longitudinal control errors (inspired by i.e. [1, 16, 25]). Lateral control incidents were defined as attention related loss of vehicle lateral control (lane excursions, steering wheel input, etc.) while longitudinal control errors denote incidents where subjects had problems controlling vehicle velocity (speed maintenance, acceleration, etc.).

Lateral and longitudinal control errors were identified by reviewing video recordings and logs. Two authors of this paper both reviewed all 48 video recordings separately by identifying, classifying, and reporting incidents. Their lists of incidents were then compared and merged into one final incidents list. An inter-rate reliability test of this analysis (weighted Cohen's Kappa) gave α=0.92. This corresponds to an excellent agreement according to Fleiss [7].

2) We integrated secondary driving task performances to include task effectiveness (task completion and interaction errors) and task efficiency (total task completion time). Task effectiveness is a common measure when conducting in-vehicle research (i.e. [1, 15, 16, 27]) as well as efficiency (i.e. [5, 24]).

Interaction errors were identified from the video recordings based on different criteria due to the nature of the systems representing each interaction technique. For the tactile interaction technique, interaction errors were defined as unsuccessful attempts to press a specific button or selecting a wrong control for the assignment (e.g. using the volume control when asked to skip one track forward). For the touch and gesture interaction techniques, interaction errors were automatically logged when touching any non-button part of the surface (touch) or producing a non-recognized gesture (gesture).

The task completion times for touch and gesture interaction were measured through the data log entries of the sessions as the laptop running the two players also logged task data. As tactile interaction offered no such data, it was necessary to manually measure task completion times through video analysis. Two authors reviewed all 48 video recordings independently by measuring the task completion times for all 1440 assignments. Due to the nature of this data, no inter-rate reliability tests were conducted, but an average was calculated from the list of the two authors. To get the total task completion times (including the time it took for participants to move their hand to and from the system), a constant was added to the values from the interaction log. The constant was calculated using a stopwatch on a sample of 20 assignments for both systems and was set to 660 milliseconds.

3) Eye glance is probably the most common predicator of driver attention and is an accepted measure for in-vehicle system evaluations as the link between visual attention and driving performance (i.e. [8, 21, 26]. We divided eye glances into three categories according to their duration (less than 0.5 seconds, 0.5-2.0 seconds and above 2.0 seconds). These categories are motivated in the following.

Eye fixations (when the eyes dwell on something) are typically glances over 0.5 seconds and can be used as an indication of what a driver is attentive towards [26]. This defines the boundary between two categories; below and above the eye fixation time of 0.5 seconds. Also, research suggests that drivers are very reluctant to continue without roadway information for more than 2 seconds also known as the "2-second rule" [21, 27]. This defines the boundary between two others of our categories; eye glances of more than 2 seconds.

We classified eye glances according to whether they were below 0.5 seconds, between 0.5-2.0 seconds, or above 2.0 seconds using video analysis. Two authors independently of each other classified eye glances in the 48 video recordings. Their classification were then compared and an inter-rate reliability test (weighted Cohen's Kappa) showed α=0.71 suggesting substantial agreement according to Fleiss [7]. Due to the number of disagreements, a third author would review all incidents (where the two authors disagreed) and classify them according to the categories.

The questionnaire included questions on the subjective preferences towards the interaction techniques. We used a 5-point scale on perceived workload, concurrent driving performance, and ease of use. Their answers served as input for the subsequent interview sessions.

RESULTS

This section presents the results from the data analysis for each measure. We present results in the following order: primary driving task performance, secondary driving task performance, eye glance behaviour, driving settings impact, and satisfaction. All results were subjected to one-way repeated-measures ANOVA tests and Tukey HSD post hoc tests at a 5% confidence level.

Primary Driving Task Performance

We included two variables for measuring primary driving performance namely lateral control (lane excursions, steering wheel input, etc) and longitudinal control (speed maintenance, acceleration). We identified 182 incidents of lateral or longitudinal control errors in the 48 sessions.

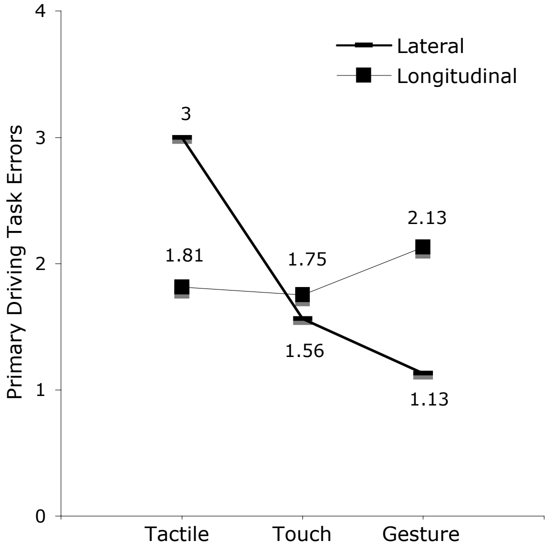


Figure 7. Lateral control and longitudinal control errors for each interaction technique.

While numbers of longitudinal errors were relatively alike for the three interaction techniques, we found a significant difference between the numbers for lateral control, *F*(2, 45) = 9.52, p < .001. A Tukey HSD post hoc test revealed that the tactile interaction resulted in significantly more lateral control errors than both the touch and gesture interaction sessions (p < .01). Four subjects did not make any errors while using touch interaction compared to three subjects for gesture interaction and none for tactile interaction.

Secondary Driving Task Performance

In addition to primary driving performance, we adapted a number of secondary driving performance measures namely interaction errors and task completion times. 1440 tasks (16 participants × 30 tasks × 3 interfaces) were assigned during the experiment. The result shows only marginal difference in interaction errors between the three interaction types and no significant differences were identified, *F*(2, 45) = 0.03, p > .97 (see figure 8).

Task efficiency was expressed by the total task completion time used for each of the systems (for 16 × 30 assignments) in seconds. The time spent on task execution is significantly different between the three systems according to a one-way repeated measures ANOVA, *F*(2, 45) = 65.53, p < .0001. Post hoc tests showed that the total task completion times was significantly lower for the touch interaction subjects compared to the tactile and the gesture subjects. This can partly be explained by the fact that one specific task was much easier to solve using the touch interaction system's informative display compared to the tactile interaction (smaller display) or gesture interaction (no display), which is also reflected in the deviation values for average per task values. However, omitting this particular task would not alter the statistical significant difference between the task completion times of the three interaction techniques.

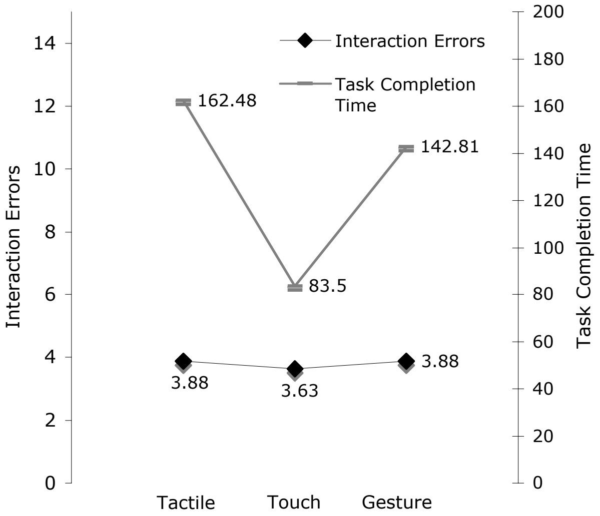


Figure 8. Task completion times and interaction errors for the three interaction techniques.

Eye Glance Behavior

Eye glances were categorized into three categories (under 0.5 seconds, 0.5 – 2.0 seconds, above 2.0 seconds) inspired by [19, 24, 25]. From the 48 driving sessions, we identified 2657 eye glances. Using the tactile interaction, subjects had the most eye glances with 1,120. The touch interaction produced 1021 (roughly 9% less eye glances compared to the tactile interaction) while the gesture interaction produced 516 eye glances (which corresponds to 54% less eye glances compared to the tactile interaction). Figure 9 illustrated number of eye glances for each of the three eye glance categories.

The gesture interaction accounted for approximately 19 % of all eye glances, while tactile and touch interaction accounted for 42% and 39%. A one-way repeated-measures ANOVA showed significant difference between the number of eye glances for the interaction technique, *F*(2, 45) = 38.4, p < .0001. This indicates that the gesture interaction led to fewer eye glances. A post-hoc test showed significant difference at the 1% level between the gesture interaction and the two other techniques. The gesture subjects varied highly on numbers of eye glances ranging from 9 to 96 eye glances to complete the 30 tasks.

Category one eye glances (less than 0.5 seconds) were less common when using tactile and touch interaction (with 60 and 64 respectively) compared to gesture interaction, which produced 229 category one eye glances. This difference was statistical significant, *F*(2, 45) = 7.08, p < .01. When using gesture interaction, it was common for the subjects to use quick eye glances (below the fixation limit) to coordinate their hand with the gesture canvas. Almost half of the gesture interaction eye glances (44%) were category one. Somewhat surprisingly, this type of eye glances was not common for tactile or touch interaction, but it seemed that their hand/eye coordination often involved fixation time on the displays.

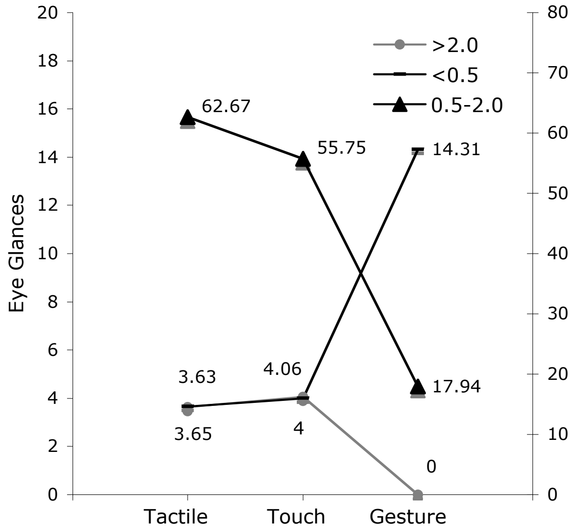


Figure 9. Number of eye glances for the three interaction technique on eye glance categories.

All three techniques yielded more category two glances (0.5 - 2.0 seconds) compared the other glance categories. This is perhaps not surprising, but a repeated measures ANOVA showed significant difference between the techniques on these eye glances, *F*(2, 45) = 62.14, p < .0001. A Tukey HSD post-hoc test showed significant difference at the 1% level between the gesture interaction and the two other techniques, but now significant difference between tactile and touch interaction. Perhaps not surprisingly, gesture interaction did not yield any eye glances of category 3 (above 2 seconds), which is interesting due to their impact on driving performance. In contrast, the tactile and touch interaction techniques yielded 58 and 65 total eye glances. This difference was significant, *F*(2, 45) = 10.43, p < .001.

The number of tasks solved with zero eye glances also differed across the interaction techniques, with 176 (out of 480 possible) for the gesture interaction compared to 4 and 35 for the touch interaction and tactile interaction respectively. If the three categories were given estimates for average duration (based on Green [9, 10] type 1 = 0.2 seconds, type 2 = 0.8 seconds, type 3 = 2.4 seconds), the subjects would remove their eyes from the road for 60 seconds using the tactile interaction technique compared to 55 seconds with touch interaction and only 17 seconds for gesture interaction.

Controlled versus Simulated Driving

We chose to conduct the experiment both in a controlled driving environment and a simulated driving facility. This was chosen to reduce some of the known limitations of two settings. Not surprisingly, the settings illustrated a number of similarities and differences. Task completion times and interaction errors showed quite similar patterns for the two settings. Also, eye glances produced similar results with the exception of eye glance over 2.0 seconds where controlled driving subjects would have significantly more eye glances than simulated driving subjects. This is perhaps surprising given the safety critical condition for the controlled driving.

Longitudinal control was, however, quite different between the two settings. Controlled driving subjects had significant fewer longitudinal control errors than simulated driving subjects. It seemed that the lack of vehicle movement made it difficult to maintain the desired speed. Further findings on the impact of the settings can be found in [2].

Satisfaction

Overall, our subjects preferred gesture interaction to both touch and tactile interaction. However, all 16 test subjects indicated that they would use any of the three interaction techniques during real world driving. When asked to prioritize the three interaction techniques, gesture was ranked first by 10 participants, touch was preferred by 5 while one participant preferred the tactile technique). The tactile interaction technique ranked third with 13 of the 16 subjects (gesture interaction was ranked third by 3 subjects and the touch interaction was not ranked third by any subject).

The gesture based music player was characterized as being intuitive and very easy and fast to use while the tactile interaction based player (car stereo) was criticized for its small buttons and poor layout. The gesture interaction technique was generally described as very pleasant and less demanding and distracting than the other two interaction techniques.

DISCUSSION

In-vehicle systems research has shown that we need new ways of interacting with in-vehicle systems as conventional interaction techniques decrease driving performance (i.e. [10, 15, 16, 23]). We investigated three different interaction techniques in their abilities to support drivers interacting with in-vehicle systems while driving. In the following, we will discus our findings in terms of the three interaction techniques and reflect our findings against other research studies. In this discussion, we will pay special attention to the gesture interaction technique and we will also discuss possibilities of using multimodal interfaces.

Tactile Interaction

Tactile interaction was less intuitive and efficient than we had expected. With the highest average task completion times, the most eye glances, and the highest number of in-complete assignments, tactile interaction was inferior to the two other interaction techniques. Having said that, tactile interaction illustrated a few strengths and opportunities not directly visible in the findings section. The tactile feedback was much appreciated by the subjects (though they did not stress this to a be lack for the other interaction techniques) who used the sensation of the physical buttons on the car stereo to "scan" for the appropriate buttons. However, it did not lead to fewer eye glances than with touch interaction.

The subjects generally used time performing the tasks when using tactile interaction, though there were certain tasks which benefited immensely from the tactile input style. This was for instance the case with volume adjustment, where a knob on the car stereo allowed the participants to quickly scroll to an appropriate volume level, which is in line with Tsimhoni and Green [24]. Gonzàlez et al. present a similar but different tactile interaction technique where drivers interact with in-vehicle systems through a thumb-based interaction technique [9]. Their objective was to have eyes on the road and hands on the wheels and they found that the thumb-based interaction technique could be a promising mean for in-vehicle systems input.

Touch Interaction

Touch interaction presented itself as the fastest and easiest interaction technique. It produced better results (although not significantly better) compared to the tactile interaction on eye glances and total task completion times. As touch interaction featured no tactile feedback (except for that of touching the screen surface) we initially expected that it would require substantially more eye glances in order to accommodate the same set of tasks compared to tactile interaction. This would be in line with the findings of [25]. However, we did discover this pattern presumably due to a rather simple interface compared to the more complex car stereos.

It may be argued that touch interaction benefited too much from the superior display capabilities allowing reasonable few buttons to be arranged in a manner that would facilitate interaction better than the smaller and more complicated car stereo. This is partly true. But touch-based screens make it possible to customize and alter the appearance of the interface; something that traditional tactile interface cannot simply provide. Button size and interface density certainly influence the accuracy and effectiveness of touch display [20]. Kristoffersen and Ljungberg found that touch screens had very high visual demands and was not suitable for use in attention limited situations [14]. This was confirmed by our study as touch-based interaction subjects produced almost as many eye glances as tactile interaction and in fact yielding more long duration eye glances than tactile interaction.

Gesture Interaction

Gesture interaction presented an interesting alternative for interacting with in-vehicle systems. As with the two other techniques it has its pronounced merits and shortcomings. As hypothesized, gesture interaction excels by its low visual demand. Our subjects used significantly fewer eye glances to perform assignments when using the gesture-based interaction. Most interestingly, we found no long duration eye glances (above 2 seconds), which are particularly devastating in terms of driving performance [6]. However, gesture interaction did not prove to be an eyes-free interaction technique as subjects often needed quick glances to support the coordination. This was also found by Alpern and Minardo who concluded that gesture interaction will not work in practice without eye glances [1].

We find it interesting that gesture interaction did not lead to significantly higher driving performance (in terms of fewer lateral or longitudinal errors), as subjects used only half the amount of eye glances compared to the other interaction techniques. Our findings seem to question the relationship between eyes-off-the-road-time and driving performance (i.e. [8, 21, 26]). It could be argued that the mental workload associated with gesture interaction (remembering the right gesture, remembering the system status, etc.) equals out the advantage gained by the limited eye glances, as it is known to be the case with speech recognition [4, 8]. But we have only limited results illustrating this. Perhaps somewhat surprisingly, gesture interaction did not result in more errors made than the other two conditions and the subjects were able to complete just as many tasks as with the tactile and touch interaction interfaces.

Our findings illuminate some limitations with the gesture interaction technique. One serious limitation was the lack of passive feedback, i.e. feedback on the current status of the systems and variable values. The implementation of gesture interaction for this experiment sought to remedy this deficiency by using a set of earcons as auditory feedback. We were inspired by Pirhonen et al. [19] who combined gesture input and earcons for a mobile music player. They found that this type of auditory feedback helped users in gaining an understanding of the current system status. We found, on the hand, that non-persistent feedback (such as earcons) was easily misunderstood, ignored, or missed. This happened several times, i.e. as subjects would fail to realize that they had paused the song or kept trying to increase the volume even though they were at the highest volume level.

Task completion time analysis revealed that using gesture interaction was generally more time consuming than touch interaction and was significantly slower on the adjusting the volume. In general, gesture interaction worked less well when it came to quickly adjusting properties, at least in the way gesture interaction was implemented in our study. To increase volume, subjects would have to input the "volume up" gesture several times. Some subjects suggested the implementation of more gestures, but again this could compromise how well drivers remember all gestures.

Subjects were mostly satisfied with the gesture interaction technique mainly due the fact that it allowed them to keep a focus on the road. Alpern and Minardo support this finding that drivers recognize the qualities of gesture interaction in driving [1]. They also found that subjects felt more in control of the vehicle when using gesture interaction.

Perspectives on a Multimodal Interaction Technique

The benefits of low visual demand from gesture interaction are somewhat questioned by the identified disadvantages and limitations. Nevertheless, reducing visual demand is in itself important enough to suggest incorporating gesture interaction into vehicles. Our subjects felt that the best way to optimize gesture interaction was use it in combination with elements from the two other interaction techniques. Combining gestures with tactile and passive visual elements could create a powerful and diverse interaction platform.

One way to achieve such a platform would be to combine gesture interaction with touch interaction. Here you could have a touch screen interface, which could receive gestures on top of the button-layer interface allowing the user to select either input technique for the basic functions and resort to traditional interaction when it comes to advanced functions. This alternative also offers some potential in terms of disabling advanced resource demanding interaction when the vehicle is moving perhaps even turning off the screen accepting only gesture input. Such a combination of interaction technique could be further augmented by offering tactile elements, such as a knob-type input device like the one found on the car stereo.

According to Wickens [26], an advantage of using multiple interfaces and modalities lies in the possibility to prey on the concept of minimal attention user interfaces. Pascoe et al. stated that minimal attention is achieved through the use of modes of interaction that does not interfere with the mode that the user is already employing [18]. In this regard, an interface could accommodate for inaccessible or inopportune perceptual channels by offering multimodality. Which modalities should be used at any given time would then either be up to the driver to decide or possibly based on context or situation. The challenge is to discover how the benefits from each interaction technique elements can be utilized without bringing with them the disadvantages of their original interaction technique.

Limitations

Our experiment suffers from a number of limitations, which could form further research with interaction techniques for in-vehicle systems. First, the three techniques differed not only in terms of their input characteristics, but also in terms of output. This was discussed briefly in the previous, but the way feedback was provided to the subjects in the three systems could certainly have influenced our findings. We need further studies to address ways to combine the input and the output. Secondly, for practical reasons we had to place the touch and gesture interfaces in a slightly different position than the tactile interface. Placement of in-vehicle systems is definitely important as drivers remove their eyes from the road to the system. The lower placement of the tactile interface could probably be a disadvantage in terms of eye glance durations and perhaps other issues. Thirdly, the tactile interface provided more functionality than the touch and gesture interfaces being an off-the-shelf product. It is acknowledged that increased system complexity can reduce user efficiency and effectiveness. Thus, the extra functionality could potentially influence the findings of the tactile sessions in a negative way.

CONCLUSION

Research on in-vehicle systems has illustrated a need for new interaction techniques for in-vehicle systems as more conventional techniques decrease driving performance. Studies on visual workload has shown significant less eyes-on-the-road time if drivers interact with in-vehicle systems with high visual demands and this directly affects driving performances. In this paper, we compared three different interaction techniques for in-vehicle systems. Our focus was to explore their effects on driver performance as well as eye glance behaviour. Hence, we aim to follow a "you can touch, but you cannot look" mantra.

Our results indicated that gesture interaction can reduce eye glances on simple secondary task interaction performances especially longer eye fixation glances. However, we found no effect of eye glances to the driving errors, i.e. on lateral control and longitudinal control. But the gesture interaction was not fully attention free as subjects sometimes had to make eye/hand coordination. The touch interaction was the fastest interaction technique, but also led to the most long duration eye glances (above 2 seconds). Finally, we found no significant differences on interaction errors.

As our experiment suffers from a number of limitations in terms of i.e. the differences on implemented feedback and placement of interfaces during the experiment, new studies could focus on how the interaction techniques perform with similar feedback forms. Furthermore, further studies could focus on how we can combine the interaction techniques to create powerful and adaptable configurations.

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