AIMMIT

Automotive Integration of Multi Modal Interaction Technologies

Project within: Electronics, Software and Communication

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Content

FFI in short

FFI is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety. FFI has R&D activities worth approx. €100 million per year, of which about €40 is governmental funding.

Currently there are five collaboration programs**: Electronics, Software and Communication, Energy and Environment, Traffic Safety and Automated Vehicles, Sustainable Production, Efficient and Connected Transport systems.**

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1. Executive summary

Visual inattention is the single most contributing factor to crashes, and demonstrates a direct relationship between eyes-off-road time and risk for accidents. New in-vehicle features as well as portable devices like smartphones and tablets add to the driver's visual inattention by using visual displays as primary sources for input and feedback. In this project, the hypothesis has been that visual inattention can be reduced by means of multimodal human-machine interaction (HMI). This project has explored, evaluated and proposed technologies and different ways of interacting with in-vehicle interfaces and systems. It has had a focus on multimodal interaction, involving visual, haptic, sound, gestures, and speech interaction, which opens up for the possibility for a driver to access in-car devices with less visual attention.

The project started with identifying the theoretical foundations and different viewpoints relevant for the scope of the project regarding multimodal user interfaces, i.e. visual, haptic, sound, gestures and speech. A framework - scorecard - that includes all relevant targets and criteria to consider when designing and evaluating HMI concepts were developed. In addition, relevant use cases that take technology development, social trends, infrastructure- and traffic conditions in the years to come into account were developed.

HMI concept ideation has been a focus in the project. The projects has been explorative to its character, and has included ideation phases in which modalities based on emerging technologies have been used in novel ways to outline new Human-Machine Interface (HMI) concepts. It has, for example, been investigated if, how and to what degree new visual technologies such as Augmented Reality and Head Up Displays (HUD) can be used. Concepts including gesture control, haptics, voice control and sounds have also been explored. Amongst other areas of interest interfaces for autonomous driving have been conceptualized and investigated. The project has given insights on how to design seamless multimodal HMI, i.e. interaction with appears natural to the user (driver) and which requires a minimum of mental effort.

HMI evaluations using driving simulators and evaluations of HMI designs in Wizard-of-Oz cars on test tracks have been conducted. In order to discuss and reach consensus on test methodology, seminars have been arranged. Evaluation methodology has been developed, as have different tools for addressing topics such as 'user experience', 'seamlessness' etc.

The project has given fundamental knowledge on which modality to use for which HMI input.

2. Background

The driving task demands more or less continuous visual attention. Looking away from the road for two seconds or more doubles the risk of a crash or near crash [1]. Research shows that visual inattention is the single most contributing factor to crashes, and demonstrates a direct relationship between eyes-off-road time and risk for accidents [2]. New car features add to the driver's visual workload by using in-vehicle displays as primary sources for feedback. In addition are portable devices like smartphones and tablets commonly used while driving and demand visual attention. In a study from UK, 31% of the drivers are admitted to texting, and 21% of them were likely to read a social media alert during driving [3]. The new features and the devices used together with the main driving task are competing in an unhealthy zerosum game for the driver's visual attention.

New vehicle functionality brings additional load to the driver's senses. For instance, automated driving systems, which very purpose is to relieve the driver from tedious driving tasks, also need to communicate their status and operation modes to make the driver aware of a possible imminent manual take-over need, or to just assure the driver that everything is under control. Here, it is less favourable to use a visual modality, as the driver may be engaged in reading or similar and may not observe a visual indication. Hence other modalities may be better alternatives. Another example is Route Guidance, which typically relies on visual instructions with direction arrows on a screen backed-up with a voice. In a complex traffic situation in an unknown area, the driver may not fully assimilate the route guidance instructions because the driver's visual channel is occupied. Using another modality than the visual may compete less with the driver's cognitive resources.

In-car human-machine interfaces (HMIs) include more than just basic functionality and use various multifunction controls and displays. Completing a task requires interplay between the hand and the eyes for controlling the input and output from the HMI, something which can be challenging during a driving situation. The shorter time the driver needs to divert his attention, visually and mentally, from the road and the driving task, the better [2, 4]. Additionally, every individual glance should be kept as brief as possible.

Some car manufacturers use multifunction devices like rotary-push knobs for user input to the system, while others rely on touch screen technology. The different solutions have different qualities. The multifunction devices are easy to locate and manipulate while driving, and may provide task-dependent tactile feedback, but are often considered difficult to use or less intuitive. Touch screen technology is often considered user friendly, but needs significant visual-motor concentration and coordination. Haptic feedback in touch screens is still mostly in research phase, and has not proved a significant improvement in usefulness [5]. Voice interaction has existed for many years but a limited set of available commands and problems with accuracy have limited its popularity. Sound is used mostly for information and warnings to support telltales and display messages. Some car functions also use spatial sound placement to increase efficiency and usability. However, using sound as a primary interaction mean (i.e. not only as support to visual information) is still uncommon. Larger full-graphic displays in multiple locations in the instrument panel have improved the possibilities of designing a more effective HMI, and head up displays with a large and reconfigurable graphic area enable drivers to read information quicker.

Legislation on which functions that are allowed while driving is becoming more strict. Handheld mobile phone use is banned in most European countries and texting while driving is illegal in 39 of the 50 states in USA [6]. In USA, the governmental body for traffic safety, NHTSA, has issued a proposal with very strict guidelines for allowed visual driver distraction caused by secondary tasks [7]. However, many drivers admit to not obeying these laws [3]; hence, enforcement is inherently difficult.

Multimodality in an automotive context is an active research area. For example, a study [14] suggests that driver situational awareness can be increased by using tactile displays integrated in the seat, giving the driver information about presence and position of vehicles in adjacent lanes. Another paper [15] deals with a concept called "WheelSense", which uses gestures on the steering wheel rim as commands to the in-vehicle entertainment system, giving the benefit that common commands can be performed without releasing the hands from the wheel. Research suggests that using voice feedback as a compliment to a visual menu in a display reduces driver distraction [16].

Car manufacturers have shown initiatives of multimodal in-vehicle technology, for example augmented reality (AR) [10]. Larger head-up displays with limited AR capability and touch screens with haptic feedback are already on the market [11].

As a base for this project, findings from previous and ongoing research projects such as OPTIVe, EFESOS (FFI USI, METOHMI, DRIVI), 3D Sound Design, AUX and HATric have been considered.

3. Objective

The objectives of this project have been to explore and propose solutions to communicate with vehicle systems and access in-car devices in a non-visual way or with less time consuming visual interaction. Key questions addressed have been:

- Which are the most promising multimodal technologies that reduce or replace the need for visual attention while still permitting desired information exchange between driver and vehicle/system?
- How should these technologies be applied in an automobile environment to minimize visual inattention and increase customer satisfaction? Which factors limit the practical application in real vehicles, and why?
- How should the effectiveness of the HMI with regards to visual inattention be measured in order to best reflect the potential safety benefits in real traffic situations?
- How should the HMI be designed in order to gain a high level of user acceptance, so that drivers will prefer this user interface over the current alternatives?

4. Project realization

The project has been divided into Work Packages (WPs). WPs 1-3 have had a state of the art and definition focus, WPs 4-7 have focused on HMI concept ideation and WPs 8-11 have targeted test tools, methods and analysis.

WP1 Multimodal HMI **WP2** Scorecard definition **WP3** Use case definition	**WP4** HUD technologies and interaction **WP5** Multi-modal HMI for automated vehicles **WP6** Haptic controls and touch HMI **WP7** Seamless multimodal HMI	**WP8** HMI simulator environment **WP9** Interaction design and simulator test set-up **WP10** Evaluations **WP11** Analysis and recommendations

Multimodal HMI: state-of-the-art, criteria and use cases

Initially in the project, there was a focus on reaching a consensus among the partners regarding what constitutes a multimodal HMI for a vehicle and to create a common ground, by conducting seminars, workshops and literature studies. The objective was to gather different viewpoints relevant for the scope of the project and to identify theoretical foundations. The workshops and seminars have discussed theoretical foundations and the literature studies have identified answers to the questions of how humans combine multimodal information and what preferences for modalities humans have.

A Scorecard with categories that includes corresponding criteria and targets that needs to be considered when designing and evaluating multimodal HMI concepts for an OEM was created. Not only categories relating to HMI were taken into account, but also categories relating to strategy, business and technology. The categories that were considered to be the most relevant were: safety, usability, usefulness, desirability, development, requirements, hardware and software. Related test methods were designed to measure fulfilment of defined targets for each criterion in the scorecard. The scorecard serves as a tool when taking decisions in the concept ideation phase as well as in the evaluation phase.

A set of appropriate use cases was defined that are relevant and important to an end customer. The use cases aimed at also taking into account technology development, social trends, infrastructure- and traffic conditions in the years to come. The focus in the project was on the commute journey, including use cases when approaching and entering the car, use cases in the car and use cases when parking and leaving the car. Both main tasks and subtasks were defined. There was a focus on NHTSA Automation level 2 (including driver support such as adaptive cruise control and steering aid), which was the main level to aim for in the AIMMIT project at this stage. The use cases have served as a template in concept ideation phases and when designing user studies in the project.

HMI concept ideation

WP4 has focused on exploring benefits of Augmented Reality (AR) projected in a Head Up Display (HUD). AR is a technology that augment/ superimposes the real-world with computer-generated sensory input and a HUD is a display that presents data on the windshield without requiring users to look away. There was a focus on use cases relating to the commute journey, as defined in WP3. The most important use cases and scenarios for AR HUD, relating to driver distraction and user experience, were used. To be able to demonstrate, evaluate and test the different use cases for AR HUD a prototype AR HUD environment was built up in the Volvo Cars Digital User Experience (DUX) lab. A projector dynamically projected information on the driving simulator’s screen for different use cases. Workshops and a user study were performed to test the different use cases.

Based on the outcome of the AR HUD activities conducted in the lab, a concept ideation was conducted which focused on three different times of implementation, with various technical limitations. A dialog with suppliers gave a realistic view on what is technically possible within different time frames. A HUD installation in a car was made and it became evident that a big challenge is to pack the space consuming HUD gear in the instrument panel and at the same time maximize the displayed HUD area at the windshield. User tests of the AR HUD concepts were conducted at Asta Zero, which showed promising results in terms of user experience and perceived safety.

The aim of the closely related WPs 5 and 6, was centered on investigation and conceptualization of user interfaces for emerging functions. Market trends and societal trends emphasize autonomous driving, which needs not only user friendly interfaces aiming for high user acceptance, but also safe, and context-specific interfaces. In order to do so, HMI concepts were developed and evaluated in and agile and iterative user-centered processes. User feedback and validation data were taken into account during the interaction design process, including repeated loops of ideation, prototyping and evaluation. The goal was to design proper interfaces with a focus on the interactions rather than technological implementation, yet taking into account possible technical constraints limiting practical application in real vehicles. For instance, the practicality of seat-integrated haptics and a brain-control interface (BCI) was explored in relation to the application domain, i.e. a moving car interacting with human beings. Furthermore, a haptic concept was integrated into Volvo's in-production Orrefors gear-shift lever. Results show that the context is indeed challenging, but advances in technology may facilitate usable interfaces in the near future.

One of the major concerns with automated driving is keeping the driver in the loop, in cases (levels) where the driver is required to take over at some point. A concept was designed to explore navigation in higher levels of automation, from a user experience perspective, not only for destination setting and feedback, but also for increased situation awareness (SA) and in-the-loop performance.

Command-based driving, or tactical control, in highly automated driving became another area of interest. The idea is based on automated driving, where the user is allowed to give tactical input during the trip without directly manipulating the vehicle's lateral or longitudinal position. The driver might for instance be allowed to command a takeover, a stop, or a detour, which is similar to giving directions or destination input to a driver as a passenger. Multiple concepts were designed and evaluated against each other in Volvo Cars' fixed-base driving simulator, including nomadic devices, touch-based, gesture-based, auditory, and haptic interaction in different ways.

The aim of WP7 was to develop further insight on how to design *seamless multimodal HMI*, i.e. interaction with appears natural to the user (driver) and which requires a minimum of mental effort. This has been accomplished by the completion of a series of altogether five experimental studies which together build further, fundamental knowledge on which modality to use for which HMI input (driver initiated input being the focus of the WP). In these experimental studies, speech, and/or touch, and/or gestures have been considered.

The first study investigated the notion of basic operations as a basis for a systematic approach to multimodal interface design, how users choose to complete such an operation given a certain modality, and which modality users prefer when completing such operations. This study was completed without reference to device or context.

In a second study, basic operations were combined into typical tasks when using an in-vehicle infotainment system. In this study the principles of unimodality and multimodality, i.e. how users experience interacting using one mode compared to a combination of mode, were compared. In addition, the principles of temporally cascaded versus redundant multimodality were assessed from a user experience perspective.

In the third study, context (i.e. car and driving) was added to investigate if and how context influences users' modality choices and preferences when completing a secondary task. The study was performed in VCCs fixed-based driving simulator. Users' choices of modality or combinations of modalities were observed and their experienced mental effort documented. In the fourth study, the focus was instead on interaction as a primary task in order to settle the impact of a driving context on users' choice and preference of interaction modalities.

In addition, two studies were completed that investigated the impact of habit on users' choice of and preference for modalities, how output modality may influence users' choice of input modality and if users could be 'guided' to use a certain modality.

Test tools, methods and analysis

As a tool, the Scorecard created in WP2 proved less beneficial than expected. A main reason is that the project had an overall more explorative character than that originally planned, searching for new and innovative solutions, whereas the Scorecard is judged to be more appropriate for systematic comparisons of more or less completed interface designs.

User evaluations of different HMI designs have been a fundamental part of the AIMMIT project and have consequently been carried out in several WPs, more specifically WPs 4-7. The evaluations have involved a range of different set-ups, from more fundamental and controlled experimental studies, to HMI evaluations in simple driving simulators and evaluations of HMI designs in Wizard-of-Oz cars on test tracks. Both existing and project-created simulators have been used.

To explore whether or not drivers feel the need to control tactical decisions when operating highly automated vehicles, which tactical decisions are important to control, and under which conditions this may be needed, a Wizard-of-Oz study was carried out in a fixed-base driving simulator (in the VCC DUX lab). A Wizard of Oz approach where the automation is simulated by a wizard driver was applied to make the test drivers believe that they were experiencing a highly automated vehicle. The test drivers were informed that they would interact with an automated vehicle, however, none of them suspected that the vehicle was driven by a wizard; in that respect the Wizard of Oz approach was also successful. Also, this approach along with the interview and questionnaire procedures developed in the project proved to be a powerful tool for gathering information early in the development process. Gathering information about participant's perception about and expectations of automated vehicles prior to the experiment could be a way to support understanding of subjective measures.

In order to discuss and reach consensus on test methodology, several seminars have been arranged with project partners. Evaluation methodology has been developed, as have different tools for addressing topics such as 'user experience', 'seamlessness' etc.

Within WP8, the HMI simulator (in the VCC DUX lab) has been updated with new hardware - a cockpit based on the latest platform and which includes the windshield. In addition, a concept for force feedback in the steering wheel has been developed. Eye tracking measurement equipment, which enables video and audio recording has been integrated, and biometric sensors and upgraded simulated software have been explored. There has been a focus on being able to collect objective data in the lab. The lab facilities have also been updated in order to be able to conduct different sorts of tests, which are needed for example for the different types of tests defined in the scorecard among other test needs.

5. Results and deliverables

5.1 Delivery to FFI-goals

AIMMIT has contributed to the overall FFI targets:

- Increase research and innovation capacity in Sweden. The work has contributed to knowledge regarding multimodal HMIs and their relevance to visual attention, user experience and other important factors. The work has helped Volvo Cars in designing a safe, still enabling and efficient

HMI, which is a competitive advantage. Semcon will utilize the competence gained in this project to remain a competent partner to other automotive OEM manufacturers in Europe and, increasingly, China. Participation in forward thinking research projects is vital for Semcon's ability to attract and retain talented engineers.
- Develop internationally connected and competitive research and innovation clusters in Sweden.
- Promote cooperation between industry and universities and institutes. In addition, the AIMMIT has contributed to the establishment of new international collaborations.

AIMMIT has supported two areas of the FFI collaboration program "Vehicle Development":
- Vehicle electrics and electronics
- Methods and tools for vehicle development. AIMMIT has included research and ideation activities as well as development of tools and processes for evaluation, which have already been successfully applied in other ongoing research and development projects.

6. Dissemination and publications

6.1 Knowledge and results dissemination

Several seminars and workshops have been held among the project partners for discussions, knowledge transfer, as well as concept and study ideation. Presentations of thesis work have invited parties outside the project. In addition, the following activities involving external parties have been conducted:
- Presentation of Command-based Driving for Tactical Control at AutomotiveUI 2015, Workshop on the attribution of cognitive abilities to vehicles.
- Presentation of Command-based Driving for Tactical Control at Transportforum 2016.
- Presentation of Tactical Control and Wizard of Oz in relation to automated vehicles at Automated Vehicles Symposium 2016.
- Presentation of studies concerned with seamless interaction at an open seminar at Chalmers, 2017.

6.2 Publications

Reports and papers

- Ahlstrand H. & Karlsson, I.C.M. (2014, revised 2017): Multimodal Interaction: System Input and System Output. A Literature Review. Division Design & Human Factors, Chalmers University of Technology, Göteborg, Sweden.
- Ekman, F. & Johansson, J. (2016): Defining Seamless Interaction and Investigating Users' Interaction with and Perception of Multimodal Interfaces. Division Design & Human Factors, Product and Production Development, Chalmers University of Technology, Göteborg, Sweden.
- Ekman, F. & Johansson, J. (2016): Investigating Users' Interaction with and Perception of Multimodal Interfaces. Exploring the Influence of a Driving Context and Interaction as a

Secondary Task. Division Design & Human Factors, Product and Production Development, Chalmers University of Technology, Göteborg, Sweden.
- Ekman, F. & Johansson, J. (2017): Investigating Users' Interaction with and Perception of Multimodal Interfaces. Focusing on Interaction as a Primary Task. Division Design & Human Factors, Product and Production Development, Chalmers University of Technology, Göteborg, Sweden.
- Habibovic, A., Andersson, J., Nilsson, J., Nilsson, M., and Edgren, C. (2016). Command-based Driving for Tactical Control of Highly Automated Vehicles. In Proc of The 7th International Conference on Applied Human Factors and Ergonomics (AHFE) 2016.
- Habibovic, A., Andersson, J., Nilsson, M., Malmsten Lundgren, V., Nilsson, J. (2016). Evaluating Interactions with Non-existing Automated Vehicles: Three Wizard of Oz Approaches. In Proc of the 2016 IEEE Intelligent Vehicles Symposium (IV).
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- Kalladithodi, S.K. & Karlsson, I.C.M. (2014): Multimodality, Natural Interaction and User Interface Design. Exploring the Idea of Basic Operations. Division Design & Human Factors, Product and Production Development, Chalmers University of Technology, Göteborg, Sweden.
- Klingegård, M. (2014). The multimodal Vehicle. RISE Viktoria, Göteborg, Sweden.

Theses

- Andjelkovic, A. & Carcelén, G. (2015): Developing a strategic controller with haptic and audio feedback for autonomous driving. Master thesis. Department of Signals & Systems, Chalmers University of Technology, Göteborg, Sweden.
- Edgren, A. & Kaalhus, M. (2015): Brain-Computer Interfaces in a car: Science fiction or a realistic concept? Master thesis. Department of Signals & Systems, Chalmers University of Technology, Göteborg, Sweden.
- Golematis, V. & Nawilaijaroen, J. (2015): Touch Drive: A touch-based multi-function controller for autonomous driving. Master thesis. Department of Interaction Design & Technologies, Chalmers University of Technology, Göteborg, Sweden.
- Hammar, J. & Karlsson, A. (2015): The design of a multi-touch gestural system for semi-autonomous driving. Master thesis. Department of Interaction Design & Technologies, Chalmers University of Technology, Göteborg, Sweden.
- Mikaelsson, O. & Mitton, A. (2014): Development of a Haptic HMI for Autonomous Cars. Master thesis. Linköping Institute of Technology, Linköping, Sweden.
- Modin, J. & Williams, T. (2014): Ett tvådimensionellt gränssnitt för taktil kommunikation i bilsätet. Bachelor thesis. Division Design & Human Factors, Product and Production Development, Chalmers University of Technology, Göteborg, Sweden.
- Tang, L. & Lundgren, J. (2016): Exploring Multimodality and Natural Interaction in a Driving Context. Master thesis. Division Design & Human Factors, Product and Production Development, Chalmers University of Technology, Göteborg, Sweden.

- Vechev, V. & Nilsson, S. (2017): FutureNav: Designing Navigation Interfaces for Semi-Autonomous Vehicles. Master thesis. Department of Interaction Design & Technologies, Chalmers University of Technology, Göteborg, Sweden.

7. Conclusions and future research

The objectives of this project have been to explore and propose solutions to communicate with vehicle systems and access in-car devices in a non-visual way or with less time consuming visual interaction. The work have contributed to the knowledge on multimodal HMIs and their relevance to visual attention, user experience and other important factors.

One of the conclusions from the project is that there is not a unity regarding the definition of multimodal interaction. There is a distinction between human and system-oriented definitions. Also they differ in the requirement for being denoted a multimodal system; (1) the mere presence of multiple modalities, (2) the way it is being processed in coordination/combination, or (3) the meaning it creates.

In the project promising multimodal technologies that reduce or replace the need for visual attention while still permitting desired information exchange between driver and vehicle/system has been explored. Based on the various studies conducted within AIMMIT, it can be concluded that performance of a multimodal interface is highly context and user dependent. It is hence difficult to say exactly which of them performs best. However, one important insight is that a successful multimodal interface needs to provide feedback to the user to gain acceptability and to reduce visual workload. As an example, AR HUD is a promising technology to use to increase user experience and perceived safety. However a that a big challenge is to pack the space consuming HUD gear in the instrument panel and at the same time maximize the displayed HUD area at the windshield.

The results from the experiments on the command-based driving where each driver used two of three different multimodal controllers (interfaces) indicate that the drivers experienced a need to affect tactical decisions of highly automated vehicles. Several of the tactical commands were found useful, especially on rural roads and highways. It also gave them a feeling of being in control of the vehicle, suggesting that command-based driving might be a way to keep drivers in the control loop. The results show also that all three controllers performed equally well in the evaluation; however, a more detailed analysis of the rest of experimental data is planned. An additional insight is that providing feedback and motivating important decisions seem to be a key feature of a controller for command-based driving, independently of the modality combination. Providing feedback increases overall user satisfaction.

In terms of seamless multimodal HMI, i.e. interaction which appears natural to the user (driver) and which requires a minimum of mental effort, some conclusions can be drawn in terms of which modalities that should be used for system input and system output:

- The different studies showed that the choice of / preferred modality is complex and depends on a number of factors including whether system input or system output as well as the interdependency between them. For example, a speech based cue for action may trigger sound (speech) input etc.

- For system input, the studies showed an interdependency between type of basic operation and preferred modality, more specifically an interdependency touch (modality and activate/deactivate (basic operation), touch and increase/decrease, speech and search, and gestures and navigate.
- The studies showed that consistency throughout an interaction sequence is preferred by users, hence the same modality for a specific operation - provided that interaction is not based on redundancy.
- Context, in terms of not driving - driving, influenced preferred modality for system input. The studies showed that context can override the 'natural' choice of modality. In the context of driving a car, the modality is chosen that is least affecting the ability to control the vehicle, in this case speech. Furthermore, the vehicle context also affects the choice of modality since for instance speech and gestures could be less favorable when passengers are present.
- Regarding the effectiveness of a multimodal system, the studies show that being able to 'skip steps' in a system hierarchy and hereby get directly to the goal is important for users. For example, speech as system input can allow users to more directly manipulate the system and accomplish a set goal.
- The studies provided indications of a differentiation between more 'active' and 'passive' operations and modalities. Some modalities offered a lower feeling of control than others and were therefore considered less appropriate for operations considered 'active' (e.g., requiring more precision etc). However, this is something that needs to be further investigated.

In terms of which modality or modalities should be used in order to create more natural interaction, i.e. interaction that requires a minimum of mental effort, the following conclusions can be drawn:

- The studies showed that what is perceived as 'natural interaction' when interacting with in-car systems is highly influenced by previous experiences, not experiences of human-human interaction but rather of other human-machine interaction.
- A redundant multimodal system, i.e. a system where users could choose between modalities, was in general perceived as more natural and easy to use since it gave a feeling of freedom and control compared to a fixed multimodal system. A redundant system also allows unimodal interaction which is deemed as the 'easiest' type of interaction, perhaps due to previous experiences.
- The studies showed that when adding a contextual layer (e.g. driving context) upon the interaction with an infotainment system, certain modalities become more cognitively demanding than others, e.g. speech was used more when visual attention was required for the primary task (driving).
- Certain modalities were perceived as more or less cognitively demanding to switch between. Also the order influenced perceived effort, for example speech to touch was considered less demanding than touch to speech, something that needs further investigation.

In terms of which new multimodal technologies have the potential to reduce or replace the need for visual attention while still permitting desired information exchange between driver and vehicle/system the following conclusion can be drawn:

- The studies show that a multimodal system that allows the driver to use gestures and speech to a higher extent (especially in demanding environments i.e. cities etc.) could reduce the need for visual attention. This could be a redundant system as well as a 'naturalistic and fixed' multimodal system that allows for a more speech- and gesture based interaction in this type of context.

How should the new technologies be applied in an automobile environment to minimize visual inattention and increase customer satisfaction?

- The studies have indicated that a redundant system, where the driver can choose modality to their liking, could minimize visual inattention (through eliciting modalities that are better suited for different situations) and also increase the customer satisfaction through allowing a sense of freedom, control and being able to individually choose uni- or multimodal interaction.

Examples of future research steps include a) validation of the results from Wizard of Oz experiments in a more realistic setting, and with a larger sample size, b) investigation of differences in drivers' experience of automation with and without access to tactical controllers. The large-scale evaluations of highly automated vehicles that are on the way (e.g., Drive Me project) could be used for such purposes.

8. Participating parties and contact persons

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