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A Comparative Analysis of Tap-based and Slide-based Interfaces: Evaluating Efficiency in In-Vehicle Touchscreen Interactions under Cognitive Load

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A Comparative Analysis of Tap-based and Slide-based Interfaces: Evaluating Efficiency in In-Vehicle Touchscreen Interactions under Cognitive Load

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ABSTRACT

The study investigated the efficiency and effectiveness of two in-vehicle touchscreen interfaces utilizing only one type of interaction under an intentionally increased cognitive load. The experiment utilized tap-based and slide-based interfaces, offering vehicle climate control functions.

Twenty participants, irrespective of gender and age but possessing a valid driver's license, took part in the experiment. The setup included a driving simulator, a gaming steering wheel, and a tablet simulating an in-vehicle touchscreen. Participants performed tasks to activate climate control functions during two rides, where each ride tested one type of interaction. A cognitive load was maintained using a countdown task.

After completing both rides, participants filled out the NASA-TLX questionnaire assessing secondary interaction and answered interview questions. The results indicated that the tap-based interface outperformed the slide-based interface in terms of efficiency and effectiveness, as measured by the average time spent completing tasks on the touchscreen. All participants, as per the interviews, expressed a preference for tapping over sliding.

According to NASA-TLX questionnaire ratings, participants found interaction with the touchscreen to be mentally demanding under increased cognitive load. Additional factors, such as driving experience, familiarity with in-vehicle touchscreen interfaces, and experience with racing games, driving simulators, and gaming steering wheel, were examined. While driving experience did not significantly influence task completion time, familiarity with touchscreen interfaces and related experiences facilitated faster task completion.

Further research is recommended to test interfaces under increased cognitive load in real-life driving conditions and with a larger participant pool.

SAMMENDRAG

Studien undersøkte effektiviteten og funksjonaliteten til to berøringsskjerms grensesnitt i biler som kun brukte én type interaksjon under bevisst økt kognitiv belastning. Eksperimentet brukte grensesnitt basert på tapping og sliding, og tilbød funksjoner for klimakontroll i biler.

Tjue deltakere, uavhengig av kjønn og alder, men med gyldig førerkort, deltok i eksperimentet. Oppsettet inkluderte en kjøresimulator, et spillratt og et nettbrett som simulerte en berøringsskjerm i kjøretøyet. Deltakerne utførte oppgaver for å aktivere klimakontrollfunksjoner under to kjøreturer, der hver tur testet én type interaksjon. Kognitiv belastning ble opprettholdt ved hjelp av en nedtelling oppgave.

Etter å ha fullført begge turene, fylte deltakerne ut NASA-TLX-questionnaire som vurderte sekundær interaksjon og besvarte intervju-spørsmål. Resultatene indikerte at grensesnittet basert på tapping presterte bedre enn grensesnittet basert på sliding når det gjaldt effektivitet og funksjonalitet, målt ved gjennomsnittlig tid brukt på å fullføre oppgaver på berøringsskjermen. Alle deltakerne, ifølge intervjuene, ga uttrykk for en preferanse for tapping fremfor sliding.

Ifølge NASA-TLX-skårer fant deltakerne interaksjon med berøringsskjermen å være mentalt krevende under økt kognitiv belastning. Ytterligere faktorer, som kjøreerfaring, kjennskap til berøringsskjermgrensesnitt i biler og erfaring med racingspill, kjøresimulatorer og spillratt, ble undersøkt. Mens kjøreerfaring ikke påvirket oppgavens gjennomføringstid betydelig, muliggjorde kjennskap til berøringsskjermgrensesnitt og relaterte erfaringer raskere oppgavefullføring.

Det anbefales ytterligere forskning for å teste grensesnitt under økt kognitiv belastning under reelle kjøreforhold og med en større deltakergruppe.

PREFACE

Firstly, I express my sincere gratitude to my main supervisor Yavuz Inal, whose invaluable support and guidance were instrumental in the completion of this master's thesis. His consistent availability for advice and weekly progress meetings played a crucial role in maintaining my writing momentum.

I extend my thanks to Frode Volden and Mari Bjerck for their assistance in obtaining necessary equipment, securing experiment locations, and providing essential information on deadlines and templates. Special appreciation goes to Thomas Berg for his generous help in participant recruitment. I am also thankful to the students who, having participated in the experiment, actively shared information with their friends and fellow students about the experiment.

The inspiration for this experiment stemmed from widespread dissatisfaction with the integration of touchscreens in car dashboards, replacing traditional buttons and switches. Drivers are concerned about safe driving. Driver complaints on forums about touchscreen distraction and difficulty in finding functions motivated me to explore interfaces solely reliant on one type of interaction.

This research deepened my understanding of integrating touchscreens into modern car dashboards, revealing the advantages and disadvantages for drivers. It heightened my awareness of the critical importance of safety for drivers and other participants of driving environment.

Looking ahead, I aspire to contribute to the development of in-vehicle interactive systems that prioritize safe driving. I am optimistic that the insights gained from this research will guide me toward achieving this goal.

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INTRODUCTION

In today's rapidly evolving technological landscape, where human behavior, vehicle design, and the rising integration of digital interfaces in today's cars converge, ensuring driver safety is a top priority. Self-regulation (Ebel et al., 2022), Advanced Driver Assistance System (ADAS) (Tigadi et al., 2016), and the use of touch interfaces (Ebel, Lingenfelder & Vogelsang, 2023) in infotainment systems are all important components in driver safety and safe driving behaviors.

The pursuit of the highest level of safe driving is essential, driven by the potential consequences of compromised road safety. The consequences of traffic accidents extend far beyond the individuals involved, affecting families, communities, and the economy on a larger scale.

The importance of driver safety cannot be emphasized, given the frightening increase in the number of automobiles on the road worldwide. According to the World Health Organization (WHO,2018), around 1.35 million people die each year in traffic accidents, making traffic accidents one of the major causes of mortality globally. The Road Safety Thematic Report states that 5-25% of car accidents are caused by driver distraction in Europe (European Commission, 2022). The report does point out that these figures may not truly reflect the state of affairs now because they are based on previous surveys. According to recent naturalistic study, there appears to be a correlation between the rise in car accidents and driver distraction.

Recent data from the European Transport Safety Council's (ETSC) emphasizes the escalating problem of distracted driving. Distracted driving has become the primary cause of car accidents in Austria causing 10,176 car accidents, 9,290 injured, and 76 deaths in 2023 (ETSC, 2023). These data emphasize the critical importance of prioritizing safety measures and mitigating factors that contribute to accidents.

The advancement of technology in automobiles is one of the factors influencing distracted driving. On the one hand, the technical sophistication of the vehicle has enhanced the driving experience by providing ease and functionality. On the other hand, this increases the chance of car accidents and presents potential risk.

To comprehend all types of driver distraction, it is critical to define what identifies driver distraction and to distinguish between different categories. Driver distraction is defined broadly as anything that draws attention away from the primary interaction as driving. The distraction can include any activity or event that takes the driver's attention away from the primary task, resulting in poor driving performance (Young et al., 2007).

Bach, Jaeger, Skov, and Thomassen, referencing Brown's classification, defined two types of driver distraction: general distraction and selective distraction. General distraction, which is frequently connected with visual distraction, refers to poor perception of essential visual driving information, which accounts for approximately 90% of the driver's input (Bach et al., 2009). This happens when the driver shifts his eyes-off-the-road, diverting their attention to other tasks, such as non-driving activities.

Selective distraction is characterized by mind-off-the-road from the road and puts a load on the driver's cognitive processes. This type of distraction can be caused by activities like as conversing with passengers, talking on the phone, and making decisions. Drivers may not effectively register objects in the driving environment even while looking straight at them when their minds are diverted from the road (Bach et al., 2009).

The driver's cognitive processes struggle to distribute attention effectively in both types of distraction. If a secondary task requires a high cognitive load, the time it takes to perform it increases, resulting in more occurrences of eyes-off-the-road or mind-off-the-road time (Young et al., 2007).

Cognitive load is closely linked to the concept of distraction, which is a measure of the mental work required to execute a task. The likelihood of making an error while doing a task increases as cognitive load increases (Palinko et al., 2010). Increased cognitive load due to complex interactions in the car can significantly impair driving performance and increase distractibility.

The replacement of physical manipulators on the car's dashboard with a touch interface is the current trend, which is due to the expansion in the functionality given by the car. In terms of visual attention, several operations have gotten more complex and demanding (Bach et al., 2009). Tapping and sliding has replaced the simple act of pressing a physical button. Given these facts, it is essential to pay special attention to new infotainment systems in cars that use a touch interface. The system that minimizes the need for visual attention will likely be in high demand.

This study dives into an essential component, with the goal of fully understanding the relationship between touchscreen interaction design, particularly associated with climate control, and driver safety. The main focus is on two types of interaction: tapping and sliding. This research incorporates increased cognitive load affected by factors like countdown task and secondary task interactions. The major goal is to evaluate how these two types of interactions affect drivers performance with touchscreen interfaces, with a focus on their effectiveness and efficiency.

The following research questions guided the study:
Which touchscreen interaction method, either tap-based interface or slide-based interface, offers the most efficient and effective means of interaction in a simulated driving scenario where cognitive load is intentionally increased?

The study was also supported by the following sub questions:

a) Which interface design was more intuitive and user-friendly according to participants performances and their comments?
b) To which degree mental demand was raised by secondary interaction?
c) Which of two secondary tasks was less mentally demanding?
d) What is the effect of driving experience and experience with in-vehicle touchscreen interfaces on participants’ performance?

LITERATURE REVIEW

In an era of rapid technological integration into our daily lives, the design and interaction of automobile systems has taken center stage in ensuring both driver safety and user experience. To delve into modern driver safety issues, a wide range of studies focusing on cognitive load, driver attention, interface design, and methods of interaction can be found. This section contains papers that highlight findings that have contributed to the current experiment.

Driver Safety

The need for thorough research on this subject has been made clear by the growing concern over the increase in accidents caused by distracted driving (European Commission, 2022). The focus of automotive research is driver safety, which includes a wide range of technologies and approaches intended to minimize accidents and improve overall safety.

In a study highlighting the importance of Advanced Driver Assistance Systems (ADAS), Tigadi, Gujanatti, and Gonchi (Tigadi et al., 2016) make the argument that the implementation of ADAS could significantly reduce or eliminate driver errors, thereby improving road traffic efficiency and transportation. The authors emphasize that while ADAS is important, it is not the sole remedy to issues with safe driving. According to Tigadi, Gujanatti, and Gonchi (Tigadi et al., 2016), the implementation of assistance systems moves the driver's responsibility further toward supervising the (partially) automated vehicle.

In a recent study by Ebel, Berger, Lingenfelder, and Vogelsang (Ebel et al., 2022) explored the aspect of driver self-regulation while engaging in secondary tasks, which they feel has not gotten enough attention. Based on an analysis of 10,139 interaction sequences from 2,755 trips between October 2021 and January 2022, they found that interaction and driver gaze behavior were more influenced by the level of vehicle automation than by vehicle speed and road curvature (Ebel et al., 2022). In particular, active Adaptive Cruise Control (ACC) and Lane Centering Assist (LCA) systems enabled the driver to interact with complex In-Vehicle Information Systems (IVIS) often and for significant periods of time, which led to prolonged eyes-off-road glances (Ebel et al., 2022).

Eyes-off-road glances are also associated with the growing number of infotainment systems being implemented in car panels (Ecker et al., 2010) (Colley et al., 2015). These systems frequently include touchscreens, which are usually assumed to demand substantial visual attention. However, factors such as touchscreen size, user interface design, and subtask boundaries may be able to reduce this visual demand. Grahn and Kujala (Grahn & Kujala, 2020) conducted two experiments to investigate the impact of these parameters. The Carrio automobile application was evaluated on a 7-inch tablet screen in the first experiment, and Android-based applications were tested on a 4.5-inch smartphone screen in the second. A driving simulator was used in the investigation.

The results showed that screen size does have an impact on visual demand. However, the size had a lesser effect than the application design used (Grahn & Kujala, 2020). Interestingly, when compared to Android applications, the in-car application needed significantly less driver attention (Grahn & Kujala, 2020). The study emphasized the significance of app design in positively impacting driver safety. Furthermore, drivers' ability to divide a single activity into subtasks was found to lower gaze length in the car, indicating a potential path for distraction mitigation (Grahn & Kujala, 2020). Analyzing the study's data provides a better understanding of how the design of a car's touchscreen influences driver distraction.

Driver Distraction

Driver distraction is a major threat to road safety, especially with the expansion of in-vehicle technologies. Understanding the types, causes, and consequences of driver distraction is critical for limiting its negative impacts.

The study by Regan, Hallett, and Gordon (Regan et al., 2011) sought to distinguish between driver inattention and distracted driving, taking into account various definitions for both. While various interpretations exist, efforts have been made to develop definitions that serve scientific and operational goals. A review of research articles revealed key elements for defining driver distraction, which included diversion from primary interaction, allocation of attention to non-driving-related activities, potential complete attention shift due to a secondary activity, and an implied or explicit assumption of compromised safe driving quality.

Concerning inattention, the writers emphasized many definitions from diverse sources, noting that not all of them are directly applicable to distracted driving. However, in the end researchers define driver inattention as paying insufficient or absent attention to critical activities for safe driving (Regan et al., 2011). The authors also stressed that driving distraction is a subcategory of driver inattention (Regan et al., 2011). Each category of inattention is classified, defined, and distinguished in the article.

This article significantly contributes to defining driver distraction and driver inattention, foundational for the terminology used in the current study. The following paper presents the classification of driver distraction.

A comprehensive study by Bach, Jaeger, Skov, and Thomassen (Bach et al., 2009) the concept of driver attention was investigated by categorizing 100 papers. The classification was based on a pair of main factors: the settings for evaluating on-board systems and the evaluation of driver attention in relation to on-board Human-Computer Interaction (HCI) systems.

The article describes driver distraction and its various forms. Driver distraction was classified into two types: general distraction (eyes-off-the-road) that transpires when the driver directs their gaze away from the road and selective distraction (mind-off-the-road) that involves the mind being diverted from the road, engaging in activities like conversing with passengers, talking on the phone, decision-making, and daydreaming (Bach et al., 2009).

The research further investigates the cognitive load that occurs during secondary interactions. Overload occurs when the demand for secondary interaction is extremely strong (Bach et al., 2009). Various studies have extensively examined overload. Underload, on the other hand, refers to situations in which driver assistance technologies reduce the driver's attention, preventing prompt responses to potentially hazardous situations (Bach et al., 2009).

The paper also focused on common driving settings used in research, such as no driving, simulated driving, controlled driving, and real traffic driving, with each presenting differing levels of controlled environments and related safety threats.

Finally, the paper covers various metrics used in research focusing on driver attention. These metrics include primary interaction metrics including lateral and longitudinal control, car-following performance, and driver reaction (Bach et al., 2009). In addition, measurements relating to secondary interactions, such as task effectiveness and efficiency, are considered (Bach et al., 2009). Eye gaze behavior and physiological indicators provide useful information on driver distraction and attention distribution (Bach et al., 2009). Another cognitive load assessment tool, particularly recognized method such as NASA-TLX, are also included in the measuring category.

Cognitive Load and Visual attention

When designing in-vehicle interfaces, cognitive load is an essential issue to consider alongside visual attention because they have significant effects on driver performance and safety.

Engstrom, Johansson, and Ostlund conducted a thorough investigation of the effects of cognitive and visual load on driver performance in both simulated and real-world driving settings. They carefully examined the consequences of each load type, providing information on which specific metrics can reveal changes in driver performance.

Lane-keeping performance is a common criterion in numerous research that shows driving performance (Engstrom et al., 2005). Drawing on previous studies, Engstrom, Johansson, and Ostlund explain that deviations in maintaining a steady lane of driving are detected when a driver's attention is diverted from the road. It is stated that increased visual demand has a negative impact on a driver's ability to maintain their lane of driving (Engstrom et al., 2005).

Increased visual load prompts drivers to engage in self-regulation by reducing vehicle speed (Engstrom et al., 2005). The researchers use data to support the idea that when faced with an excessively demanding secondary task, drivers tend to slow down in order to preserve the quality of their driving performance.

Aside from a decrease in lane-keeping abilities and speed reduction, there is also a decrease in the effectiveness of detecting events or signals in the driving environment (Engstrom et al., 2005). Engstrom et al. (2005) mentioned The Peripheral Detection Task that attempts to identify this impact caused by increased visual load by secondary tasks. Increased cognitive load can produce a similar effect, and studies have demonstrated a decrease in the effectiveness of detecting road events as a result.

The research's primary discovery, however, is the contrast between the effects of cognitive and visual load on driving performance. According to the results, when drivers face a high visual load, they prefer to adopt a lane-keeping approach, slowing down and making more steering adjustments. When faced with a high cognitive load, drivers tend to concentrate on the middle of the road, losing their ability to detect changes or signals on the road (Engstrom et al., 2005). The common effect, as emphasized by the study's authors, is an overall reduction in driving quality.

In a similar study Lee, Y. C., Lee, J. D., and Ng Boyle, L., looked at how cognitive load effects visual attention control and drivers ability to detect changes occurred in driving environment. Using a dynamic change blindness paradigm, they compared how cognitive load effects both internally and externally driven control of visual attention. According to this paradigm, identifying changes in the environment during blank situations can be difficult (Lee et al., 2007, pp. 721-733). Even significant changes can be difficult to spot if the observer anticipates the change or the change is recurrent (Lee et al., 2007, pp. 721-733).

Apart from visual changes, participants in their research completed an additional auditory task. Participants were given information on three restaurants, including pricing, quality, and waiting time. Further on they were then required to process and match this information to restaurant categories (Lee et al., 2007, pp. 721-733).

The researchers carried out two experiments in a medium fidelity simulated driver setting, employing a vehicle cab modified to provide a 50° visual field of view, a force feedback steering wheel, and an immersive audio setting. Each experiment's participant groups were chosen based on specified characteristics such as driving experience, frequency of driving, and holding a valid driver's license. Each group had a equal number of participants.

The study's findings demonstrated that, regardless of the circumstances, cognitive load consistently reduced participants' capacity to identify changes therefore affecting drivers` visual attention. Even when external signals were masked, this effect persisted (Lee et al., 2007, pp. 721-733). Furthermore, cognitive load influenced the ability to detect both safety-critical and non-safety-critical events, emphasizing its impact on attentional control. Ignoring changes and events poses a risk to your level of safe driving (Lee et al., 2007, pp. 721-733).

Interaction methods

The design of methods for interacting with touchscreens in car dashboards is another aspect that affects both driver distraction and driving safety. Touchscreen interfaces play a central role in modern vehicles, providing a means for drivers to interact with various in-vehicle functions. User experience, driver distraction and driver attention are significantly impacted by the design of interface interaction methods.

Tuomo Kujala conducted a study to investigate the influence of various touch interface interaction methods in a simulated driving situation. The study examined distraction effects through kinetic interaction, button interactions, and swiping interaction within a music application. Twenty-four people were recruited to complete activities in a medium fidelity driving simulator using an application on a touchscreen (Kujala, 2013, pp. 815-823).

The study assessed distraction effects using a variety of metrics, including an efficiency of visual sampling, visual demands of search tasks, driving performance compared to baseline driving, search task performance, and participants' subjective experiences on task demands and preference (Kujala, 2013, pp. 815-823). The author established time restrictions for evaluating the effectiveness of visual sampling, with a maximum of 1.6 seconds and a minimum of 2 seconds. Prolonged visual sampling over 2 seconds was found as a potential source of a car accident (Kujala, 2013, pp. 815-823). Questionnaires, including the NASA-TLX technique, were used to collect subjective experience data.

The study found that the kinetic interaction method was the most demanding in terms of attention and the least user-friendly based on various measurement data acquired during the experiment (Kujala, 2013, pp. 815-823). When using kinetic scrolling, participants reported increased visual load, workload and decreased visual sampling efficiency (Kujala, 2013, pp. 815-823). Furthermore, when compared to baseline driving, the use of kinetic scrolling resulted in lower lane-keeping accuracy.

In comparison, button-based and swipe interactions outperformed, although with minor differences. Buttons outperformed kinetic swipes only in subjective evaluations, with no meaningful benefit in objective measurements. When compared to swiping, button engagements resulted in longer glances at the display, however the difference was not significant (Kujala, 2013, pp. 815-823). The author proposed that the extended gaze could be related to the size of the graphical user interface (GUI) elements, meaning that increasing element size could potentially relieve the problem. Furthermore, it was found that swiping may have a modest advantage over other interaction methods due to the decreased necessity for precise tapping or interaction.

The subjective data revealed valuable insights into the perceptions of participants about button and swipe interactions. Even though metrics showed that swiping was the least distracting interaction method, people preferred buttons (Kujala, 2013, pp. 815-823). The author claimed that their preference for buttons could be explained by their familiarity with this interaction style on mobile phones.

Further on, Annegret Lasch and Tuomo Kujala conducted a separate study on the impact of numerous aspects on driver distraction, including interaction methods, the number of items on the interface, and screen orientation. The study was carried out with 18 participants who were tasked with scrolling through music tracks in a list style utilizing a medium fidelity simulated driver setting. One of the objectives of this research was to discover how screen orientation affected driver distraction. To do this, the participants were divided into two groups: one used a portrait mode screen, while the other utilized a landscape mode screen.

The primary objective of this experiment was to investigate the impact of three methods of interaction on driver distraction when interacting with a touchscreen interface: kinetic scrolling, buttons, and swiping. These methods have been tested in a variety of interface setups, including three, five, and seven items on a list. The experiment measured a variety of characteristics, including visual sampling efficiency, visual demands, and the subjective experiences of the participants. To assess the risk of car accidents linked with extended stares, gaze time limitations of 1.6 and 2 seconds were imposed.

Swiping was found to be the most effective interaction method, overcoming kinetic scrolling and buttons in the course of the research. Swiping outperformed buttons in terms of visual sampling efficiency and visual demands. Kinetic scrolling produced results comparable to swiping, with modest differences in the duration of in-vehicle glances and the percentage of glances lasting more than 2 seconds (Lasch & Kujala, 2012, pp. 41-48). Workload measurements revealed no statistically significant variations. The findings supported the notion that swiping is the least distracting interaction mode, as proven by subjective and objective measures (Lasch & Kujala, 2012, pp. 41-48).

The amount of items on the list was also assessed, and it was discovered that interfaces with 3 or 5 items were less distracting than those with 7 items. Surprisingly, there were no significant changes in screen orientation between the two groups of participants. In line with Tuomo Kujala's earlier study, the principal finding of this experiment underlines the preference for swiping as the most effective and least distracting interaction mode for in-vehicle touchscreen activities (Lasch & Kujala, 2012, pp. 41-48).

Although several studies have explored interaction methods such as tapping and swiping in the context of in-vehicle devices there is a significant lack of research on sliding interaction withing the same context. The primary difference between sliding and swiping is the requirement for accurate targeting of the interactive element (Sundar et al., 2014, pp. 109-152). Sundar and a group of researchers demonstrated a similar type of interaction; however, in their work, sliding was conducted using a computer mouse on a computer, instead of a human finger on a touchscreen. As a result, this paper is an important addition that intends to shed light on the use of sliding interaction method with a touchscreen in a in-vehicle setting.

METHODOLOGY

This section provide details of the methodology used to perform the experiment with the aim to increase driver safety. The study looked at two types of touchscreen interactions (tapping and sliding) and how they affected driver distraction and mental workload. The methodology incorporated multiple research methods, data collection techniques, and data analysis tactics. These methodologies have been used to study user interactions, associated cognitive load, and safety implications in driving simulation environments.

Purpose of the Study

The main objective of this study was to understand the various kinds of interactions with an in-vehicle interface when the driver's cognitive load was intentionally increased. The study was also driven by the desire to accurately comprehend and assess the effectiveness and efficiency of various types of interactions in complex mental circumstances. Another purpose was to assess the level of driver distraction when interacting with the interface. Furthermore, driving performance was analyzed, perceived workload was investigated, and the interface's usability was appraised - all in accordance with user-centered design principles.

Participants

For the driving simulator experiment, 20 people were recruited. The most crucial selection criteria was the presence of a valid driver's license. Since the study aimed to cover a wide spectrum of people, the participants' age and gender were not determining characteristics for recruitment to participate in the experiment. Questions on gender and age, on the other hand, were included in the demographic form that participants completed prior to the experiment as they offered possible insight into how these factors would influence the study's final results.

Moving forward with the list of essential selection criteria, it's worth noting driving experience, familiarity with touch interfaces in cars, and experience with racing games, driving simulators, and gaming steering wheels and pedals as potential sources of participants' high performance when performing tasks. The last three mentioned criteria may affect the participant's confidence in their engagement with the simulator and equipment.

Participants also reported their frequency of driving, experience and frequency of interaction with touchscreens in general on the demographic form. Similar to the collection of information on age and gender, gathering these additional data could potentially benefit the study of their impact on participant performance.

Driving Setting

There are several types of driving settings that are used for research. Bach, Jaeger, Skov, and Thomassen have characterized four basic types: no driving, simulated driving, controlled driving, and real traffic driving (Bach et al. 2009). A simulated driving situation with a driving simulator was chosen for the purposes of the experiment and master's thesis research. This option provides considerable advantages that are necessary for experimental work.

In their own research, Winter, Leeuwen, and Happee thoroughly explored the advantages and disadvantages of utilizing a driving simulator. Notably, the driving simulator allows for perfect control of the test subjects' operating circumstances (Winter et al. 2012). Variables like weather, surroundings, road type, traffic volume, the presence of pedestrians, and other factors can all be accurately modified to meet the needs of the experiment. This flexibility allows the experiment to have customized situations that can be followed systematically.

The driving simulator records a wealth of data concerning both the driver's actions and the influences exerted upon the driver, such as the impact of objects within the simulator on the test subject's virtual vehicle. For instance, if the purpose is to collect data on the driver's frequency of traffic offenses, this information can be simply captured.

Notably, one significant advantage of the driving simulator is the safety it provides to experiment participants. The simulator enables for traffic level adjustment, allowing for the introduction of large traffic density and aggressive behavior of other virtual vehicles. Sharp braking of vehicles in front, abrupt lane changes, and pedestrians running onto the road can all be reproduced. These settings might increase the driver's focus on the road, hence increasing mental load for a more thorough comprehension of the experiment's aims.

“City Car Driving" (City Car Driving, 2023) driving simulator incorporates all of the above listed benefits. Notably, it excels at providing realistic driving dynamics, taking into account a wide range of elements that influence car behavior. The simulator has been thoroughly examined and tested, and it has become clear that these combined advantages position it as the best candidate for incorporation into the experiment.

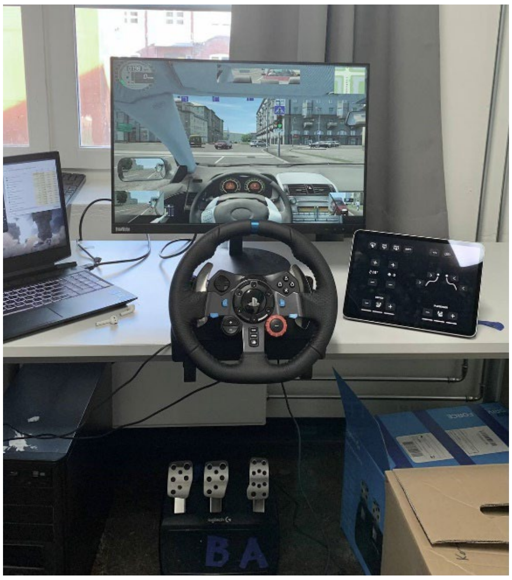

Figure 1: Driving setting

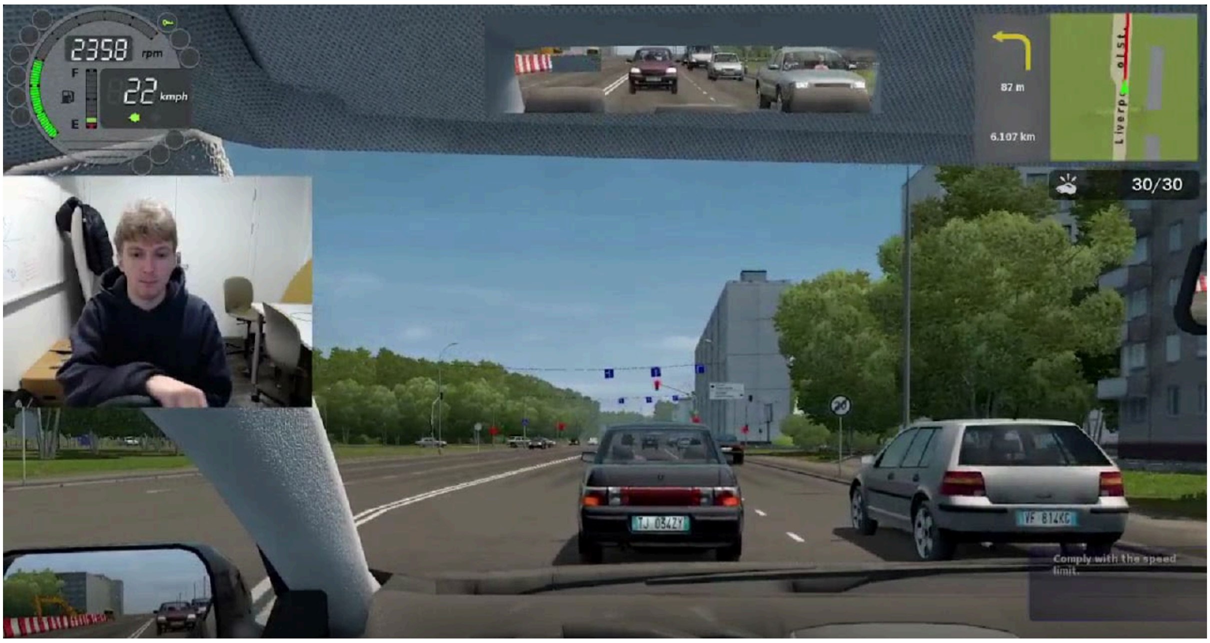

Figure 2: An example of how each session was recorded.

Apparatus

The driving simulator setup was placed at the Norwegian University of Science and Technology in Gjøvik, in a specialized office space, giving a controlled and private environment favorable to the experiment. The setup's primary components included a Logitech G920/G29 racing wheel and pedals, complete with adjustable gas, brake and clutch pedals, an ergonomic office chair, and a monitor that displays the driving simulator.

A strategically placed camera atop the monitor will record eye movements and hand movement throughout each session to acquire critical data about participant involvement. These recordings will encompass the entirety of each session, commencing at the onset and concluding at the end.

Additionally, the simulator sessions will be properly recorded in order to capture critical events that occur and are likely to influence the driver's decision-making process. This extensive recording strategy will include collecting interactions with the iPad 11 Pro (3rd generation) 2048x1536 px resolution screen, delivering a rich dataset required for thorough experiment analysis.

Two touch interface prototypes

To investigate secondary interaction activities, two touch interface prototypes were developed using Figma (Figma, 2023). A review of recent car models was used to identify the climate control features. The selected functions of the climate control system were found present across many modern car models. Functions found solely in specific models or encountered infrequently were not considered when designing prototypes. As a result, the participants in the experiment were not required to learn new climate control functions.

The main goal of the experiment is to evaluate the effectiveness and efficiency of different methods of interacting with these touch interfaces. Consequently, one prototype uses a tapping interaction, whereas the other uses sliding.

Touch-based interactions were carried out through single or repeated taps of the participant's finger on the touch interface. When a function was activated, the function icon was highlighted. The participant could activate an infinite number of functions at the same time. This prototype, like another one, solely gave visual feedback.

Slide-based interaction was executed by dragging a slider with your finger to the necessary climate control function. The slider has been moved horizontally. When the slider was moved to an assigned function, the function icon was highlighted.

Throughout the prototype development process, the concepts of user-centered design were constantly applied. The color palette was carefully chosen to be consistent with the Material Design (Material Design, 2023) and Google Design for Driving (Google Design for Driving, 2023) standards, ensuring a user-centered design approach.

Participants in a previous study on touch interface design said that certain items required more effort to interact with, owing to their small size (Tikhomirov, 2022). An investigation into the influence of touchscreen size on visual demands and distraction indicated that screen size did not have a significant impact. However, there was a significant difference in visual load between the two programs used. Notably, the Carrio app, designed for in-car use, imposed a lower visual demand, which was most likely due to its larger interface buttons (Grahn & Kujala, 2020).

Considering these insights, refining the interface elements was carried out with the objective of reducing participant errors and enhancing overall usability.

Tasks

Primary Interaction

Participants engaged in tasks related to driving a car within the driving simulator during the primary interaction phase. Their major goal was to drive the car while following regular traffic regulations and avoiding potential emergency scenarios caused by their actions. The capacity of the participants to maintain the required speed limit was especially important. Given the additional cognitive load introduced by secondary interactions, it was expected that participants would have difficulty adhering to speed limitations. Participants were obliged to drive at a speed of 50 km/h in accordance with Norwegian traffic regulations for densely populated areas (Trygg Trafikk, 2023).

In addition to adhering to speed regulations, participants were tasked with safely guiding the automobile to a final destination on the route that had been pre-determined by the experiment leader before to the ride start. A navigator was provided in the upper right corner of the interface to assist with route navigation within the driving simulator, with a red line denoting the designated route. This navigator was a built-in function of the driving simulator that displayed a visual representation of the route throughout the driving session. Completing the ride without meeting any unforeseen road hazards usually took participants 5 to 6 minutes.

Secondary Interaction Tasks

The primary objective for participants included in the secondary interactions was to interact with a tablet's touchscreen. In their study, Bach et al. (2008) also resorted to using tasks for experimental participants. The tasks in their study related to interaction with a music player. In the current study secondary interaction simulated the use of a car's dashboard with a touchscreen. Two different climate control interfaces were developed and demonstrated on the tablet. Each of these interfaces relied on specific type of interaction - tap-based or slide-based interaction.

Engaging with these interfaces involved completing tasks to activate climate control functions. Participants were handed an equal amount of tasks for both interfaces to preserve objectivity. A total amount of five tasks have been developed. Participants were asked to use climate control settings on the touchscreen interface at regular intervals of 60 seconds while concurrently focusing on the primary interaction of driving a car within the driving simulator.

Each touch interface included the following tasks:
1. Elevate the air temperature by two units
2. Activate the front shield heating
3. Increase the power of the fan by four units
4. Increase the heating of the passenger seat by one unit
5. Adjust the air flow towards the driver's head

Countdown Dynamics

Increase in cognitive load can be triggered by a variety of factors, both internal and external. Internal factors, such as decision-making and mental processing, are classified as selective distraction according to Bach, Jaeger, Skov, and Thomassen (Bach et al., 2009).

The current experiment incorporated a mental task to create increased cognitive load, drawing on this concept and insights from Hochreiter, Daher, Bruder, and Welch's work on cognitive load.

Counting down was the key cognitive load-inducing task for participants in this trial. This counting exercise was used in the study to increase cognitive load among participants. The authors also cited previous research publications that supported their findings (Hochreiter et al., 2018).

In the current experiment, the experiment leader asked participants to count down from 500 to 0, subtracting 3 units with each count. The decision to employ the identical numerical sequence, with the exception of the subtracted units, was taken for consistency and safety, as well as to be in line with the approaches tested in the Hochreiter et al. (2018) study. The counting down task remained active from the start to the end of each participant's trip in the driving simulator, ensuring a continual cognitive load. If a participant got confused or made mistakes during the exercise, they were instructed to keep counting. The goal of introducing this activity was to keep cognitive load increased, but not to measure mathematical skills, and participants were made aware of it prior to the start of each session. The experiment was conducted with participants from different countries, allowing the countdown to be performed in their preferred language.

MEASURES

Demographics

As already established above, demographic data about the experiment's participants was collected at the recruitment stage, before the experiment began. This data was gathered using a demographic form comprising 12 questions. These questions covered the participants' age, gender, driving experience, experience with touchscreens, experience with driving simulators, among others, to provide a comprehensive profile of each participant. Each participant individually completed this form. At the analysis stage, the collected data was used for comparisons with other quantitative data, such as driver performance with tap-based and slide-based interfaces. Some of this data is presented in tables.

Visual Distraction

Visual distraction, which occurs when drivers take their eyes off the road to engage in secondary interactions, is a major safety risk. Visual perception is essential to successful primary interaction. According to Bach et al. (2009), 90% of the feedback a driver gets while driving is visual. Enhancing safety is one of the key objective for the research. Therefore each session was captured with a camera attached to the monitor to measure visual distraction during the experiment.

The recorded videos were evaluated to identify for how long each participant had to gaze at the touchscreen in order to perform secondary interactions, specifically activating climate control features. Each participant's average time off the road was then calculated. The calculated data on average time off the road were used to make conclusions about the impact of different touchscreen interfaces on visual distraction and its implications for driving safety.

Cognitive Distraction

Cognitive distraction, as outlined by Green (2001), is synonymous with "mind-off-the-road" distraction, as also written by Bach et al. (2009). This sort of distraction happens when the driver's cognitive capacity is challenged by the processing of multiple pieces of information. Green (2001) identifies perceptual interpretation, memory processes, mental processing, decision selection, and decision execution as examples of mental functions that require attention and can significantly reduce overall attention capacity. The countdown task chosen for the experiment would produce cognitive distraction by imposing mental processing, hence increasing the cognitive load of the participants.

Questionnaire

Another quantitative method involved utilizing the NASA Task Load Index (NASA-TLX), a widely established survey-based tool used to estimate the driver's workload (Agency for Healthcare Research and Quality, 2023). Bitkina et al. (2021) have previously acknowledged NASA-TLX as an excellent technique for measuring workload in human-computer interaction research.

Participants in this experiment completed the NASA-TLX survey to provide information about their experiences with the climate control touch interface. The survey included 6 questions about Mental Demand, Physical Demand, Temporal Demand, Performance, effort, and Frustration. Participants utilized a scale ranging from "Very Low" to "Very High" and from "Perfect" to "Failure" to evaluate both the secondary interaction tasks.

In the data analysis phase of the experiment, the values from the scales were converted into numerical format for easier interpretation. Each scale consisted of 21 divisions, with the central division serving as the baseline and marked as 0. Divisions to the right of this central point, ranging from 0 to 10, were classified as positive values. Conversely, divisions to the left, ranging from 0 to -10, were classified as negative values. By translating participants' responses on the questionnaire into this numerical format, the data was effectively organized into tables for comprehensive analysis alongside the main experiment data.

Interview

The experiment leader interviewed each participant in order to collect qualitative data. These interviews were carefully planned to supplement and expand the information gathered via questionnaires. The primary purpose was to explore deeply and get qualitative insight into the participants' perspectives on several important aspects of the study.

The questions were made to explore the nuances of the various elements of the experiment. Participants were asked to express their thoughts on touchscreen interface design components, their experiences with different types of touchscreen interactions (tap-based and slide-based), and how these interactions influenced their overall engagement.

Furthermore, the interviews expanded on participants' observations regarding distractions encountered throughout the experimental tasks and how these distractions influenced their cognitive load. Their thoughts on visual feedback, an important part of touchscreen interface, were also investigated in order to better understand how it influenced their interactions and decision-making processes.

The qualitative data gathered from these interviews complemented the quantitative results of the questionnaire, resulting in a thorough and in-depth study of the experiment's goals.

Procedure

Each participant was given a consent document summarizing the full experimental protocol and explaining the use of the video and audio recording of each session. By signing this consent form, participants granted permission for video and audio recordings to be used solely for analysis within the context of the experiment and then erased once the research was completed.

The next stage was to fill out a demographic questionnaire with information about the participants, such as gender, age, driving experience, frequency of driving, experience with driving simulators, and use of gaming steering wheels. This form's data was used in later studies to investigate potential correlations between the given demographic characteristics and the experiment's results.

Immediately after that, the experiment leader explained the tasks that the participants would be needed to complete during the experiment. It was highlighted that the participants needed to complete the countdown task until they arrived at their final destination. The experiment had two rides, which corresponded to the testing of two different touch interfaces. Participants were assigned a task relating to activating climate control functions on one of the interfaces every minute from the start of the ride.

Following that, an instructive and training phase was carried out, during which the experiment leader presented the participants with the equipment with which they would engage. Participants were initially introduced to the gaming steering wheel and pedals, as well as the functionality handled by the steering wheel buttons, such as changing gears and adjusting the in-car camera. From that, participants were offered to do a practice drive without reaching a specific location in order to become familiar with the car simulator.

After that, participants were introduced to the touchscreen and shown a demonstration of the two interfaces with which they would engage. The main phase of the trial began when participants confirmed that they were ready.

Following completion of the two rides, participants were invited to fill out the NASA Task Load Index questionnaire, which gathered information about their workload faced during the experiment.

Finally, the experiment concluded with a brief interview with participants in which qualitative information about their preferences for interaction methods, interface design, distraction, cognitive load, and visual feedback was gained. Participants were given the opportunity to make suggestions on how to improve interaction method, interface design, and feedback.

Prototype

First version of the prototype

The first step to developing the first version of the prototype was to examine modern cars dashboards and control panels. The study concentrated on panels with touchscreen interfaces (Tikhomirov, 2022). The primary attention was placed on the climate control system's functions. The functions that were consistently present throughout all selections were discovered from the array of panels chosen for examination. During the following phases of prototype development and testing, these selected functions formed the essential elements.

For the creation of the climate control prototype, the following functions were chosen: front windshield heating, maximum defrost, rear windshield heating, air recirculation, auto mode, air conditioning, maximum cooling, fan power, air temperature adjustment, air flow direction control, and passenger and driver seat heating.

The prototype's initial version was designed to accommodate a screen size similar to that of the iPhone XR, and it had previously been used in a study focused on testing three analog interaction methods (tapping, dragging, and rotating) transferred to a touchscreen interface. Thus, in the prior study, participants interacted with three interfaces, each of which was tailored to a specific method of interaction. The climate control functions were the same across all three interfaces. The biggest distinction was in the interactive elements.

The selected functionalities were placed in a layout suggestive of genuine interfaces to match the design of existing automobile touch displays. The top third of the screen was filled by functions for heating the vehicle's shields and activating climate control features, while the middle was occupied by controls for fan power and temperature settings. At the bottom of the interface, there were settings for altering air direction for both the passenger and driver regions, as well as seat heating. To provide a user-friendly and visually consistent design, the size of interactive elements and color palette followed Material Design (Material Design, 2023) and Google Design for Driving (Google Design for Driving, 2023) principles.

The final stage of development included interactive animations, such as visual indications for activated functionalities and slider movement animations.

The major goal for the previous experiment participants was to complete tasks involving the activation of climate control functions utilizing three various methods of interaction (Tikhomirov, 2022).

The trial with the first prototype generated a lot of input, opinions, and suggestions for improving the first version and resulting in the move to a second version. Notably, the rotating interaction approach was considered less convenient by a large majority of participants when compared to tapping and sliding. In terms of the time necessary to engage climate control settings, rotation had the lowest efficiency (Tikhomirov, 2022).

Some users have commented about the size of key interaction elements, specifically the slider. They proposed that increasing the size of the slider will improve usability because the existing dimensions necessitate precise aiming for interaction (Tikhomirov, 2022).

Furthermore, participants noticed that in a slide-based interface, the driver can only select one active function at a time, as opposed to an interface that uses tapping interaction.

While the prototype's design did not attract clearly negative remarks from testing participants, both subjective and quantitative data showed several shortcomings that needed to be addressed.

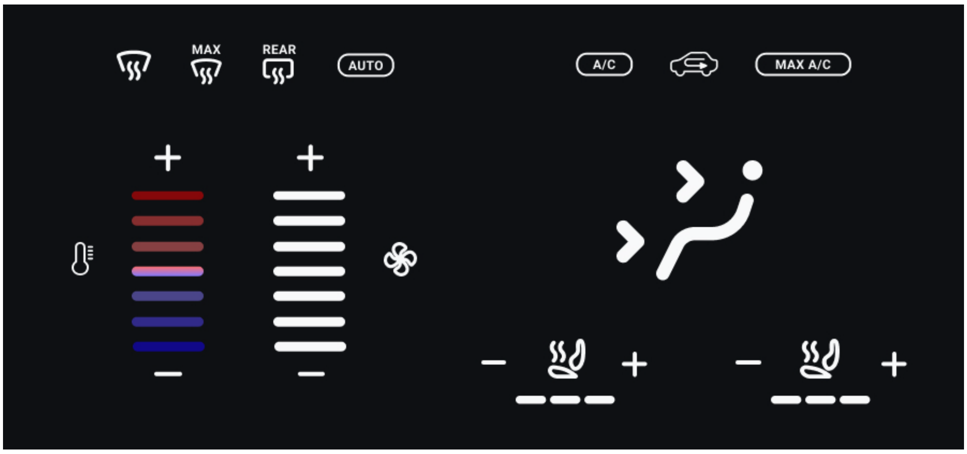

Figure 3: First version of the interface dependent on tapping type of interaction.

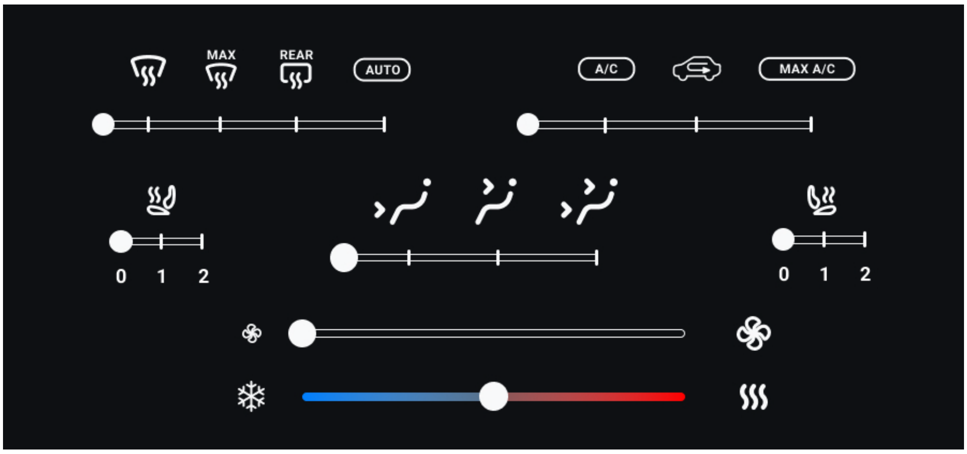

Figure 4: First version of the interface dependent on sliding type of interaction.

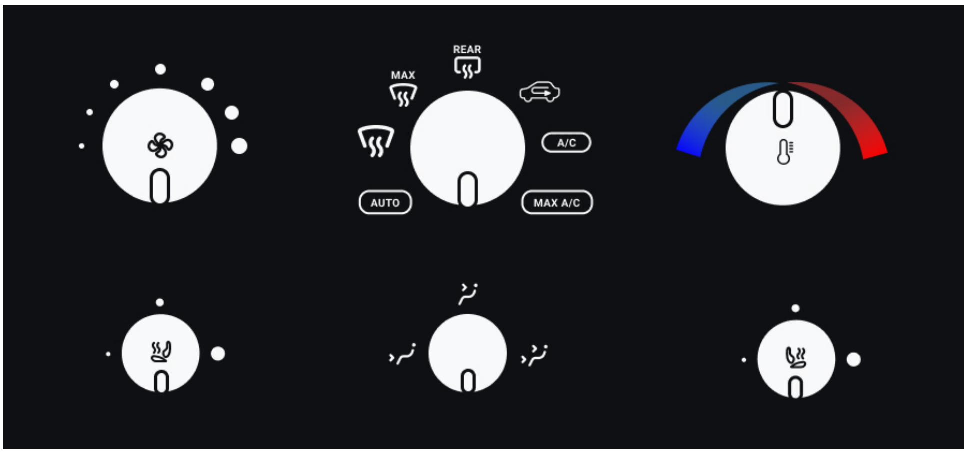

Figure 5: First version of the interface dependent on rotating type of interaction.

Second version of the prototype

The second version of the prototype was created by increasing the interactive interface by switching from the smartphone display to a tablet-sized display and adjusting both user interfaces to meet the new screen proportions. According to research by (Grahn & Kujala, 2020), screen size changes do not have significant effects on driver performance, implying that the larger screen used in this study should not cause any issues.

The design components from the first version were essentially replicated in the prototype for the second version, with some noticeable modifications. Except for the elimination of specific icons from the earlier version's slide-based interface for an improved design, the color palette and icon design were mostly carried over. Furthermore, the climate control activation features remained in the upper third of the interface in both versions, with the tap-based interface also retaining the center positioning of temperature, fan, and airflow controls.

The elimination of the rotation-based interactive elements, which had previously been rated as the least desired mode of engagement by participants due to its relative ineffectiveness, was one of the significant changes in the second iteration.

To improve usability, the interfaces were improved based on input from the previous study's participants. All interactive components within the tap-based interface were enclosed in separate containers with a contrasting border and color (#3D3D3D) against the main interface background (#0E1013). This container and border color would change to highlight active elements, with the container background changing to #7270FF and the border changing to #F8F9FA, making interactive elements more button-like in the user's eyes.

The user interface has been refined to more accurately reflect adjustments in temperature and fan power. The original design used illuminated markers to denote changes in these settings, but it did not provide numeric values, leaving users to interpret visual cues. To enhance clarity, the second prototype replaces these markers with digital readouts. In the current version, temperature can be set between 10 and 20 degrees Celsius, and fan power is displayed on a scale from 0, indicating the fan is off, to a maximum setting of 5. It's important to note that these figures are not indicative of actual car model specifications but are used here in the prototype for illustrative purposes.

Despite the transition to numeric displays for temperature and fan settings, the representation of seat heating intensity for both driver and passenger seats remains graphic-based, which is consistent with modern vehicle interface design standards.

Furthermore, the second version of the prototype's airflow direction control evolved, allowing individual changes for both driver and passenger, as compared to the original version's one general setting.

Finally, the seat heating controls for both the driver and the passenger are located in the lower area of the display.

The slide-based interaction interface has undergone several modifications. First, it is worth mentioning that the functions of heating the front and rear shields as well as the air conditioning functions have retained their location at the top of the screen. Despite the feedback from the previous study, users are still unable to activate various climate control functions at the same time — this limitation from the prior study persists. To avoid cluttering the interface and overwhelming users with too many interactive elements, the design avoids using distinct sliders for each function.

The interface design can be separated into two areas. Along with the previously mentioned defrosting and air conditioning controls, the top section also offers air temperature and fan power options. The lower area is divided into two groups: for both driver and passenger seat heating controls and air flow direction.

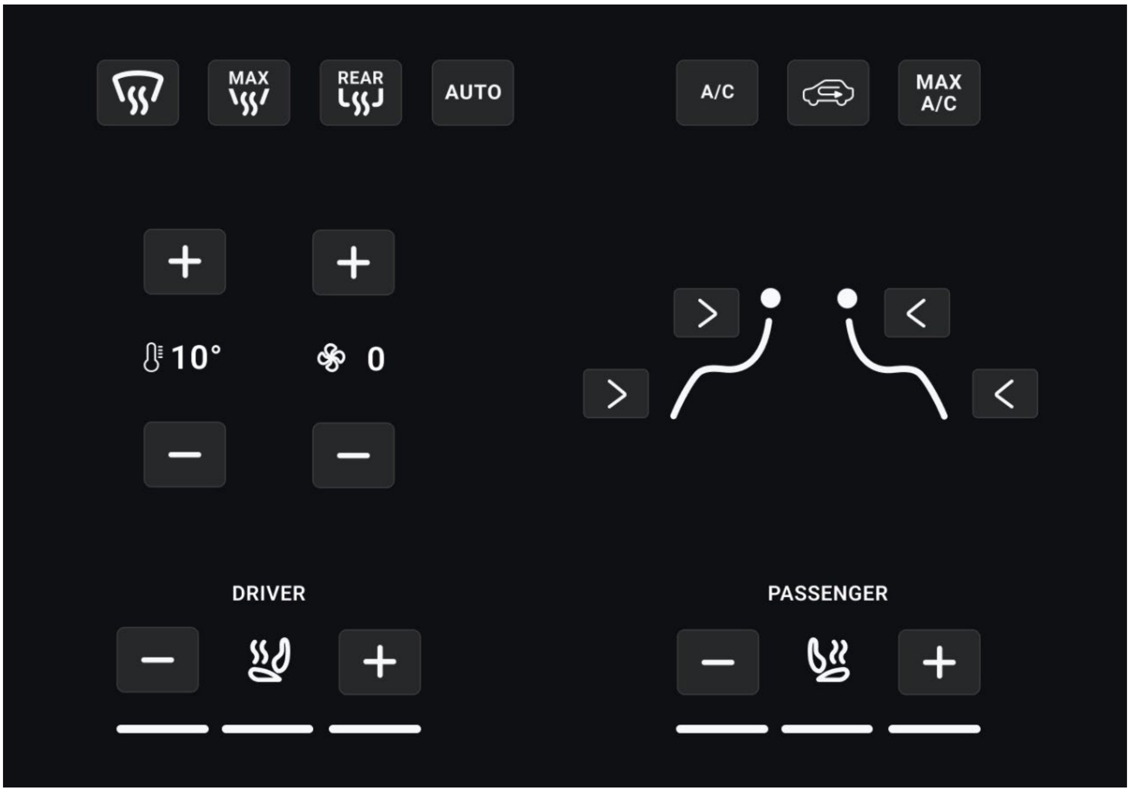

Figure 6: Interface dependent on tapping type of interaction.

Figure 7: Interface dependent on sliding type of interaction.

RESULTS

This section presents the performance of each participant in tasks involving two different types of interaction with a tablet that simulates an in-vehicle touchscreen. A total of 20 participants, with no restrictions on age or gender, were recruited for the experiment. All participants held valid driver's licenses. The age range of those recruited was from 21 to 49 years, including 7 women and 13 men.

Initially, a group of 10 participants interacted first with the tap-based interface and then with the slide-based interface. Subsequently, the next group of 10 started with the slide-based interface and switched to the tap-based interface. This approach was chosen to ensure that the testing of both types of interaction occurred under equal conditions, thereby enhancing the experiment's validity.

The data presented in this section were collected following tests with 20 participants. This data was gathered through the analysis of video recordings made during each of the 20 tests.

The overall results are displayed in two tables. One table presents the results for participants using a tap-based interface, and the other shows results for a slide-based interface. Both tables indicate the number of seconds it took for participants to complete tasks related to activating climate control functions. The last column of each table displays the average time spent on all tasks.

It may be observed that some cells in the tables are missing data, indicated by a dash symbol instead of seconds. This denotes that the participant was unable to complete the task within the given time. The universal reason for incomplete tasks, as marked by the dash symbol, is the exceeding of the speed limit. In the experiment, the speed limit was set at 50 km/h, in line with Norwegian road regulations (Trygg Trafikk, 2023). Some participants, despite being aware of this limit, exceeded it on certain sections of the road, particularly in the absence of other vehicles ahead. As a result of speeding, the designated route, which was supposed to take 6 minutes, was completed in just 4 - 5 minutes. Consequently, the experiment leader did not have enough time to assign the final task. However, the results of participants who completed the route more quickly were still considered in the analysis. The reason for not adhering to the speed limit might be attributed to the increased cognitive load, which was a crucial aspect of the experiment.

Tap-based interface interaction results

In analyzing the results for the tap-based interface, it's immediately noticeable that the shortest average gaze duration, assuming completion of all five tasks, was 1.8 seconds for participant number 16. Conversely, the longest average duration under the same conditions was 9 seconds for participant number 3. Out of all participants, only two participants did not complete all five tasks, presumably due to frequent speeding during the route. The overall average duration for all 20 participants is 3.8 seconds. If we calculate the average time for all participants, taking into account the completion of all tasks, then the average time was 4 seconds.

An interview, conducted by asking about their preferred interface, revealed that the majority of participants chose the tap-based interaction type. The most frequently mentioned argument in favor of a tap-based interface was, "I am more used to tapping." While the interface design of the tap-based interface received mostly positive comments, participants number 11, 13, and 15 recommended introducing a hierarchy based on the frequency of climate control functions used. Additionally, they suggested reworking interactive elements for changing the air temperature and fan power. Participants 13 and 15 specifically emphasized the need to place indicators above the interactive elements (plus and minus buttons). They explained that "when interacting, the finger covers the indicator for changing the temperature and power of the hairdryer, and I don’t know if a change occurred after the interaction."

Slide-based interface interaction results

In examining the data from the slide-based interface, it's evident that the average time to complete the five tasks increased compared to the tap-based interface. The average time across all tasks and participants was 4.9 seconds, which is 1 second longer than the average for the tap-based interface. With the condition of completing all tasks, the total average time was 5 seconds, differing from the tap-based interface results by 1 second. With all tasks completed, the total average time became 5 seconds. Notably, the shortest average completion time for all tasks was 2.8 seconds, achieved by participants numbered 1 and 12. In contrast, the longest average time was 10.4 seconds, recorded for participant number 10. A significant finding is that five participants, numbers 3, 7, 9, 11, and 19, could not complete all five tasks, likely due to similar reasons encountered with the tap-based interface. It is particularly noteworthy that participant number 11 failed to complete all tasks on both interfaces.

Unlike the tap-based interface, the slide-based interface garnered more critical comments. Some participants noted that they felt the slide-based interface demanded greater visual attention during interaction. Participant number 18 expressed that the interface felt 'cluttered,' leaving the participant feeling lost within it.

Participants numbered 3, 6, and 12 mentioned that the interface lacked usability because it was impossible to activate two climate control functions simultaneously. Effectiveness concerns were also raised by participants numbered 6, 14, and 15, who emphasized that the slide-based interface requires “seamless interaction.” They explained, “When the slider stops a few notches too early, it's frustrating.” Additionally, some participants expressed concerns about the design of the slide-based interface, noting that it required “precise aiming” for interaction.

Participant number 14 commented on the visual feedback of the interface, stating that, in his opinion, it was less effective than on the tap-based interface. When asked about improving visual feedback for both interfaces, most participants suggested incorporating haptic feedback. Participant number 18 offered an additional suggestion: enhancing visual feedback through more noticeable animations to make the interaction's result more visible.

Tapping	**1 task**	**2 task**	**3 task**	**4 task**	**5 task**	**Average time (s) spent for all tasks**
p1	2	4	4	2	1	2.6
p2	3	7	2	2	3	3.4
p3	10	9	17	4	5	9
p4	3	1	4	2	2	2.4
p5	2	5	3	2	3	3
p6	2	1	3	3	3	2.4
p7	4	3	20	2	2	6.2
p8	6	2	3	2	-	3.2
p9	2	1	3	3	3	2.4
p10	4	6	2	6	19	7.4
p11	3	1	2	-	-	2
P12	5	4	3	2	1	3
p13	3	1	7	2	2	3
p14	8	4	7	8	6	6.6
p15	1	1	8	4	1	3
p16	3	1	3	1	1	1.8
p17	3	5	5	4	2	3.8
p18	1	5	7	5	3	4.2
p19	3	4	4	6	4	4.2
p20	3	6	4	4	3	4
Average time spent by all participants						3.9
Average time spent by all participants if all tasks completed						4

Table 1: Results on participants performance with tap-based interface. All results are presented in seconds.

Sliding	**1 task**	**2 task**	**3 task**	**4 task**	**5 task**	**Average time (s) spent for all tasks**
p1	4	2	4	3	1	2.8
p2	2	4	9	5	6	5.2
p3	16	2	6	2	-	6.5
p4	2	5	7	7	5	5.2
p5	4	2	7	16	3	6.4
p6	5	11	2	3	2	4.6
p7	5	2	4	4	-	3.7
p8	8	1	8	1	4	4.4
p9	4	5	4	5	-	4.5
p10	22	7	12	5	6	10.4
p11	2	2	4	2	-	2.5
p12	3	5	2	2	2	2.8
p13	5	6	7	3	4	5
p14	5	2	9	3	5	4.8
p15	2	4	5	8	3	4.4
p16	3	5	5	4	9	5.2
p17	13	3	6	4	6	6.4
p18	5	2	5	4	3	3.8
p19	5	4	6	4	-	4.7
p20	4	3	6	2	4	3.8
Average time spent by all participants						4.9
Average time spent by all participants if all tasks completed						5

Table 2: Results on participants performance with slide-based interface. All results are presented in seconds.

Aggregate Gaze Duration in Seconds

During the analysis of video materials, the time each participant's gaze was off the road was calculated. The data is presented in a table where two columns showing results when tap-based interface and slide-based interfaces were used.

The average sum of off-road glance time for participants on the ride using the tap-based interface was 20.2 seconds. In comparison, the average sum of time participants gaze away from the road with the slide-based interface was 23.7 seconds, indicating a difference of 3.5 seconds.

With the condition of completing all tasks, participant number 10 spent the most time looking away from the road during a trip with a tap-based interface, totaling 43 seconds. Participants numbered 5 and 6 had less off-road glance time under the same conditions, spending a total of 12 seconds. Results for participants numbered 8 and 11 were excluded from this analysis as they consistently exceeded the speed limit but were able to complete all tasks.

Using the slide-based interface and completing all tasks, participant number 10 also spent the most time looking away from the road, totaling 33 seconds. On the other hand, participant number 1 spent the least amount of time looking away, totaling 16 seconds. Results for participants numbered 3, 7, 11, and 19 were not considered in this analysis due to consistently exceeding the speed limit.

In the interviews, participants were asked about the strategies they used to spread their attention between driving and completing tasks on a touchscreen. The most frequently mentioned strategy was reducing driving speed. For instance, in the video recordings, participants 9 and 16 were observed slowing down from 44 km/h to 15 km/h to complete the task. They also noted intentionally doing so in the interviews.

Many participants mentioned that, before completing tasks, they ensured there was no car in front of them and only then began the tasks. Participant number 1 commented, “First, I looked to see if there was a car in front of me, and if there was not, then I tried to complete the task.”

Another strategy some participants employed was a form of “aiming” interactive elements they needed to interact with. In session video recordings, some participants were seen making short glances at the touchscreen after the task was announced. The duration of such a look took less than a second, varying from 1 to 5 times. After this aiming,” participants began to complete the task. While few participants mentioned this strategy in interviews, participants 1, 6, 13, 16, and 18 did acknowledge using this method.

More on strategies to complete secondary interaction tasks were shared by participant numbered 12:

> On the first trip, I tried to complete the tasks as quickly as possible as soon as they were announced. It happened that I was performing tasks at a turn and it was hard. During the second trip, I tried to complete tasks on a clear road.
> (Participant 12)

In subsequent video analysis, it was noticeable that the majority of participants immediately began to complete tasks as soon as they were announced. In such cases, participants paid little attention to the road situation but focused on continuing the countdown. However, participants numbered 7, 12, 13, and 20, judging by the video materials, first ensured that road conditions were safe before beginning tasks on the touchscreen.

Participants	**Total eyes off road in sec. for tapping**	**Total eyes off road in sec. for sliding**
p1	13	16
p2	16	25
p3	46	24
p4	17	28
p5	12	21
p6	12	24
p7	29	16
p8	14	19
p9	12	34
p10	43	33
p11	6	13
p12	16	26
p13	13	25
p14	30	25
p15	20	26
p16	13	27
p17	31	32
p18	19	18
p19	24	19
p20	18	24
Average time for all participants	20.2	23.7

Table 3: The total gaze time for all participants using tap-based interface and slide-based interface. All results presented in seconds.

NASA-TLX scores

Table 3 presents results collected through the NASA-TLX questionnaire, administered after the main part of the experiment, comprising two trips to complete tasks. Participants used this questionnaire to assess secondary interactions (touch screen interactions) by rating Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration. The table displays the estimates converted into numerical format, with the bottom row indicating the average values for each scale.

Among all scales, Mental Demand received the highest average score, rated at 6.4 points. Effort also garnered a high average score of 5.6 points. Participants rated Frustration at 3.6 points, and Temporal Demand and Productivity at 1.6 and 1.3 points, respectively. The lowest average score was attributed to Physical Demand, recorded at (-1.2) points.

In the interview, participants were asked what was most mentally demanding for them during each trip. Absolutely all participants in the experiment responded that the countdown, which they had to perform while driving in the simulator, was “by far” the most mentally demanding. Participants shared that they often lost count and had to restart the countdown.

In addition to being highly demanding, participants 2, 9, and 18 mentioned that the countdown was a distraction, preventing them from concentrating on primary and secondary interactions. As participant 18 mentioned, “I could not focus either on driving or on completing tasks when I was counting. I had to drop one task in order to complete the other one.”

Often, participants indicated that the mental demand was higher on the first trip, but on the second trip, "the mental demand felt to become lower because I already knew the way."

Participants	**Mental Demand**	**Physical Demand**	**Temporal Demand**	**Performance**	**Effort**	**Frustration**
p1	8	-4	-2	0	6	2
p2	7	4	7	7	6	0
p3	9	2	-1	8	8	5
p4	3	-7	5	4	2	-5
p5	7	4	9	3	9	5
p6	8	4	-4	-2	8	6
p7	8	4	7	-1	7	4
p8	5	-2	-1	-4	4	4
p9	5	-5	-1	4	5	8
p10	7	3	-5	-8	4	8
p11	8	5	6	6	6	-4
p12	9	-4	7	0	6	5
p13	-5	-3	0	-6	4	3
p14	4	-3	-1	-2	5	3
p15	10	-9	8	7	10	10
p16	5	-6	-3	-3	7	0
p17	4	0	0	0	0	0
p18	10	-3	5	1	3	8
p19	9	-8	1	9	8	8
p20	8	4	-5	4	5	3
Average score for each scale	6.4	-1.2	1.6	1.3	5.6	3.6

Table 4: NASA-TLX questionnaire results.

Effect of Driving Experience on Study Variables

After analyzing the overall data, which indicated that participants, on average, spent more time interacting with elements on the slide-based interface compared to the tap-based interface, a comparison with the demographic data is insightful. Initially, a potential correlation between the average interaction time and each participant's driving experience was explored. For this analysis, participants were divided into two groups: the first group consisted of those with driving experience ranging from several months to 5 years, and the second group included those with over 5 years of experience, resulting in two groups of 10 participants each.

In addition to the previously used data, results from the NASA-TLX questionnaire were included to examine factors such as Mental Demand and its impact on participant performance.

Participants' ratings on the Mental Demand, Physical Demand, Productivity, Effort, and Frustration scales have been incorporated into the table, as these metrics were deemed most relevant to their performance on climate control tasks. It's important to note that during the experiment, participants were not under time constraints either to complete the secondary tasks or to finish the trip. Therefore, their scores on the Temporal Demand scale were not considered in the analysis.

Focusing on the overall results, Tables 4 and 5 reveal some interesting observations. There was no significant difference in the average interaction times with both the tap-based and slide-based interfaces between the group with up to 5 years of driving experience and the group with more than 5 years of driving experience. The average Mental Demand scores were also nearly identical in both groups. The group with over 5 years of driving experience reported, on average, a lower level of Physical Demand compared to the group with up to 5 years of experience, where the assessment of Physical Demand was closer to neutral.

On average, both groups rated their performance in interacting with climate control functions similarly. However, when it came to the effort scale, both groups reported high scores. Participants with up to 5 years of driving experience rated their effort as 6.1 units on average, while those with 6 years or more of experience rated it slightly lower, at 5.1 units on average. Given that all scales in the NASA-TLX questionnaire range from a maximum of 10 units to a minimum of -10 units, these scores suggest that participants exerted considerable effort to complete the touchscreen tasks.

In the Frustration column of the questionnaire, which assessed the level of stress experienced during the two simulator rides, results indicated that the test caused some degree of disappointment or stress. The group with more than 5 years of driving experience scored this aspect lower (3.1) compared to the group with up to 5 years of experience (4.2), indicating slightly less frustration or stress experienced by the more experienced drivers.

Regarding the qualitative data obtained from interviews conducted after the completion of the two drives, a majority of participants expressed a preference for the tap-based interface over the slide-based one. However, within the group with more than 5 years of driving experience, participants numbered 11, 14, and 15 mentioned that they found the slide-based interface more familiar. Specifically, participant number 15 commented, «The slide-based interface felt more intuitive, especially the visuals...» Despite this familiarity, these three participants still found the tap-based interface more convenient for use in this experiment.

From the group with up to 5 years of driving experience, participant number 16, who demonstrated the best performance with the tap-based interface, confirmed this preference, stating, «The tap-based interface was more intuitive and user-friendly for me because I am used to this type of interaction. » When discussing the slide-based interface, he noted, «With the slider interface, I had to look at the screen more often. »

Driving exp. 0 - 5y.	**Average time (s) spent on tapping**	**Average time (s) spent on sliding**	**Mental Demand**	**Physical Demand**	**Performance**	**Effort**	**Frustration**
p2	3.4	5.2	7	4	7	6	0
p3	9	6.5	9	2	8	8	5
p5	3	6.4	7	4	3	9	5
p6	2.4	4.6	8	4	-2	8	6
p7	6.2	3.75	8	4	-1	7	4
p9	2.4	4.5	5	-5	4	5	8
p13	3	5	-5	-3	-6	4	3
p16	1.8	5.2	5	-6	-3	7	0
p18	4.2	3.8	10	-3	1	3	8
p20	4	3.8	8	4	4	5	3
Average for all participants	3.9	4.9	6.2	0.5	1.5	6.2	4.2

Table 5: Group of participants with driving experience ranging from several months up to 5 years.

Driving exp. 5 - over 20 y.	**Average time (s) spent on tapping**	**Average time (s) spent on sliding**	**Mental Demand**	**Physical Demand**	**Performance**	**Effort**	**Frustration**
p1	2.6	2.8	8	-4	0	6	2
p4	2.4	5.2	3	-7	4	2	-5
p8	3.25	4.4	5	-2	-4	4	4
p10	7.4	10.4	7	3	-8	4	8
p11	2	2.5	8	5	6	6	-4
p12	3	2.8	9	-4	0	6	5
p14	6.6	4.8	4	-3	-2	5	3
p15	3	4.4	10	-9	7	10	10
p17	3.8	6.4	4	0	0	0	0
p19	4.2	4.75	9	-8	9	8	8
Average for all participants	3.8	4.8	6.7	-2.9	1.2	5.1	3.1

Table 6: Group of participants with driving experience ranging from 5 years and more.

Effect of Experience with In-vehicle Touchscreen Interfaces on Study Variables

The subsequent phase of the results analysis focused on examining the potential influence of having or lacking experience with in-vehicle touchscreen interfaces on participants' ability to complete tasks related to climate control functions. As in the previous section, the participants were categorized into two groups based on their experience. The first group, consisting of 14 individuals, had prior experience interacting with in-vehicle touchscreen interfaces. The second group, comprising 6 individuals, had no such experience. To further understand the impact of these experiences on performance, the results from the NASA-TLX questionnaire were also included in the analysis for both groups.

Contrasting with the previously observed lack of correlation between driving experience and performance, the participants' familiarity with in-vehicle touchscreen interfaces did appear to influence their performance. The first group, with prior touchscreen experience, completed tasks more quickly on average. For the tap-based interface, this group averaged 3 seconds, whereas the second group, with no such experience, took nearly double the time, averaging 5.9 seconds. Similarly, on the slide-based interface, the first group took 4.3 seconds on average, compared to 6 seconds for the second group, showing a notable difference of about one and a half seconds.

Both groups rated Mental Demand highly, but the second group's score was 1.5 units higher. Regarding the Effort scale, the first group rated it at an average of 5, while the second group's rating was considerably higher at 7.2.

The average Frustration score was also notably higher for the second group, at 5.8 units, compared to 2.7 for the first group. Physical Demand scores showed differences, but these were not substantial. The first group, experienced with in-vehicle touchscreens, had an average negative rating for physical need, indicating lesser physical difficulty during the tasks, regardless of the interface type. The second group also reported no significant issues with interaction. Finally, the average Performance scores were relatively similar for both groups, standing at 1.4 and 1.2, respectively.

Participant number 7 from the second group, less experienced with in-vehicle touchscreen interfaces, expressed a sense of being overwhelmed by the screen's content, stating, «I felt that there was too much information on the screen for me, which I was not used to. » Similarly, participant number 14 from the same group noted the differences from standard car dashboard, commenting, «In normal cars, it looks different than what I'm used to, so here I wasn't sure if I had pressed a button on the screen or not. I was forced to look at the screen. »

Conversely, participants from the group with experience interacting with in-vehicle touchscreen interfaces generally reported satisfaction with both the tap-based and slide-based interfaces, citing their intuitive design. Despite this, there was a preference for the tap-based interface among these experienced participants.

Exp. with in-vehicle touchscreen interfaces	Average sec. for tapping	Average sec. for sliding	Mental Demand	Physical Demand	Performance	Effort	Frustration
p1	2.6	2.8	8	-4	0	6	2
p2	3.4	5.2	7	4	7	6	0
p4	2.4	5.2	3	-7	4	2	-5
p6	2.4	4.6	8	4	-2	8	6
p8	3.25	4.4	5	-2	-4	4	4
p9	2.4	4.5	5	-5	4	5	8
p11	2	2.5	8	5	6	6	-4
p12	3	2.8	9	-4	0	6	5
p13	3	5	-5	-3	-6	4	3
p16	1.8	5.2	5	-6	-3	7	0
p17	3.8	6.4	4	0	0	0	0
p18	4.2	3.8	10	-3	1	3	8
p19	4.2	4.75	9	-8	9	8	8
p20	4	3.8	8	4	4	5	3
Average for all participants	3	4.3	6	-1.8	1.4	5	2.7

Table 7: Group of participants with experience using in-vehicle touchscreen interfaces.

No exp. with in-vehicle touchscreen interfaces	Average sec. for tapping	Average sec. for sliding	Mental demand	Physical Demand	Performance	Effort	Frustration
p3	9	6.5	9	2	8	8	5
p5	3	6.4	7	4	3	9	5
p7	6.2	3.6	8	4	-1	7	4
p10	7.4	10.4	7	3	-8	4	8
p14	6.6	4.8	4	-3	-2	5	3
p15	3	4.4	10	-9	7	10	10
Average for all participants	5.9	6	7.5	0.2	1.2	7.2	5.8

Table 8: Group of participants with no experience using in-vehicle touchscreen interfaces.

Additional factors influencing on Study Variables

Having assessed the impact of driving experience and experience with in-vehicle touchscreen interfaces on participants' performance in tasks involving climate control activation, it is now pertinent to consider how other related factors might have influenced the experiment's results. Specifically, experiences with racing games, driving simulators, and gaming steering wheels, although related to the broader theme, were separately recorded in the demographic form. Consequently, the data analysis was extended to include three pairs of tables, each pair corresponding to one of these additional areas of experience.

Experience with racing games

Participants in the experiment were categorized into two groups based on their experience with racing games. The first group, consisting of 13 participants with relevant experience, showed a quicker average completion time for tasks. Specifically, this group averaged 3.1 seconds for tasks using the tap-based interaction, while the group without experience in racing games (7 participants) took an average of 5.3 seconds. For the slide-based interface, the experienced group averaged 4.3 seconds, in contrast to 5.9 seconds for the inexperienced group. These preliminary findings suggest that those with racing game experience found it easier to navigate the driving simulator and perform tasks under increased cognitive load.

However, insights from the NASA-TLX questionnaire ratings provide additional context. Both groups rated the Mental Demand and effort required for secondary interactions as high. Both groups received a similar negative rating for Physical Demand, indicating that neither exerted significant physical effort during touchscreen interactions. A minor discrepancy was observed in the Performance scale ratings, with the experienced group averaging 1.7 points and the inexperienced group 0.7 points. A notable disparity emerged in the Frustration ratings: the group without racing game experience reported a higher average rating of 5.7, compared to just 2.5 for the experienced group.

Familiar with racing games	Average sec. for tapping	Average sec. for sliding	Mental Demand	Physical Demand	Performance	Effort	Frustration
p1	2.6	2.8	8	-4	0	6	2
p2	3.4	5.2	7	4	7	6	0
p4	2.4	5.2	3	-7	4	2	-5
p6	2.4	4.6	8	4	-2	8	6
p7	6.2	3.6	8	4	-1	7	4
p8	3.25	4.4	5	-2	-4	4	4
p9	2.4	4.5	5	-5	4	5	8
p11	2	2.5	8	5	6	6	-4
p12	3	2.8	9	-4	0	6	5
p15	3	4.4	10	-9	7	10	10
p16	1.8	5.2	5	-6	-3	7	0
p17	3.8	6.4	4	0	0	0	0
p20	4	3.8	8	4	4	5	3
Average for all participants	3.1	4.3	6.8	-1.2	1.7	5.5	2.5

Table 9: Group of participants familiar with racing games.

Not familiar with racing games	Average sec. for tapping	Average sec. for sliding	Mental Demand	Physical Demand	Performance	Effort	Frustration
p3	9	6.5	9	2	8	8	5
p5	3	6.4	7	4	3	9	5
p10	7.4	10.4	7	3	-8	4	8
p13	3	5	-5	-3	-6	4	3
p14	6.6	4.8	4	-3	-2	5	3
p18	4.2	3.8	10	-3	1	3	8
p19	4.2	4.75	9	-8	9	8	8
Average for all participants	5.3	5.9	5.9	-1.1	0.7	5.9	5.7

Table 10: Group of participants not familiar with racing games.

Experience with driving simulators

The analysis then shifted to comparing the performance of two groups based on their experience with driving simulators. The first group, consisting of 11 participants with simulator experience, contrasted with the second group of 9 participants without such experience. Mirroring the findings from the racing games analysis, those with simulator experience completed tasks more quickly, with an average time difference of about 1 second regardless of the type of interface used.

Despite spending less time on tasks, the group with simulator experience rated Mental Demand higher, averaging 7.4 points, compared to 5.3 points for the inexperienced group. In an interview, participant number 15 from the first group stated, "The simulated setting felt more mentally demanding than real driving." Other participants from the same group did not make similar comments.

Physical Demand ratings followed a similar pattern as in previous analyses, with both groups rating it low. However, there was a discernible difference of about 2 points between the groups. Additionally, the group with simulator experience rated their Performance higher than the inexperienced group.

Contrastingly, the Effort and Frustration ratings did not show significant differences. The experienced group rated their Effort at an average of 5.8 points, slightly higher than the 5.4 points of the inexperienced group. Frustration, measured as Disappointment, was almost equal between the groups, with averages of 3.5 for the experienced group and 3.8 for the inexperienced group.

Familiar with driving sim.	**Average time (s) spent on tapping**	**Average time (s) spent on sliding**	**Mental Demand**	**Physical Demand**	**Performance**	**Effort**	**Frustration**
p1	2.6	2.8	8	-4	0	6	2
p2	3.4	5.2	7	4	7	6	0
p3	9	6.5	9	2	8	8	5
p6	2.4	4.6	8	4	-2	8	6
p8	3.25	4.4	5	-2	-4	4	4
p9	2.4	4.5	5	-5	4	5	8
p11	2	2.5	8	5	6	6	-4
p12	3	2.8	9	-4	0	6	5
p15	3	4.4	10	-9	7	10	10
p17	3.8	6.4	4	0	0	0	0
p20	4	3.8	8	4	4	5	3
Average for all participants	3.5	4.3	7.4	-0.4	2.7	5.8	3.5

Table 11: Group of participants familiar with driving simulators.

Not familiar with driving sim.	**Average time (s) spent on tapping**	**Average time (s) spent on sliding**	**Mental Demand**	**Physical Demand**	**Performance**	**Effort**	**Frustration**
p4	2.4	5.2	3	-7	4	2	-5
p5	3	6.4	7	4	3	9	5
p7	6.2	3.75	8	4	-1	7	4
p10	7.4	10.4	7	3	-8	4	8
p13	3	5	-5	-3	-6	4	3
p14	6.6	4.8	4	-3	-2	5	3
p16	1.8	5.2	5	-6	-3	7	0
p18	4.2	3.8	10	-3	1	3	8
p19	4.2	4.75	9	-8	9	8	8
Average for all participants	4.3	5.5	5.3	-2.1	-0.3	5.4	3.8

Table 12: Group of participants not familiar with driving simulators.

Experience with gaming steering wheel

The final aspect of the analysis examined the potential influence of participants' experience with gaming steering wheels on their performance. Participants were divided into two groups of 10, based on their experience with gaming steering wheels. This analysis yielded somewhat different results compared to the previous aspects.

When focusing on the average time spent on touchscreen tasks, both groups exhibited similar completion times on the tap-based interface, with the first group (experienced) averaging 3.8 seconds and the second group (inexperienced) averaging 4 seconds. However, a notable difference emerged in the slide-based interface, where the experienced group completed tasks in an average of 4.3 seconds, compared to 5.4 seconds for the inexperienced group.

Regarding Mental Demand, a pattern similar to the driving simulator analysis emerged. The experienced group rated Mental Demand higher, at 7.5 points, compared to 5.4 points for the inexperienced group. This indicates a greater perceived cognitive challenge among the experienced participants. Participant 19 stated in the interview that he "tried to pay more attention to a high level of driving quality than quickly completing tasks on the touch screen."

The analysis also revealed interesting insights into the Effort and Frustration ratings. The experienced group reported higher levels of both, with a difference of 2 points compared to the inexperienced group. Despite this, the Performance scores were almost identical for both groups, at 1.3 and 1.4, respectively.

As in previous analyses, the assessment of Physical Demand was negative for both groups, indicating that physical effort required for task completion was minimal regardless of the interface used.

Familiar with gaming steering wheel	Average time (s) spent on tapping	Average time (s) spent on sliding	Mental Demand	Physical Demand	Performance	Effort	Frustration
p1	2.6	2.8	8	-4	0	6	2
p3	9	6.5	9	2	8	8	5
p6	2.4	4.6	8	4	-2	8	6
p7	6.2	3.75	8	4	-1	7	4
p8	3.25	4.4	5	-2	-4	4	4
p9	2.4	4.5	5	-5	4	5	8
p12	3	2.8	9	-4	0	6	5
p15	3	4.4	10	-9	7	10	10
p16	1.8	5.2	5	-6	-3	7	0
p20	4	3.8	8	4	4	5	3
Average for all participants	3.8	4.3	7.5	-1.6	1.3	6.6	4.7

Table 13: Group of participants familiar with gaming steering wheel.

Not familiar gaming steering wheel	Average time (s) spent on tapping	Average time (s) spent on sliding	Mental Demand	Physical Demand	Performance	Effort	Frustration
p2	3.4	5.2	7	4	7	6	0
p4	2.4	5.2	3	-7	4	2	-5
p5	3	6.4	7	4	3	9	5
p10	7.4	10.4	7	3	-8	4	8
p11	2	2.5	8	5	6	6	-4
p13	3	5	-5	-3	-6	4	3
p14	6.6	4.8	4	-3	-2	5	3
p17	3.8	6.4	4	0	0	0	0
p18	4.2	3.8	10	-3	1	3	8
p19	4.2	4.75	9	-8	9	8	8
Average for all participants	4	5.4	5.4	-0.8	1.4	4.7	2.6

Table 14: Group of participants not familiar with gaming steering wheel.

DISCUSSION

This section discusses the results obtained during the experiment, focusing on answering the main research question regarding the effectiveness and efficiency of the in-vehicle touchscreen interaction method under intentionally increased cognitive load. The explanation of the main research question is accompanied by responses to sub-questions, providing a comprehensive examination of the results from different angles. Furthermore, the study compares its results with those of previously conducted studies mentioned in the literature review.

Interaction Types: Effectiveness and Efficiency

After analysing the data presented in Tables 1 and 2, it is evident that the interface, dependent on the tapping type of interaction, is more effective and efficient compared to the results of the slide-based interface under intentionally increased cognitive load. Even when all tasks were completed, participants demonstrated faster completion times with the tap-based interface. Interview responses further affirmed this conclusion, with participants expressing a preference for the tap-based interface in setting climate control functions, citing its more intuitive design.

The preference for interacting with touchscreen buttons aligns with Tuomo Kujala's findings in his research (Kujala, 2013, pp. 815-823), where subjective data indicated a preference for tapping. Notably, in Tuomo Kujala's research, swiping outperformed tapping, while in the current study, tapping outperformed sliding in terms of metrics.

The slide-based interface received mixed comments on interface design, with participants noting its lack of intuitiveness and ease of use. In addition to objective data showing sliding to be inferior to tapping, participants suggested that the slide-based interface required precise aiming to interact. This aligns with Kujala's study, where he proposed that larger interaction elements would result in less focus on the touchscreen (Kujala, 2013, pp. 815-823). Increasing the size of the slider could potentially improve user experience and reduce gaze duration.

An issue arose during the experiment, as some participants struggled to complete all 5 tasks to activate climate control functions. One participant failed to complete tasks on both interfaces, possibly due to increased cognitive load induced by the countdown task. Participants mentioned in interviews that the countdown, spanning two rides, was more mentally demanding than interacting with a touchscreen.

This cognitive load issue aligns with Lee et al.'s study (2007, pp. 721–733) and Engstrom et al. (2005) study, which both explored the impact of cognitive load on driver attention and performance. Similar to their findings, the present study suggests that cognitive load caused problems for participants, leading to lapses in attention, potential violations of speed limits, and failure to complete tasks on the touchscreen.

Driver Self-Regulation Discussion

The findings regarding the total time participants spent looking away from the road are further scrutinized in relation to the interface used. Off-road gaze duration is intimately tied to driver visual distraction and attention, with driver self-regulation playing a pivotal role. During interviews, participants were queried about their strategies for balancing attention between primary and secondary interactions. Strategies included slowing down when interacting with the screen, seeking reassurance of road safety by confirming the absence of vehicles ahead, "aiming" with their gaze before starting interaction, and performing tasks on safe road sections. Some participants did not explicitly mention these tactics during interviews, but video materials analysis revealed the utilization of one or more of these strategies.

Ebel et al. (2022), in a study on drivers' self-regulation during secondary tasks, asserted that vehicle automation encourages drivers to take a more extended view of in-vehicle systems. In our experiment, despite the absence of car automation in the driving simulator, each participant controlled the car while performing tasks. Instances were observed where participants alternated between long glances at the touchscreen and short glances. These short glances, often multiple and lasting less than one second, involved participants targeting the interactive element before engaging in interaction. This control strategy was explicitly mentioned by some participants, including participants 1, 6, 13, 16, and 18. The impact of this strategy is evident in Table 3, where these participants exhibited a low overall gaze duration, whether using a tap-based or slide-based interface, or both. This example suggests that in the absence of automatic vehicle control systems such as ACC and LCA, participants endeavoured to keep their attention on the road, occasionally directing short glances at the touchscreen.

A decrease in speed during a demanding secondary task, as noted in the study by Engstrom et al. (2005), is indicative of driver self-regulation. This scenario was observed in the video materials of our experiment and was also highlighted by participants in interviews. The data from our study, coupled with the findings of Engstrom et al. (2005), affirm that drivers exhibit a tendency to reduce their vehicle speed, even within a simulation, when initiating a demanding secondary task.

Cognitive Load and Mental Demand Discussion

Throughout the experiment, participants faced a consistently increased cognitive load, induced by the countdown task over two rides. In a post-experiment NASA-TLX questionnaire, participants rated various aspects, including the perceived Mental Demand when interacting with the touchscreen. Notably, the Mental Demand score was, on average, the highest among other scores, indicating that intentional cognitive load made touchscreen interaction challenging for participants. However, in interviews, all participants consistently expressed that, when comparing the Mental Demand of the countdown to interacting with the touchscreen, the countdown was decidedly more demanding.

Based on the results presented in Table 4 and participants' comments in interviews, it can be inferred that the increased cognitive load from the countdown had a direct impact on participants' performance and attention.

Previous studies by Engstrom et al. (2005) and Lee et al. (2007, pp. 721-733) explored the effects of high cognitive load on participants' ability to detect changes in the driving environment and traffic events. In both studies, participants exhibited decreased driving performance. Notably, Engstrom et al. (2005) differentiated between the effects of visual load and cognitive load on driving performance, highlighting that under high cognitive load, drivers tended to focus attention on the center of a road, diminishing their ability to notice changes. While the present study did not specifically focus on visual load, some participants commented that the interface design necessitated keeping eyes on the screen to locate desired climate control functions. It can be postulated that the strategy of short and multiple glances at the touchscreen was a consequence of high visual load, although this hypothesis warrants further research.

Concerning the influence of cognitive load, it's worth noting that during the experiment, some participants struggled to monitor the car's speed, resulting in incomplete tasks on the touchscreen. Consequently, a decline in driver attention due to cognitive load contributed to frequent or constant speeding throughout the experiment.

Driving Experience Impact

The analysis of the primary data indicates that participants' performance during touchscreen tasks is contingent on the type of interaction interface used. Additional insights from demographic data allowed a comprehensive examination of the underlying factors, including an exploration of how the average time spent on tasks across the two interfaces correlates with age. Results from the NASA-TLX questionnaire were incorporated to enhance the depth of analysis.

Two tables were generated, categorizing participants based on their driving experience: the first group comprised participants with up to 5 years of experience, while the second group included those with over 5 years of driving experience. Surprisingly, the analysis revealed no correlation between age and participants' performance on the interfaces. The average time for both groups, using either the tap-based or slide-based interface, remained identical. Thus, driving experience in this experiment had no discernible effect on how quickly participants completed tasks to activate climate control functions on the touchscreen, suggesting that other factors played a more significant role.

Noteworthy differences emerged when comparing data from the NASA-TLX questionnaire. Both groups reported nearly identical scores for Mental Demand when interacting with the touchscreen, highlighting the shared challenge of operating the touchscreen under increased cognitive load. This observation is consistent with findings from the previous section and participants' interview comments. Performance also received almost identical ratings.

Both groups did not consider the tasks to be Physically Demanding, as the ratings were either around 0 or lower. The only comments related to Physical Demand were in reference to the slide-based interface. Participants expressed expectations of a 'seamless interaction' but were disappointed when the slider stopped before reaching the desired function. Additionally, sliding required precise aiming, and it is suggested that increasing the size of interactive elements could alleviate this issue, as proposed by Kujala (2013, pp. 815-823).

This is reflected in the performance results, where the slide-based interface was inferior to the tap-based interface.

A small difference was observed in Effort and Frustration ratings, with the group with less driving experience rating these categories one notch higher. While this creates a significant difference favouring the group with more experience, it can be assumed that participants in the second group felt more confident due to their greater driving experience. Further research is needed to thoroughly analyse the influence of confidence in this type of experiment.

In-Vehicle Touchscreen Experience Impact

A notable variation in data emerges when comparing participants' performance results with two interfaces to their experiences with in-vehicle touchscreen interfaces. Participants' results were stratified into two groups based on their in-vehicle touchscreen interface experience, with the majority of participants in the experiment already having such experience.

It is evident that the first group, comprising participants with in-vehicle touchscreen interface experience, completed tasks on both interfaces, on average, 2 seconds faster than the group without relevant experience. In contrast to driving experience, the experience with in-vehicle touchscreen interfaces did influence how quickly participants completed tasks. Representatives of the group without experience shared in interviews that they were more accustomed to the design of car panels with physical buttons or, as participant number 14 stated, "to the design of a normal cars."

The performance results align with the outcomes of the NASA-TLX questionnaire. Except for the Performance scale, the group without experience scored higher on all scales than the group with experience. Despite the higher assessment of Mental Demand in the experienced group, both groups faced challenges in performing secondary interactions under conditions of increased cognitive load.

A significant difference was observed in the Effort and Frustration ratings, with the lack of experience resulting in participants exerting more effort and experiencing increased frustration and stress during secondary interactions. Comments from participants in interviews regarding the shortcomings of the slide-based interface may have contributed to the increased difficulty experienced by participants with no experience.

There is also a difference in the assessments of Physical Demand; however, judging by the assessments themselves, the interaction did not pose problems for both groups. Considering the results from Tables 7 and 8, along with participant interview transcripts, it can be concluded that experience with in-vehicle touchscreen interfaces had a positive effect on participants' performance when performing tasks to activate climate control functions under persistently high cognitive load.

Gaming/ Driving Simulator Experience Impact

Further, the impact of experience with racing games and driving simulators was discussed. Prior to the experiment, participants were given the opportunity to undergo a training drive to become familiar with the equipment and the driving simulator. This decision was prompted by a lack of understanding of how a driving simulator function, and the absence of a training session could have potentially influenced the experiment's data.

The influence of experience with racing games and driving simulators was assessed similarly to previous methods. Participants' results were categorized into two groups based on the presence or absence of relevant experience.

Examining how experience with racing games and driving simulators impacted the average time participants took to complete tasks on the touch screen reveals that participants with experience outperformed those without experience.

The Mental Demand assessments yielded intriguing data. Participants with relevant experience had higher average Mental Demand scores when interacting with the touch screen compared to participants without such experience. In interviews, some participants, like participant number 19, mentioned paying significant attention to the quality of driving in the simulator. This observation could likely explain the difference in Mental Demand scores, as participants without experience attempted to balance workload between the simulator and touchscreen interaction, while participants with experience focused more on secondary interactions.

CONCLUSION

A study was conducted to examine two interfaces, each dependent on a different type of interaction: one tap-based and the other slide-based. Both interfaces handled the functions of the car's climate control. The experiment utilized a driving setting consisting of a driving simulator, a steering wheel, pedals, and a tablet simulating an in-car touchscreen.

For the experiment, 20 participants were recruited without restrictions on gender and age but with the condition of having a valid driver's license. Each participant completed two runs during the experiment, with one of two interfaces demonstrated on the touchscreen in each race. Participants used the touchscreen to complete tasks activating climate control functions. Additionally, participants faced a consistently increased cognitive load due to the countdown that they maintained throughout the two rides.

After the trips, participants filled out the NASA-TLX questionnaire and answered interview questions. The experiment aimed to investigate which of the two types of interaction with an in-car touchscreen is more effective and efficient under intentionally increased cognitive load. The results indicated that, under conditions of consistently increased cognitive load, tapping outperformed sliding in terms of the average time spent completing touchscreen tasks.

Regarding intuitiveness and usability, the data demonstrated that the tap-based interface performed better than the slide-based interface. This finding was further confirmed by participants' comments, as they unanimously preferred tapping interaction over sliding.

The interview revealed that the secondary interaction requiring the greatest mental demand for all participants was the countdown, serving as a means of increasing cognitive load. Additionally, the degree of Mental Demand was measured using the NASA-TLX questionnaire. Participants' responses, converted into numerical format, indicated that Mental Demand received the highest average rating. The questionnaire also showed that interacting with the touchscreen was physically demanding based on the Physical Demand score. However, participants had to exert considerable effort to achieve their level of performance with the touchscreen, as Effort received the second-highest score.

Further factors influencing participant performance were examined, such as driving experience and experience interacting with in-vehicle touchscreen interfaces. The comparison results revealed that driving experience did not affect participants' performance significantly. The average time spent completing tasks on the touchscreen was almost identical for participants with less than 5 years of driving experience and those with 5 years or more of driving experience. In contrast, experience interacting with in-vehicle touchscreen interfaces had an impact on participants' performance, with participants in the experienced group completing the task faster on average than those without relevant experience.

In summary, the analysis of the experiment results indicated that, under simulated driving setting conditions with increased cognitive load, tapping interaction is superior to sliding interaction. Additionally, the average time spent on tasks was positively influenced by participants' experience with in-vehicle touchscreen interfaces.

LIMITATIONS

At first, it's essential to note that this experiment faced limitations in participant recruitment. The pool of eligible individuals with valid driver's licenses was constrained, as recruitment occurred on campus, primarily involving students.

Another notable limitation was the constrained time frame of the study, spanning three months. This limited time frame impacted the participants' training duration, leading to a restricted exposure to in-vehicle touchscreen interfaces, driving simulators, and gaming steering wheels. Extending the study duration could not only offer participants more training time but also potentially allow for a broader and more diverse participant pool.

Furthermore, the use of a driving simulator introduced another constraint. While a driving simulator provides a controlled environment, ensuring safety for both the experimenter and participants, it is essential to acknowledge that data obtained under simulated conditions may differ from those gathered in real driving scenarios.

FUTURE WORK

The present study suggests that the tap-based interface is superior to the slide-based interface in terms of efficiency and effectiveness under deliberately increased cognitive load. However, certain aspects of the experiment could be enhanced to obtain more accurate and comprehensive data.

Firstly, future work should incorporate real driving conditions. Using an actual car in authentic road conditions can provide insights that a driving simulator might not capture.

If conducting experiments in real driving conditions proves impossible or unsafe for participants, introducing VR technologies could be considered. This would offer greater immersion compared to simulated driving.

Secondly, increasing the number of recruited participants for future research is advisable. Seeking participants with more experience interacting with driving simulators or in-vehicle touchscreen interfaces can contribute more diverse data.

Additionally, providing comprehensive training before participants engage in the experiment is worthwhile for future studies. This is particularly beneficial for participants without prior experience with driving simulators or gaming wheels.

An alternative approach for the experiment could involve implementing the interfaces being tested in real cars, allowing participants an extended period to use them. This way, participants would become familiar with the interface, potentially yielding different performance results.

Ultimately, for future studies, expanding the time frame of the experiment would be beneficial. This would facilitate the recruitment of more participants and allow for longer pre-experiment training.

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APPENDICES

Appendix A – Informed Consent (In English)
Appendix B – Interview Guide (In English)
Appendix C – Demographic form (In English)

Appendix A

TITLE OF STUDY

A Comparative Analysis of Tap-based and Slide-based Interfaces: Evaluating Efficiency in In-Vehicle Touchscreen Interactions under Cognitive Load

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PURPOSE OF STUDY

You are being asked to take part in a research study. Before you decide to participate in this study, it is important that you understand why the research is being done and what it will involve. Please read the following information carefully. Please ask the researcher if there is anything that is not clear or if you need more information.

The purpose of this study is to investigate two types of touchscreen interactions (tap-based and slide-based) in the context of driving. The participant will be asked to follow a route in a driving simulator while performing secondary interactions on a touchscreen and counting down. By introducing a counting down task, the leader of the experiment will try to increase participant’s cognitive load to see how this effect performing secondary interactions. After the data collection process, the results of every participant will be evaluated and analyzed.

STUDY PROCEDURES

1. Participants will be asked to take part in an experiment designed to examine the effects of different types of touchscreen interactions while performing tasks in a driving simulator. Before the experiment, the experiment director will provide participants with all information about the study and ask them to sign Information consent. By signing consent, the participant gives his/her consent to audio and video recording.
2. Next, participants will complete a demographic questionnaire to collect information about their age, driver's license status, driving experience, experience with driving simulators and games, and experience using touch screens in vehicles.
3. The leader of the experiment presents the tasks that the participants will perform during the experiment: reaching the final point of the route in the driving simulator; performing tasks on the tablet’s touch screen; performing an arithmetic task.
4. Participants will be shown the equipment they will use during the experiment. For those who are not familiar with driving simulators, an instruction and training session will be held. Participants will be able to learn how to interact with a touchscreen and test the functionality of touchscreen prototypes.
5. After confirming their readiness, the experiment will begin. The experiment will consist of two parts. In both parts, the leader of the experiment will set the end point of the route in the car simulator. Each part will have a different type of touchscreen interaction.
6. After completing all tasks on the driving simulator, participants will be given a questionnaire to fill out independently. The questionnaire will collect feedback on tasks, touchscreen interface design, and potential distractions.
7. After filling out the questionnaire, participants will undergo a short interview conducted by the leader of the experiment. The interview will focus on participants'

impressions of the tasks, touchscreen interface design, and any distractions. The interview will be recorded on a voice recorder for further analysis.

CONFIDENTIALITY

Your responses to the questionnaire will be anonymous. Please do not write any identifying information on your questionnaire. Every effort will be made by the researcher to preserve your confidentiality including the following:

- Assigning code names/numbers for participants that will be used on all research notes and documents
- Keeping notes, interview transcriptions, and any other identifying participant information in a locked file in the personal possession of the researcher.
- Video and voice recordings captured during the experiment will only be used for research purposes related to the study.
- Participants' video and voice recordings will not be shared, published, or disseminated outside of the research team without express written consent, except for anonymized and aggregated data.
- Following the conclusion of the experiment and completion of analysis, all video and voice recordings will be promptly deleted to ensure participants' privacy and confidentiality, unless explicit consent for continued use and storage has been obtained in writing from the participant.

Participant data will be kept confidential except in cases where the researcher is legally obligated to report specific incidents. These incidents include, but may not be limited to, incidents of abuse and suicide risk.

CONTACT INFORMATION

If you have questions at any time about this study, or you experience adverse effects as the result of participating in this study, you may contact the researcher whose contact information is provided on the first page. If you have questions regarding your rights as a research participant, or if problems arise which you do not feel you can discuss with the Primary Investigator, please contact the Institutional Review Board at (865) 354-3000, ext. 4822.

VOLUNTARY PARTICIPATION

Your participation in this study is voluntary. It is up to you to decide whether or not to take part in this study. If you decide to take part in this study, you will be asked to sign a consent form. After you sign the consent form, you are still free to withdraw at any time and without giving a reason. Withdrawing from this study will not affect the relationship you have, if any, with the researcher. If you withdraw from the study before data collection is completed, your data will be returned to you or destroyed.

CONSENT

I have read and I understand the provided information and have had the opportunity to ask questions. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving a reason and without cost. I understand that I will be given a copy of this consent form. I voluntarily agree to take part in this study.

Participant's signature _______________________________ Date __________

Appendix B

Interview Guideline after the Session

1. What type of interaction method (tapping or sliding) did you find more intuitive and user-friendly?

    If they say Tap-based interaction:

    a) Were you able to easily and accurately select the desired climate control settings using the tap-based interaction?
    b) Was the interaction physically demanding?
    c) Anything you like or dislike?

    If they say Slide-based interaction:

    a) Did the slide-based interaction method allow for precise adjustments of the climate control settings (e.g., temperature, airflow)?
    b) Was the interaction physically demanding?
    c) Anything you like or dislike.

2. What prototype interface design (tap-based interface or slide-based interface) did you find more intuitive and user-friendly? Why?
3. Did you experience any distractions while using the touchscreen for climate control while driving?
    a. If so, what aspects were distracting?
4. Were there any features or elements in the touchscreen interface that could be improved to reduce distractions?
5. How did the countdown task while driving affected your ability to interact with the touchscreen for climate control functions?
    a. Did it increase your sense of cognitive load?
6. Can you describe any strategies you employed to manage the spread of attention between the two tasks?
7. Do you recall which secondary interaction task was more mentally demanding: countdown task or touchscreen interactions?
    a. Can you say when was the highest peak of your Mental Demand?
    b. How did you feel yourself during this peak?
8. How helpful was the visual feedback provided on the touchscreen while interacting with the climate control functions during the driving simulation (Visual feedback such as highlighted button after activation)
9. Are there any suggestions you have regarding visual feedback to enhance efficiency and effectiveness?

Appendix C

Age:
What is your age?

____

Gender:

Male
Female
Other

Experience with Navigation Systems (GPS):
Have you used navigation systems (e.g., GPS) in vehicles before?

Yes
No

Experience Interacting with In-Vehicle Touchscreen Interfaces:
Have you interacted with in-vehicle touchscreen interfaces in the past?

Yes
No

Driving Experience:
How many years of driving experience do you have?

Less than 1 year
1-5 years
6-10 years
11-20 years
Over 20 years

Frequency of Driving:
How often do you drive in a typical week or month?

Daily
3-5 times a week
1-2 times a week
A few times a month
Rarely or never drive

Age at Obtaining Driver's License:
At what age did you obtain your driver's license?

____

Experience with Touchscreens:
How would you describe your experience with using touchscreens in your daily life (e.g., smartphones, tablets, ATMs)?

Novice (little to no experience)
Intermediate (moderate experience)
Advanced (frequent and proficient usage)

Frequency of Touchscreen Interaction:
How often do you typically interact with touchscreens in your daily life?

Rarely or never
Occasionally
Several times a day
Hourly
Constantly

Familiarity with Racing Games:
Are you familiar with playing racing video games?

Not familiar
Familiar

Familiarity with Driving Simulators:
Are you familiar with using driving simulators or simulation software for training or entertainment purposes?

Not familiar
Familiar

Familiarity with Gaming Steering Wheel and Pedals:
Have you ever used a gaming steering wheel and pedals for driving simulation or racing games?

Not familiar
Familiar