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Acceptability of Interactive Dashboard Technology in Electric Vehicles among Two Different User Profiles

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CERTIFICATE OF ETHICS APPROVAL

This is to confirm that the research project described below has been evaluated in accordance with ethical conduct for research involving human subjects, and that it meets the requirements of our policy on that subject.

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Résumé

L'intégration croissante d'interfaces numériques avancées dans les véhicules soulève des questions quant à leur facilité d'utilisation, leur impact cognitif et la satisfaction de divers groupes d'utilisateurs. Cette étude examine les effets des interfaces de tableau de bord à écran unique et à écrans multiples sur les performances de l'utilisateur, la charge cognitive, la compréhensibilité, la fiabilité et la satisfaction de l'utilisateur, en mettant particulièrement l'accent sur les différences liées à l'âge. Un plan expérimental intra-sujet a été utilisé, impliquant 24 participants répartis en deux groupes d'âge: 18-35 ans et 50 ans et plus. Les participants ont évalué une interface à écran unique (Tesla Model 3) et une interface multi-écrans (Hyundai Ioniq 6) à travers des tâches structurées qui simulaient des scénarios du monde réel.

Les résultats sur la performance des tâches révèlent que les interfaces à écran unique sont nettement plus performantes que les systèmes multi-écrans en termes de réduction de la charge cognitive, de l'effort et de la frustration, tout en augmentant la satisfaction des utilisateurs, en particulier pour les jeunes participants âgés de 18 à 35 ans. Les participants plus âgés (50 ans et plus), bien que plus familiers avec la conception traditionnelle des véhicules, ont montré une charge cognitive plus élevée et une satisfaction moindre avec les systèmes multi-écrans en raison des difficultés à comprendre et à naviguer dans ces interfaces. L'analyse de médiation indique que la charge cognitive, la compréhensibilité, la facilité d'utilisation et le divertissement influencent de manière significative la relation entre le nombre d'écrans et la satisfaction de l'utilisateur. Alors que les jeunes participants tirent une plus grande satisfaction et un plus grand divertissement des configurations multi-écrans, les participants plus âgés affichent une préférence pour des conceptions plus simples et plus intuitives.

Ces résultats soulignent la nécessité de concevoir des interfaces qui tiennent compte de l'âge et qui équilibrent la compréhensibilité, la facilité d'utilisation, la fiabilité et le divertissement tout en minimisant les exigences cognitives. L'étude se termine par des recommandations concrètes à l'intention des constructeurs automobiles pour améliorer les systèmes de tableau de bord et s'assurer qu'ils répondent aux attentes en constante évolution des différents groupes démographiques d'utilisateurs.

Mots-clés: Infotainment des véhicules, interface à écran unique, interface multi-écrans, charge cognitive, satisfaction de l'utilisateur, utilisabilité, véhicules électriques.

Abstract

The increasing integration of advanced digital interfaces in vehicles raises questions about their usability, cognitive impact, and satisfaction among diverse user groups. This study investigates the effects of single-screen and multi-screen dashboard interfaces on user performance, cognitive load, understandability, reliability and user satisfaction, with a particular focus on age-related differences. A within-subjects experimental design was employed, involving 24 participants divided into two age groups: 18–35 and 50+. Participants evaluated a single-screen interface (Tesla Model 3) and a multi-screen interface (Hyundai Ioniq 6) through structured tasks that simulated real-world scenarios.

Results on task performance reveal that single-screen interfaces significantly outperform multi-screen systems in reducing cognitive load, effort, and frustration while enhancing user satisfaction, particularly for younger participants aged 18-35. Older participants aged 50+, although more familiar with traditional vehicle designs, demonstrated higher cognitive load and decreased satisfaction with multi-screen systems due to challenges in understanding and navigating these interfaces. Mediation analysis indicates that cognitive load, understandability, usability and entertainment significantly influence the relationship between the number of screens and user satisfaction. While younger participants derive greater satisfaction and entertainment from multi-screen setups, older participants exhibit a preference for simpler, more intuitive designs.

These findings emphasize the need for age-inclusive interface designs that balance understandability, usability, reliability, and entertainment while minimizing cognitive demands. The study concludes with actionable recommendations for automakers to enhance dashboard systems, ensuring they cater to the evolving expectations of diverse user demographics.

Keywords: Vehicle infotainment, single-screen interface, multi-screen interface, cognitive load, user satisfaction, Usability, Electric vehicles

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List of Abbreviations & Acronyms

MF = Mediator Factors

EV = Electric Vehicles

HUD = Heads-Up Display

AR = Augmented Reality

HMI = Human-Machine Interfaces

FTIM = Full-Touch Interaction Mode

CIM = Conventional Interaction Mode

OEM = Original Equipment Manufacturer

AV = Autonomous Vehicle

SAE = Society of Automotive Engineers

HCI = Human-Computer Interaction

AOI = Areas-of-Interest

VR = Virtual Reality

ADAS = Advanced Driving Assistance Systems

NDRT = Non-Driving-Related Task

UI = User Interface

GUI = Graphical User Interface

REB = Research Ethics Board

PSI = Pound per Square Inch

UX = User Experience

ECU = Electronic Control Unit

CPU = Central Processing Unit

GPU = Graphics Processing Unit

SDK = Software Development Kits

API = Application Programming Interfaces

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Chapter 1: Introduction

1.1 Context

As electric vehicles become a standard, the center display has become a key area for automakers to differentiate themselves. However, the rush to bigger screens might be advancing too quickly.

Just a decade ago, touchscreens in cars were relatively small and singular, if they even existed at all. Most were added reluctantly by manufacturers, often in response to new regulations like the US mandate for backup cameras or as an early move from Elon Musk, who introduced a 17-inch touchscreen in the Tesla Model S in 2012. Further, navigational capabilities were still a DIY effort, with drivers relying on portable GPS devices or smartphones wedged into cupholders.

Fast forward to the year 2024, today, touchscreens have evolved from an optional feature to an industry standard. Around 97% of new cars globally now come with at least one touchscreen, and their size is expanding rapidly. According to S&P Global Mobility (2022), nearly a quarter of all new US vehicles have displays measuring 11 inches or more, with luxury brands now adding separate screens for passengers (Zhao & Lin, 2022). This trend is particularly pronounced in electric vehicles, as electric drivetrains transform cars into performance machines, from powerful trucks to compact hatchbacks, the central display has become the most prominent area for brands to make a statement (Smith & Johnson, 2024).

The prevalence of multiple screens in electric vehicles (EVs) compared to traditional gasoline-powered vehicles can be attributed to several key factors. EVs require drivers to monitor additional metrics such as battery levels, range estimates, and charging station locations. Multiple screens facilitate the organized presentation of this information, ensuring drivers have easy access to critical data without distraction (Moshagen & Thielsch, 2013). EV manufacturers often prioritize sleek, futuristic interiors. Multiple screens contribute to this aesthetic by providing a seamless digital interface that aligns with the advanced technology image of EVs (Smith & Johnson, 2024). The integration of advanced driver-assistance systems (ADAS) and autonomous driving features in EVs necessitates clear and organized information display. Multiple screens, thus, allows for the effective presentation of data related to these systems, enhancing driver awareness and safety (Zhao & Lin, 2022).

Early adopters of EVs are often tech-savvy and expect innovative features. Multiple screens meet these expectations by offering interactive and customizable interfaces that enhance the user experience (Nimblechapps, 2024). In a growing EV market, manufacturers use multiple screens to differentiate their vehicles, offering a more luxurious and technologically advanced user experience compared to traditional vehicles.

In contrast, traditional gasoline-powered vehicles typically do not require the same level of information integration and often maintain simpler dashboard designs, resulting in less emphasis on multiple screens (Smith & Johnson, 2024). With this new adoption of bigger and more, one question remains: at what cost?

1.2 Research Questions

Existing research suggest that there may be a direct influence between increased cognitive workload and the presence of multiple screens in vehicles. While advanced infotainment systems and large touchscreens may offer enhanced features and convenience, they also come with the risk of mental overload, distractions, and safety concerns (Owens et al., 2013). As automakers continue to design vehicles with more complex user interfaces, it's essential for designers to consider human factors like cognitive workload. Simple, intuitive, and non-distracting interfaces, possibly with a more integrated or streamlined approach, may be key to reducing the cognitive burden on drivers. Therefore, to further test this research, this study will address the following research question:

1. **R1:** Would a multi-screen digital interface be more usable than a single digital interface?
2. **MF1:** Would age groups significantly influence overall satisfaction when comparing a single-screen interface to a multi-screen interface?

1.3 Thesis Structure

This thesis is structured into several sections. Chapter 1 introduces the topic by offering background information and context on the growing need for multi-screen interfaces. It also highlights the importance of effective design in minimizing cognitive load, especially as the industry transitions to alternative fuel sources. It outlines the research question that will guide the investigation. Chapter 2 presents a thorough literature review, summarizing the current state of research. It defines key concepts and constructs related to the research question and confirms the existing literature using new and relevant data. Chapter 3 will further articulate the confirmatory (hypothesis-testing) research, as existing research has been conducted in identifying the relationship between certain variables under investigation. In this approach, we will assess if a theory, specified as hypotheses, which will be reviewed in the next section, is supported by new and relevant data. For example, variables under investigation may include if *multiple screens* are to become a significant factor that undermines the collective satisfaction among participants. Other variables may identify if the *generational demographic* possesses any significance under this study's experiment. In other words, mixed research will compliment this paper as both qualitative and quantitative data will enrich the results and the research methodology. Chapter 4 will effectively discuss the investigated results and present the results in a manner that proves or disproves any significance to the experiment’s variables and hypotheses. Chapter 5 concludes our study by presenting key findings, business implications, limitations, and suggestions for future research. We finalize this thesis with Chapter 6 concluding with a summary of the completed work.

Chapter 2: Literature Review and Proposed Hypotheses

In this chapter, we present our theoretical framework based on BC approaches and discuss the hypotheses for this study.

2.1 Introduction to the literature review

The aim of this literature review is to explore scholarly research on vehicle dashboard design, with a specific emphasis on how the number of screens influences overall satisfaction. It begins by examining the recent rise of multi-screened interfaces and its impact on society. Prior studies are reviewed, including those that both support and challenge the significance of a multi-screen interface. This chapter then identifies its counterpart by examining the potential added value by minimizing the number of screens down to a single-screen interface.

This study will also examine recent advancements in in-vehicle AI, including voice assistants and gesture-based controls. It will then explore studies comparing interface designs that extend beyond traditional screens, such as voice interfaces and tactile feedback. Additionally, it will focus on human factors in automotive user experience, emphasizing safety, user satisfaction, and accessibility. Finally, the chapter will synthesize these insights to guide the experimental design.

The literature was sourced from online databases available through the HEC Montréal library. The search strategy for this literature review employed multiple screening processes. Initially, titles and abstracts were analyzed to determine relevance, followed by an in-depth review of full-text articles to evaluate their contributions to the core topics. To identify relevant papers, searches were conducted using targeted keywords across a variety of databases, carefully chosen for their reputable academic resources and publishers. Additional searches included international journals, key conference proceedings and statistics derived from official motor vehicle organizations. Details of the search queries are provided in Table 1: List of Search Keywords and Scientific Databases Used. Boolean operators ("OR," "AND," and "NOT") were used to refine and focus the search results. This approach ensures a comprehensive and focused review aligned with the research objectives.

Table 1: List of Search Keywords and Scientific Databases Used

Search keywords	Scientific databases/organizations
“Cognitive Load”	ACM Digital Library
“Cognitive Load and Dashboard Technology”	arXiv
“Cognitive Load and Multi-screen Interface”	Cognitive Engineering and Decision Making
“Electric Vehicles”	Google Scholar
“Electric Vehicles and Single-screen interface”	IEEE Access
“Electric Vehicles and Multi-screen Interface”	IEEE Transactions on Intelligent Vehicle

"Age and Modern Vehicles" "Modern Vehicle Infotainment" "Modern Vehicle Infotainment and Frustration "Modern Vehicle Infotainment and User Satisfaction" "Trust" "Usability"	Information Systems Journal International Journal of Human–Computer Interaction J.D Power MDPI Nielsen Norman Group NHTSA Oxford Academic PubMed Central ResearchGate World Electric Vehicle Journal

2.2 Rise of the Multi-Screen Interface

Multi-screen infotainment systems feature multiple displays positioned strategically throughout a vehicle's interior, each dedicated to specific functions. Typical configurations include a primary driver-focused display (like a digital dashboard or heads-up display), a central touchscreen for managing entertainment and climate controls, and additional passenger screens, often integrated into seatbacks or foldable armrest displays. In some advanced designs, entire dashboards transform into customizable display surfaces (J.D. Power, 2023).

Automakers are advancing multi-screen technology, especially in electric vehicles (EVs), to redefine user experience (DeGuzman et al., 2024). From Tesla's expansive touchscreens to innovative layouts by companies like Kia and Hyundai, interconnected multi-display systems are becoming hallmarks of modern EV interiors. These designs emphasize personalization, seamless integration, and enhanced usability, paving the way for a more connected and interactive driving experience (Li et al., 2024).

A key feature of multi-screen infotainment systems is the seamless integration of information across all displays (Zhu et al., 2023). Instead of functioning as isolated units, future systems are designed to operate in unison, enabling content and controls to transition fluidly between screens based on the user's needs and context. For instance, navigation guidance might appear on a heads-up display (HUD) for the driver, while secondary tasks like media controls are managed on a central touchscreen or passenger-dedicated displays (Zhu et al., 2023). Advanced technologies, such as eye-tracking or gesture recognition, could further enhance this experience by allowing information to "follow" the user's focus, enabling a more intuitive and distraction-free interaction.

Future multi-screen systems are set to offer personalised and customizable user interfaces (J.D. Power, 2023). Depending on who is driving or sitting in the passenger seat, the infotainment system will adapt to individual preferences. Settings such as preferred layouts, colour schemes, and frequently used apps or controls will be automatically loaded, ensuring a personalized experience every time someone enters the vehicle (Li et al., 2024).

This level of customization could also extend to the various displays for passengers. For instance, children in the back seat might access a screen dedicated to entertainment, while an adult in the front passenger seat could adjust the navigation or assist with other vehicle functions through their dedicated display, however, for the purpose of this study, we will limit to the front cockpit.

Additionally, HUDs are evolving with the integration of augmented reality (AR), offering drivers real-time primary information directly on the windshield (Zhou et al., 2024). Future AR-enhanced HUDs will overlay navigation guidance, hazard alerts, and other essential data onto the road itself, minimizing the need for drivers to look away and onto the screen (Chen et al, 2024). In electric vehicles (EVs) equipped with multi-screen systems, the HUD can work synergistically with other displays (Zhou et al, 2024). This type of integration allows drivers to access contextual information, such as charging station locations, battery status, and other primary information within their direct field of view. Meanwhile, passengers can utilize separate screens for their own activities, creating a layered and immersive informational environment tailored to each occupant's needs (Skirnewskaja & Wilkinson, 2021).

2.3 The Multi-Modal Effect on Cognitive Load

The design of in-vehicle interfaces significantly influences driver cognitive load, with both multi-screen and single-screen configurations presenting unique challenges and benefits (Budiu, 2019). Research indicates that multi-screen setups, such as the integration of Head-Up Displays (HUDs) with central control screens, can effectively reduce driver cognitive load (Zhan, 2014). A study published in the International Journal of Human–Computer Interaction found that HUDs, by presenting critical information within the driver's line of sight, minimize the need for drivers to divert their gaze, thereby enhancing reaction times and reducing cognitive strain (Zhu et al., 2021). However, human cognitive resources are inherently limited, making it easy for excessive information to lead to driver distraction. The effectiveness of multiscreen interconnections in reducing such distractions remains a topic of debate. This study explored the types of information requiring driver attention. Using findings from a user study, a simulated driving experiment was conducted to measure drivers' response times and cognitive loads when interacting with driving-assistance information to complete driving tasks. The objective was to determine whether displaying driving-assistance information on a HUD, separate from the central screen, could help drivers respond more efficiently and with reduced cognitive demand (Zhu et al., 2021).

Experimental findings demonstrated that HUDs significantly lower cognitive load compared to displaying information solely on a single central screen (Zhu et al., 2021). Furthermore, HUDs improved drivers' reaction times across all types of driving-assistance information. The study also compared drivers' reaction times and cognitive loads when using HUDs versus a single central control screen, examining scenarios where the same or different types of information were displayed. Results indicated that when identical content was displayed across screens, there was no substantial difference in reaction times between using a HUD and relying solely on the central screen (Zhu et al., 2021). The analysis of information distribution between multiscreen interfaces highlights the potential of HUDs to optimize driver response while managing cognitive resources effectively.

When further evaluating an all-touchscreen interface, Tesla's Model 3 represents the benchmark of minimalistic design centered around a single, large touchscreen interface that consolidates various vehicle controls and information displays (Budiu, 2019). While this design offers a streamlined aesthetic, it has been critiqued for potentially increasing cognitive load (Eva et al., 2019). The reliance on a single touchscreen for multiple functions may require drivers to navigate through menus and focus on screen-based controls, potentially diverting attention when on the road (Eva et al., 2019).

Direct comparative studies between multi-screen interfaces and Tesla's single-screen design are limited. However, existing research suggests that interfaces requiring drivers to look away from the road to interact with controls can elevate cognitive load and distraction levels (J.D Power, 2023). In contrast, multi-screen configurations, particularly those incorporating HUDs, may distribute information more ergonomically, thereby supporting better driver attention management (Zhan, 2014). Therefore, considering these findings, and in-line with this paper, we may suggest the following:

H1 – "Participants interacting with a multi-screen interface will report a lower cognitive load than those using a single-screen interface."

2.4 The Multi-Screen Effect on In-Vehicle Performance

It's been expressed earlier that in recent years, the full-touch human–machine interaction (HMI) has gained significant traction in the automotive industry. However, limited research has explored how this interaction influences user's behavior and in-vehicle performance. Yuan et al., (2022) assessed the visual engagement and interface performance of thirty (30) participants while operating vehicles equipped with either several full-touch interaction modes (FTIM) or the conventional interaction mode (CIM) provided by the original equipment manufacturer (OEM).

The results indicated that while under a multi-screened interface, simple tasks related to the control of air-conditioning required more visual engagement, longer task completion times, and poorer lateral vehicle control under FTIM (Yuan et al., 2022). Additionally, the study introduced “driving speed” as an independent variable and found that the speed of the vehicle significantly affected both user behavior and interface performance in both interaction modes (Yuan et al., 2022). While the current study does not include an “on-road” experiment, participants adjusted their behavior to accommodate additional tasks as speed increased. They found that this adaptation was insufficient to offset the decline in interface performance caused by higher speeds. Yuan et al. (2022) outlines that, although, multiple screens affected the users, these findings did not suggest a strong correlation.

Additional research suggests that integrating multi-screen interfaces in vehicles offers several advantages over single-screen systems, or even conventional and tactile interfaces primarily with physical buttons, suggesting that multiple screens enhance the user experience and increase the operational efficiency when navigating the internal cockpit of a vehicle (Li et al., 2022). That said, users often need to perform multiple tasks simultaneously, such as navigation, communication, and system control. Multi-screen interfaces could potentially distribute information across displays, reducing the need to switch between screens and making tasks more accessible (Li et al., 2022).

Prior research highlights the obvious advantage by discussing enhanced multitasking capabilities. Ferris and Suh (2018) investigated this benefit and examined how the characteristics of in-vehicle interfaces affect drivers' multitasking performance, specifically regarding the users’ visual attention of in-vehicle touchscreens. Unlike physical controls, which provide natural non-visual cues, in-vehicle touchscreens rely heavily on vision, consequently, increasing the time spent with their eyes on screens, and potentially off the road raising safety concerns and increasing the cognitive load, despite increased informational accessibility. In short, we can suggest that although, there may be the potential for greater in-vehicle performance with tasks as the user navigates independent screens, there still the underlining assumption that more screens are present, the greater the potential risk for safety concerns when driving and the greater the cognitive load needed to operate each screen (Ferris and Suh, 2018).

Ferris and Suh (2018) found that the addition of nonvisual feedback significantly enhanced both the accuracy and speed of visual detection on the multiple screens. These results assist us in understanding that conventional design, accompanying modern touchscreens may work harmoniously, ultimately, can help maintain visual attention, improve multitasking for in-vehicle performance and increase in-vehicle performance.

While these studies include simulated visual cues, recent studies continue to show controversial arguments when determining the optimal interface. However, considering these findings, and in-line with this paper, we may suggest the following:

H2 – "Participants interacting with a multi-screen interface will report higher task success rates than those using a single-screen interface."

2.5 The AI Boom

Autonomous vehicles (AVs) are on the verge of becoming a reality, with major automotive manufactures like Tesla, BMW, and Hyundai, alongside technology giants such as Google's Waymo, driving efforts toward achieving fully self-driving capabilities. The SAE (Society of Automotive Engineers) J3016 taxonomy classifies autonomous driving into six levels, ranging from Level 0 (entirely manual) to Level 5 (completely autonomous), where vehicles are designed to operate in any geographic location, weather condition, or situation. The anticipated advantages of intelligent vehicles include fewer road accidents, improved safety, reduced traffic congestion, more efficient use of commute time, and a more enjoyable, comfortable ride (Goodrich & Schultz, 2008).

As autonomy advances, drivers will transition to passengers, focusing on non-driving tasks and being less involved in traditional traffic interactions. This shift creates opportunities for new forms of interaction. To facilitate these interactions, an increasing number of interfaces and sensing modalities, such as gesture control, voice commands, and eye-gaze are being integrated into vehicles to detect the actions, emotions, and preferences of drivers and passengers, enabling personalized functionalities and services for a more enjoyable journey (Zhang & Wang, 2021).

As discussed in previous sections, the automotive industry has increasingly shifted from traditional buttons and dials to touchscreen displays offering multiple functionalities, becoming the new standard. However, given the potential for multiple visual displays to distract drivers, researchers are exploring alternative, intuitive and less distracting methods to provide feedback. That said, tactile or haptic interfaces present several notable advantages: (1) *non-visual interaction*: secondary information can be conveyed to drivers, enabling task completion without glancing at a screen or taking their eyes off the road; (2) *privacy:* communication between the vehicle and the driver can occur discreetly, without the need for public visual or auditory cues and (3) *reaction time:* research indicates that tactile feedback elicits faster response times compared to visual feedback. These innovations bridge the complexity of modern vehicle systems and user accessibility, fostering more intuitive interaction and informed decision-making (Zhang & Wang, 2021).

Over recent decades, eye-tracking has garnered significant interest in Human-Computer Interaction (HCI) (Jacob, 1990). By tracking users' gaze direction, eye-tracking provides a natural interface that eliminates the need for touch-based inputs (Quek, 1995). However, the effectiveness of eye-tracking methods depends on factors such as the type of sensors used (e.g., head-mounted or non-contact devices). Eye-gaze interaction, though promising, has limitations, including volatility and an "always-on" nature, which lacks a natural trigger for object selection within the vehicle (Zhai et al., 1999).

However, mid-air gestures, such as pointing, have also become a key focus for user interaction. These gestures allow users to reference objects that are out of reach in a natural manner, especially when combined with speech commands (Schweigert et al., 2019). This multimodal integration, rather than an all-tactile interface, serves two purposes: (1) compensating for the limitations of one modality with the strengths of another, and (2) enhancing overall interaction performance by leveraging temporal relationships between inputs. While these techniques have broad applications, including aiding individuals with disabilities (Sauras-Perez et al., 2017), this literature review will focus their use on the automotive industry. Mitrevska et al. (2015) conducted a study with 120 participants and two vehicles, utilizing adaptive multimodal control systems that incorporated individual modalities such as speech, gaze, or gesture, as well as combinations of two or more modalities. Research consistently demonstrates that systems leveraging multiple input modalities have the potential to outperform those relying on a single modality (Esteban et al., 2005). Consequently, many researchers have adopted multimodal fusion techniques for user interaction.

For example, this approach enables users to select objects on a screen by fixating on a target and using mid-air gestures to confirm the selection (Chatterjee et al., 2015). Exclusively using gaze for selection poses challenges, particularly when objects are positioned closely together (Hild et al., 2019). To address such limitations, Nesselrath et al. (2016) employed a combination of three modalities—speech, gaze, and gestures—to facilitate the initial location of vehicle settings (e.g., side mirror defrosters) and subsequently control these elements using either gestures or speech.

These methods primarily utilize gaze information to enhance interaction naturalness by integrating secondary modalities like gestures or speech. In contrast, Sauras-Perez et al. (2017) proposed a system combining speech with finger-pointing gestures for selecting Areas-of-Interest (AOI) while driving or stationary. This highlights the versatility of multimodal systems in improving user interaction within vehicles.

Inspired by BMW's Natural Interaction system introduced at the Mobile World Congress in 2019, this multimodal operation for in-vehicle application will become the stepping block for innovation in the automotive industry. We now know that tasks such as managing infotainment systems or operating control units can impact cognitive attention. It's been hypothesized that the greater the cognitive load, the greater the risk of decreased user performance. Although, with the advancements of gestural interfaces, and intuitive design, it will assist in reducing this cognitive load (Roider & Raab, 2018).

Freehand pointing gestures have become increasingly popular in in-vehicle infotainment systems, as they allow users to interact with objects naturally, consequently, improving the users' ability to understand the vehicle's interface (Ahmad, 2017). Additionally, as we enter the age of AI-driven systems, in which, can provide real-time feedback and instructions, it teaches users about vehicle features as they interact with vehicle controls. For example, a voice assistant could guide a driver through unfamiliar settings, such as activating a new safety feature, fostering better understanding of the vehicle's capabilities (Zhang & Wang, 2021). Traditionally, understanding advanced vehicle systems required reading manuals or undergoing some form of training with a salesperson or a previous owner of the vehicle. AI interfaces significantly lower this barrier by offering intuitive controls and simplifying complex operations, making high-tech vehicles accessible to a, now much, broader audience, ultimately, reducing possible barriers for adoption with an improved user educational guide (Zhang & Wang, 2021). Therefore, considering these findings, and in-line with this paper, we may suggest the following:

H3 – "Participants who report a lower cognitive load will report a higher level of understandability."

Studies have suggested that a deeper understanding of vehicle systems fosters trust and a sense of reliability in their interaction. When users feel confident in their ability to control and interact with the vehicle, they are more likely to engage with its advanced features, improving overall satisfaction and safety (Walker et al., 2023). Therefore, considering these findings, and in-line with this paper, we may suggest the following:

H4 – "Participants who report a lower cognitive load will report a higher level of reliability."

H8 – "Participants who report higher levels of reliability will report a higher level of user satisfaction."

As we dig deeper into building an effective design during an in-vehicle interaction, research indicates that to increase the acceptance of autonomous vehicles (AVs) and its innovative design, it would require engaging users in activities that prevent boredom, reduce cognitive load, and promote relaxation (Huysduynen et al., 2018). This can be achieved through features such as larger screen displays for work or entertainment, as well as immersive technologies like VR (Virtual Reality) and AR for gaming, infotainment, and more (Detjen et al., 2021). These advancements, also discussed in earlier sections aim to enhance the passenger experience by transforming the vehicle into a versatile "living space," suitable for gaming, mobile working, relaxing, socializing, and even sleeping. Therefore, considering these findings, and in-line with this paper, we may suggest the following:

H6 – "Participants who report a lower cognitive load will report a higher level of entertainment."

2.6 The Multi-Modal Effect on Usability

The current automation level of mass-produced vehicles corresponds to SAE Level 2, or "Partial Driving Automation." At this level, Advanced Driving Assistance Systems (ADAS) are capable of managing both lateral and longitudinal vehicle control, however, the driver remains responsible for object and event detection and response (Nagy et al., 2023). The increasing number of controllable functions and non driving related tasks (NDRT) within newer vehicles heightens the complexity of these tasks, leading to an increased cognitive load (Greenlee et al., 2018).

Despite these advancements, vehicles remain predominantly controlled manually by the driver, who assumes the role of operator in the context of HCI. This raises a critical question outside of this study: are current HMIs equipped to ensure effective communication and maintain the safety levels promised by ADAS? Presently, HMIs and HCI concepts are designed for manually controlled vehicles. However, the cognitive demands imposed by on-board interfaces often result in excessive manual and visual distractions, which are particularly problematic in moving vehicles (Strayer et al., 2019).

Although ADAS offers significant benefits, these systems are not infallible and can make erroneous decisions in certain scenarios. In such cases, the human driver remains the only flexible and adaptable component capable of intervening and modifying system processes to prevent errors. As a result, the situational awareness of the human driver is a critical factor for ensuring safety in automated or assisted driving, ensuring that the usability of the vehicle's interface remain a top priority (Kovács et al., 2021).

A study conducted by Nagy et al. (2023) was performed with 16 participants to investigate driver distraction, cognitive load and interface usability during a naturalistic driving test conducted on a closed track, comparing various user interfaces (UIs) through the use of a wearable eye-tracking device and psychological questionnaires.

Previous research has demonstrated that interactions with in-vehicle systems while driving significantly increase cognitive demand and distraction levels (Strayer et al., 2019). However, the type and extent of distraction are influenced by the specific NDRT and the interface design. A wide range of multimodal in-car interaction methods has been explored, including physical buttons, dials, touchscreens with varying graphical user interface (GUI) layouts, as well as speech and gesture controls (Ng et al., 2017; Jung et al., 2021).

The design of the comparative pilot study builds on these earlier findings while aiming to generate new insights into driver distraction, cognitive load and usability across different UI modalities. The results revealed that using a single-modal multi-touchscreen interface integrated with in-vehicle systems leads to increased driver distraction, and lower levels of interface usability even during the execution of NDRTs (Skaramagkas et al., 2021).

Contrary to single-modal in-vehicle systems, by allowing drivers to issue natural language commands, voice assistants can simplify the process of interacting with vehicle systems. For example, drivers can adjust settings or retrieve information without needing in-depth knowledge of the vehicle's interface, reducing cognitive load and enhancing usability. Additionally, gesture interfaces enable users to interact with systems without physical manipulation of buttons or screens. This is especially helpful in reducing driver distraction mental effort and making advanced systems more intuitive to use. Therefore, considering these findings, and in-line with this paper, we may suggest the following:

H5 – "Participants who report a lower cognitive load will report a higher level of usability."

2.7 The Multi-Modal Effect on User Satisfaction

EV manufacturers such as Tesla and Hyundai have made notable progress through open-road testing and the development of advanced virtual systems (Lawson et al. 2019). These innovations have not only improved the functionality of EVs but have also accelerated the evolution of in-vehicle display technologies to meet the growing need for multitasking in modern driving environments. While some research has examined the connection between in-vehicle display configurations and user experience, a systematic evaluation of user satisfaction with NDRTs in electric driving scenarios remains underexplored (Coppola & Morisio, 2017). Additionally, much of the existing literature indicates that when users find these interfaces intuitive and in simple terms, easy to navigate, their overall satisfaction and engagement with the system improve because of how easy it is to understand the interface (Akamatsu et al., 2023). Research has shown that well-designed interfaces enhance visual ergonomics, leading to improved usability and user satisfaction. For instance, Zhang et al. (2024) studied the effects of interface layout on the usability of in-vehicle systems and found that intuitive layouts contribute to better driver performance and satisfaction. The study utilized four types of eye movement data—total fixation count, total gaze duration, scanning paths, and hotspot maps, along with behavioral data to compare participants' visual search behavior across interfaces with varying layout orders and complexity levels. In doing so, they performed two (2) experiments. In summery, experiment 1 identified a significant interaction between layout order and interface complexity, showing that participants performed notably better under the high-level layout order condition. Experiment 2 highlighted the critical influence of primary information placement, demonstrating that positioning primary information on the left side of the dashboard's horizontal axis, closest to the driver, optimizes users' visual search behavior (Zhang et al., 2024). Their findings would indicate that designers embrace the principle of "order is more" alongside the traditional "less is more" approach to interface design.

As computer technology continues to advance, user interfaces have become increasingly robust and informative, integrating a diverse range of visual elements such as maps, diagrams, monitoring screens, and information lists (Nadal et al., 2010). A prominent example, and the study of this paper, is the vehicle dashboard, which typically features multiple charts and graphs arranged to meet specific operational requirements, thereby establishing a visual hierarchy (Huynh et al., 2021). However, with the expansion of system functions, dashboards have grown more complex, incorporating an increasing number of charts and diagrams. This complexity often results in overly intricate interfaces, challenging the limits of human attention and cognitive resources. As the number of visual elements in dashboard interfaces increases, users allocate less attention to each component, reducing visual processing efficiency (Kerzel et al., 2019). Consequently, minimizing interface complexity while maintaining functionality has become a critical focus in dashboard design among todays OEMs.

Current dashboard designs primarily rely on conventional web interface layout methods, including checkerboard, horizontal, masonry, vertically integrated, and center layouts (Li et al, 2017; Chang et al., 2006; Yang et al., 2023; Chen et al., 2021). For instance, center layouts primary core elements, such as maps, at the center of the interface or in direct sight of the driver, with secondary elements placed on either side or on secondary screens. While these designs adhere to principles like narrative, analytical, and embedded layouts, they often prioritize information categories, system functions, or task relevance over the overall visual order of the layout (Bach et al., 2022; Martin et al., 2018). This lack of regularity and alignment in layout organization can disrupt the user’s visual experience, making interfaces appear more complex, thus, affecting the interface’s overall usability.

Previous studies have hypothesized that the visual order and logical structure of layout organization significantly affect interface complexity (Yang et al., 2023). This assumption is supported by related research indicating that psychologically relevant organization such as symmetry, structural variables, and grouping influences aesthetic evaluation and user experience (Liu et al., 2022). Thus, a well-ordered and logically structured interface layout may enhance usability by reducing perceived complexity and, therefore, improving user satisfaction. Therefore, considering these findings, and in-line with this paper, we may suggest the following:

H9 – "Participants who report higher levels of usability will report a higher level of user satisfaction."

Additionally, recent empirical studies indicate that complexity is not determined solely by the number of visual elements but is also shaped by factors such as familiarity and stimulus type (Reder et al., 2016; Martin et al., 2013). For instance, Zhang et al., (2020) revealed that familiarity mitigates perceived complexity, as prior knowledge influences how complexity and understandability is processed and converted into positive user satisfaction. These findings suggest that dashboard interface complexity is a relative, multidimensional characteristic rather than a simple, one-dimensional attribute, that the overall understanding of in-vehicle system do rely on intuitive design, but on your past experiences as well. We may find this significantly important due to the nature of this paper's experimental design, as we challenge different age groups, one whom have experience with traditional design layouts, and one eager for a new design. Therefore, considering these findings, and in-line with this paper, we may suggest the following:

H7 – "Participants who report higher levels of understandability will report a higher level of user satisfaction."

Earlier sections of the literature review emphasized the importance of user-friendly and intuitive guidance interfaces, noting that simplifying interaction processes can significantly enhance user satisfaction with entertainment features (Li et al., 2017). A study published in the World Electric Vehicle Journal explored how twenty-six (26) participants responded to various in-car display setups during non-driving-related tasks. The study, which utilized virtual reality head-mounted displays to simulate autonomous driving scenarios, found that a combination of portrait displays and HUDs was preferred in highly automated driving conditions. This configuration enhanced the immersion experience during non-driving tasks (Li et al., 2024). Although the current study did not include real-world driving obstacles, it highlights the importance of customizing in-vehicle display configurations to individual user preferences in order to reduce distractions and increase engagement, whether that be for entertainment purposes or not. Therefore, considering these findings, and in-line with this paper, we may suggest the following:

H10 – "Participants who report higher levels of entertainment will report a higher level of user satisfaction."

However, the user satisfaction with in-car infotainment systems can be influenced by factors such as usability and reliability (Bach et al., 2022). While entertainment features and design have the potential to enhance user satisfaction, some users have reported frustration with the high complexity of advanced systems. This highlights, once again, the need for thoughtful implementation to minimize potential distractions and usability challenges (Lawson et al. 2019). Incorporating thoughtfully designed entertainment features into in-vehicle interfaces can enhance user satisfaction, as long as these features are intuitive and maintain both safety and usability.

2.8 The Generational Gap

Finally, we may review the generational perspectives on modern design. The increasing number of older drivers on the road coincides with the rapid evolution of automotive technology (Owens et al., 2015). To explore the impact of these intersecting trends, a cross-generational study was developed to examine drivers' attitudes toward advanced automotive technologies. Around 1,000 drivers aged 18 to 70 from across the United States participated in a survey assessing their views on general technology, advanced in-vehicle systems, and emerging connected vehicle technologies. Responses were analyzed using a generational framework, considering not just age but shared life experiences such as economic conditions, and cultural influences.

Findings revealed that the oldest group, the "Silent" generation, displayed the least interest and comfort with advanced multi-screened technologies, despite owning and using in-vehicle technology at rates comparable to the middle generations (Owens et al., 2015). In contrast, the youngest group, the "Z" generation, showed the highest interest and comfort with technology but were least likely to own vehicles equipped with advanced systems. Across all generations, there was strong interest in safety-related connected vehicle features, while infotainment applications generated less enthusiasm. Common concerns about data security and system costs were noted across age groups (Owens et al., 2015).

Additionally, a study by J.D Power (2023) revealed that consumers with young children and those who frequently use their vehicles for work-related activities, such as deliveries or client transportation, show greater interest in expansive infotainment screens. These groups often drive longer distances daily and seek functionalities that enhance efficiency and convenience, making them more receptive to multi-screen interfaces. In summary, younger drivers and individuals with specific lifestyle needs, such as families with young children and in-vehicle multitaskers, are more receptive to multi-screen vehicle interfaces (J.D Power 2023). However, older generations (Baby Boomers and Older Gen X) respond to technology familiarity, which, is defined by simplicity and functionality over complexity. A single-screen interface combined with tactile controls is less likely to overwhelm users who might not be as comfortable with multitasking or advanced digital systems. Additionally, they often prioritize reliability, ease of use, and safety features over customizable or entertainment-focused interfaces (DeGuzman et al., 2024).

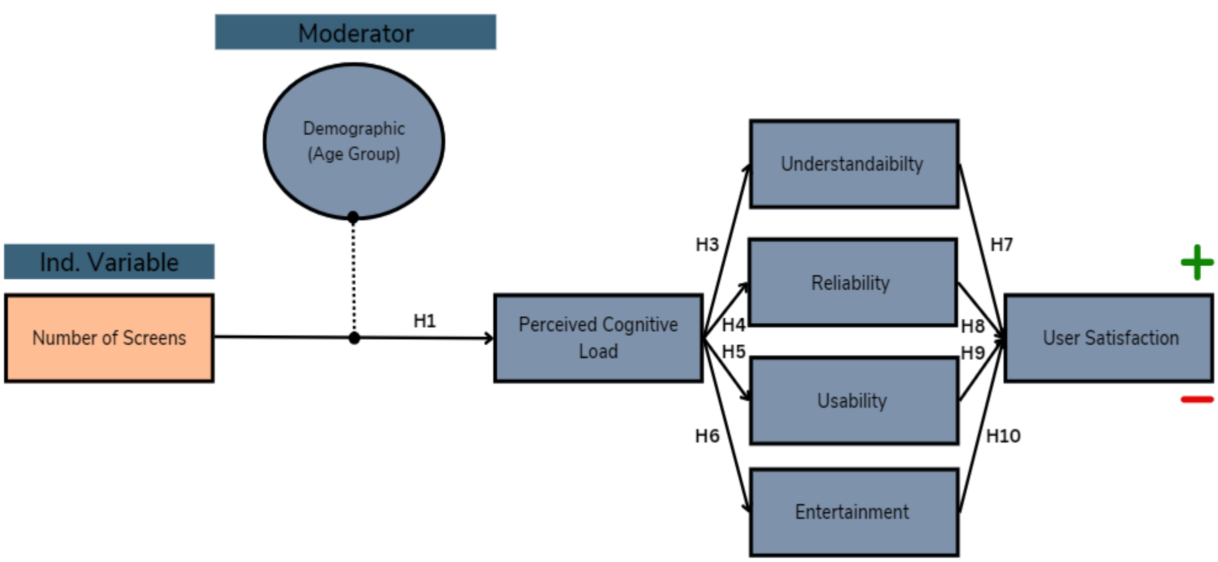
These results highlight the unique needs of an aging population, offering insights for designing vehicle technologies and planning large-scale implementation of connected systems. The study emphasizes the importance to meet the diverse expectations of different generational cohorts.

2.9 Research Model

In this study, we utilized theoretical tools within a BC framework to address our research question. The BC approach was employed to enhance the empirical applicability of increased and decreased cognitive load of the multi-single screen interface effect. To incorporate temporal conditions as contextual variables, we first recorded the number of task completions to define the effects on the study's demographic distribution such as age group, included as moderating variable to test the number of screens and user satisfaction

Using the BC theoretical approach, we developed our research model (see Figure 1: Proposed Research Model). In this model, the number of screens served as the independent variable. Understandability, reliability, usability, and entertainment serve as the dependent variables in order to measure overall user satisfaction. The experiment's tasks were repeated twice, once per tested vehicle (see Chapter 3 for details) to investigate the desired research questions.

Figure 1: Proposed Research Model



Chapter 3: Methodology

This chapter outlines the specifics of the experimental design and the procedure followed during the experiment. To address the research questions and test the hypotheses, we conducted a controlled experiment with participants interested in purchasing a new vehicle.

3.1 Experimental Design

The experimental design selected for this evaluation is within-subjects since we wish for all participants to evaluate both interfaces. The order of which the interfaces are presented to the participants have been randomized because any possible order and learning effect may offset the available data. The Hyundai Dealership, along with their inventory of the required vehicles was selected as the research location due to its ability to control variables and directly observe the effects of specific moderators, such as age and the generation they fall under, during each of the participants' tasks.

3.2 Participants

This study draws from a population sample of twenty-four participants, (see Appendix A for the demographic distribution). To ensure participants could comprehend our instructions and navigate both interfaces, we recruited individuals eighteen (18) to seventy (70), who hold an active driver's license, and who reported no prior knowledge to the vehicles in testing. The data collected will be sub-divided by two (2) age groups as followed: 18-35 (N=12) and 50+ (N=12) (see Appendix A for full table details). This breakdown will assist in demonstrating which age group is particularly receptive to certain interfaces or variables of the study. Participants are primarily gathered from a convenience sample, and primarily recruited by creating a relationship with Hyundai Saint-Laurent and requesting permission to approach potential clients of the vehicle in testing who satisfied the inclusion and exclusion criteria. Those who possess prior knowledge, who have tested either interface responsible in this study, who do not possess an active licence and/or fall above or below the age requirements are excluded from this study. Ultimately, this exclusion criteria are set in place to disqualify potential participants who may skew the results or introduce a level of biased influence. To secure and maintain participation, participants would enter a draw for a chance to win a CAD $200 pre-paid Master Card, to be drawn once all data had been collected, using https://wheelofnames.com/ to assist in the selection process. Further, participants wishing to participate signed a consent form, reviewed and approved by the Research Ethics Board (REB).

3.3 Experimental Procedure

This experiment informed participants that they would be evaluating two dashboard technologies with two (2) different dashboard design themes, a multi-interfaced dashboard from Hyundai's 2024 Ioniq 6 compared to a single-interface dashboard from Tesla's 2024 Model 3 (see Appendix B for details). Participants were then given the option to decide whether to participate in the experiment. The estimated completion time for both evaluations was approximately thirty-five (35) minutes, and free to withdraw at any point. However, their name would be removed from the draw if they chose to exit the experiment early.

For the evaluation, once a participant has agreed to participate in the study, we are then ready to commence the tests. Participants are expected to meet back or remain in the Hyundai Dealership to await further instructions. Once arrived and ready, they then received an electronic link to the Qualtrics platform via email or QR Code, in which, exposes the evaluation scenario and individual tasks (see Appendix C and Appendix D for details). Participants are in the market for a new electric vehicle and are expected to evaluate two (2) very distinctive user-experiences, therefore, in order to further express their desired selection, participants must complete the following three (3) questions directly in the vehicle in order to further evaluate the perceived cognitive load used during the tasks:

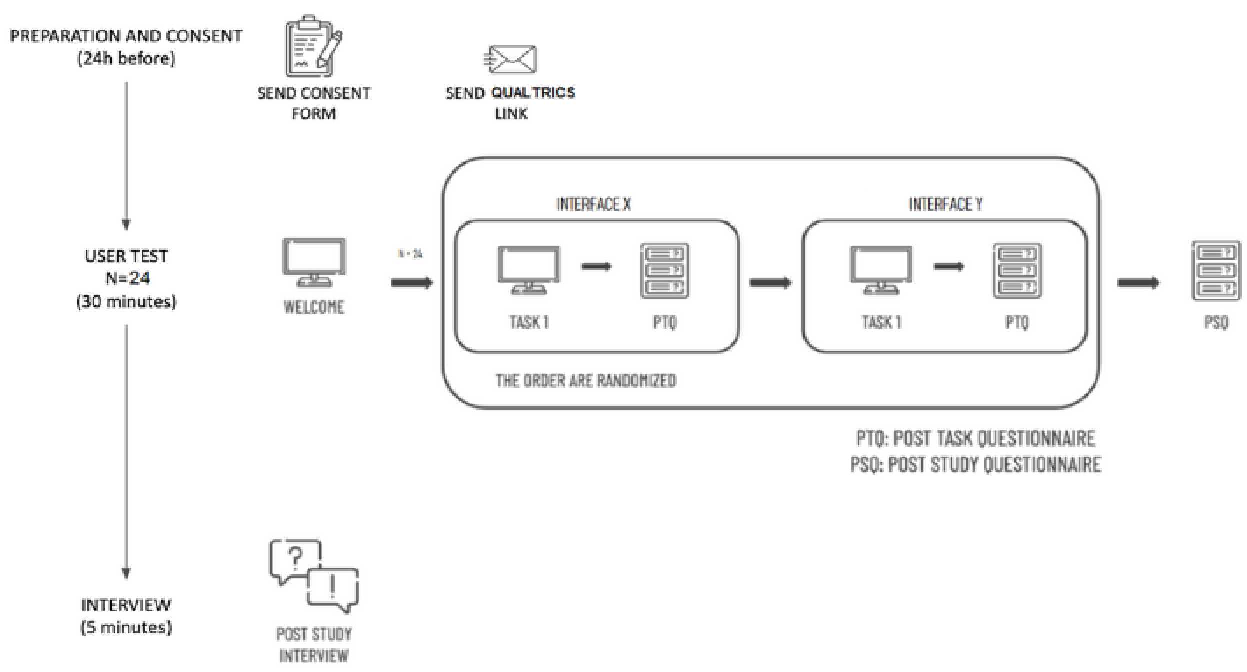
1. When understanding the health of the vehicle, using the vehicle's controls, locate the vehicle's tire pressure and determine the tires' PSI (pressure) reading. *If no numerical value is available, in the text below, indicate what is displayed.
2. Another inscrutable piece of important information is your odometer reading, locate and determine the vehicles odometer.
**Odometer: an instrument for measuring the distance travelled by a vehicle, in KM or Miles*
3. Locate the vehicle's software update portal and identify if the vehicle is available for a new update.
**In the text below, if the vehicle is available for an update, indicate, "Update is available", if no update is available, indicate, "No update is available".*

The participants are notified and expected to use their personal mobile devices and to have a stable and strong internet connection to participate in the study. In the event that they did not satisfy the technical requirements, a laptop with direct access to the initial tasks was made available ensuring full participation. Once a stable connection is secured and the link has been initiated, participants are reminded that the tasks are to be completed independently and at they own pace. Additionally, as each participant begins their evaluations, a recording device was installed in the vehicle to capture both the participant's facial expressions and the interface at whole in order to identify the time and steps taken to complete each task, which will be further discussed in section 3.4 Measures.

A task was considered successful if participants correctly identified the required vehicle information within the allocated time of three (3) minutes. If participants were unable to locate the correct information or chose to "give up", by leaving the text box empty, the task they abandoned was recorded as a failure. The task completion time and task success rate were recorded electronically upon completion of each task.

Once all three (3) tasks have been addressed, participants are directed to the post-task questionnaire, in which, after completion will record the results for the first vehicle tested. This process will repeat itself twice, until both vehicles have been tested. After recording the results within Qualtrics, and the participant behavior during each task, each participant will receive a post-study questionnaire in order to measure their overall satisfaction towards both vehicles, the below figure represents the overview of this experimental procedure.

Figure 2: Overview of Experimental Procedure



3.4 Measures

Task Completion Time and Task Success Rates: This study utilized task completion time and task success rates as metrics to evaluate objective usability—specifically, task performance. These metrics have been established as primary measures of task performance in previous research (e.g., Lavie et al., 2011; Quinn & Tran, 2010).

Perceived Cognitive Load: To assess cognitive load, we adapted the NASA-TLX questionnaire developed by NASA's Human Performance Group at the Ames Research Center (Hart, Sandra G.; Staveland, Lowell E, 1988) (see Appendix E). This cost-efficient measurement method has proven effective in capturing users' straightforward perceptions of the mental effort and frustration when exposed to certain dashboard technologies.

Further, to analyze the perceived cognitive workload, the average was calculated for each question and for each interface. The averages were then compared back between Tesla's Model 3 and Hyundai's Ioniq 6.

Satisfaction: To assess overall satisfaction, participants rated their experience using a 5-point Likert scale, which measured the understandability, reliability, usability, and entertainment value of each interface (see Appendix F).

Qualitative data is collected through the interview session at the end of the study. Participants were asked about their **overall experience** of each interface in order to extract certain conclusions from the population sample (see Appendix G).

3.4 Statistical Analysis

To begin, the UX (User Experience) calculator, created by Tech3Lab was used to perform statistical analysis on performance. Bilateral t-tests were used to compare participants' success against each interface. Simple proportions of successes and failures were used.

Questions related to the measures previously mentioned were based on a five-point Likert-scale from strongly disagree (1) to strongly agree (5). A mediation and moderation analysis were then performed in order to test for the potential influential significance among each relationship. Therefore, a multiple regression was administered using Python 3.7, running Statsmodels to identify the interaction effects and to calculate their slopes. Additionally, the Sobel test is used to then assess the significance of each mediation effect. Significance was determined at $p < 0.05$.

Chapter 4: Results

In this chapter, we begin by analyzing the descriptive statistics of each variable to explore their variation among the required tasks. Next, we perform mixed models to investigate whether cognitive load, understandability, reliability, usability and entertainment mediates the relationship between the number of screen and user satisfaction. Finally, we explore how demographic factors, such as age group may influence these relationships.

4.1 Descriptive Statistics

Before conducting the main analysis, all data were assessed for normal distribution. An alpha level of 0.05 was applied for all statistical tests. Tables 2 and 3 below presents a summary of the descriptive statistics for the experimental data for in-vehicle performance.

Table 2: Descriptive statistics of Hyundai's Ioniq 6 Performance Analysis

	Task Success Rate		Task Completion Time(sec)	
	Mean	**SD**	**Mean**	**SD**
Task 1	38%	1.67%	247	33.33
Task 2	38%	1.67%	195	-18.67
Task 3	33%	-3.33%	199	-14.67

Table 3: Descriptive statistics of Tesla's Model 3 Performance Analysis

	Task Success Rate		Task Completion Time(sec)	
	Mean	**SD**	**Mean**	**SD**
Task 1	54%	-7.33%	174	8
Task 2	63%	1.67%	184	18
Task 3	67%	5.67%	140	-26

To gain deeper meaning into how performance variables changed over time, we performed t-tests to determine whether significant differences existed between the two interfaces.

Figure 3: Mean Task Success Rate

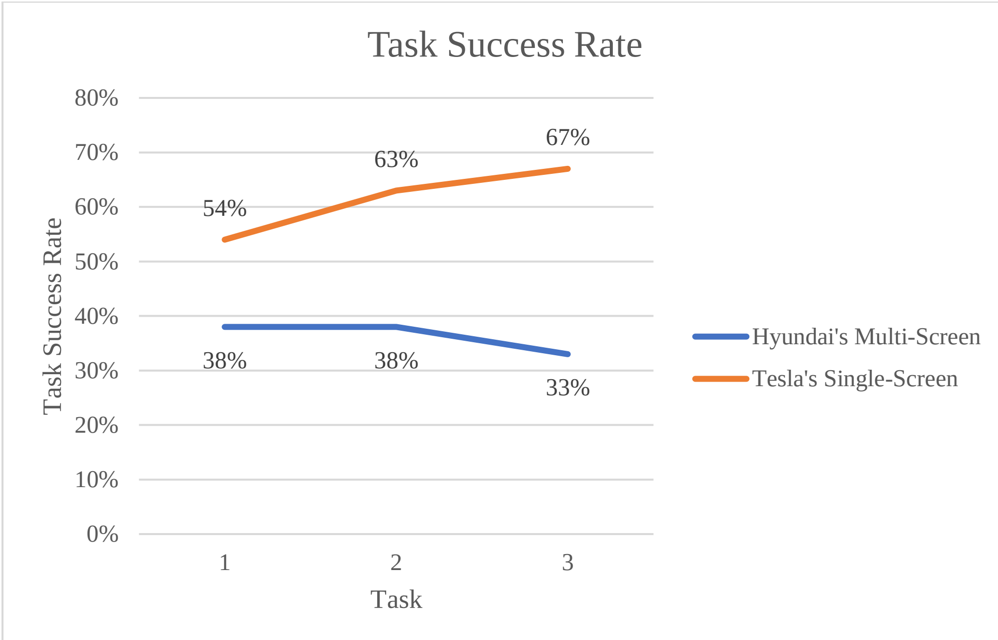


Table 4: Task Success Rate T-test

	1st	2nd	3rd
M	0.16	0.25	0.34
p	0.102	0. 067	<0.05

Despite some independent variations, the task success rates for Hyundai's Ioniq 6 and Tesla's Model 3 exhibit opposing trends throughout the experiment. Given that task success rate is a binary variable, a Wald test was employed to assess the differences in proportions between the two user groups. Figure 3 (*Mean Task Success Rate*) and Table 4 *(Task Success Rate T-test*) illustrate that tasks one (1) and two (2) were not statistically significant, likely attributable to the relatively small sample size of twenty-four (24) participants in the experiment. However, despite the small sample size, task three (3) exhibits statistically significance with a mean difference of 0.34.

Figure 4: Mean Completion Time (in seconds)

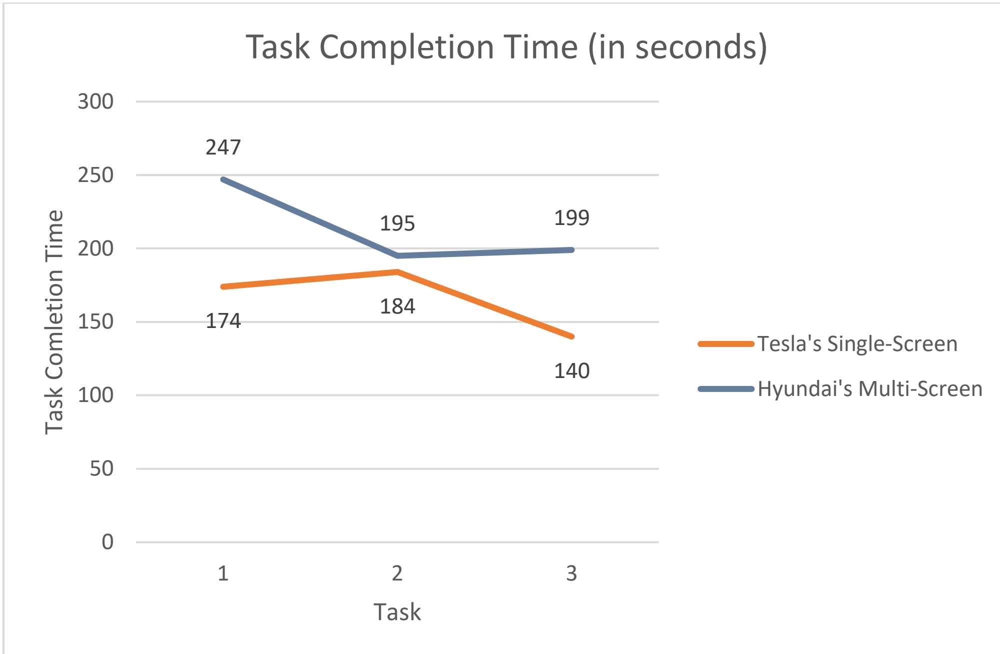


Table 5: Mean Task Completion Time T-test

	1st	**2nd**	**3rd**
M	73	11	59
p	<0.05	0.894	<0.05

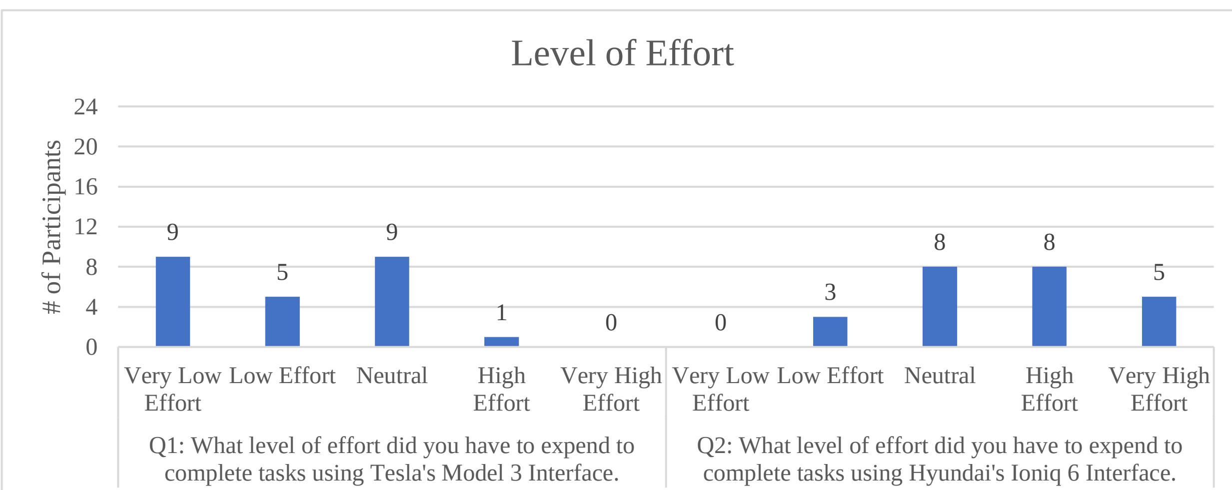
Despite some independent variations, the task completion time for Hyundai’s Ioniq 6 and Tesla’s Model 3 indicate an inverted trend throughout the experiment. Figure 4 (*Mean Completion Time*) and Table 5 *(Mean Task Completion Time T-test*) illustrate that tasks one (1) and two (3) exhibits statistical significance with a mean difference of 73 and 59, respectively. However, with a mean difference of 11 for task two (2), there is no statistical significance. Participants engaging with Hyundai's multi-screen interface demonstrated longer task completion times. Given the opposite effect towards its hypothesis, *H2 – “Participants interacting with a multi-screen interface will report higher task success rates than those using a single-screen interface.”* is rejected.

Table 6: NASA-TLX

NASA_TLX	Telsa Model 3	Hyundai Ioniq 6	Telsa Model 3	Hyundai Ioniq 6	Telsa Model 3	Hyundai Ioniq 6	Telsa Model 3	Hyundai Ioniq 6
Participant #	How mentally demanding was the task?		How successful were you in accomplishing the task?		How hard did you have to work to complete the task?		How insecure, discouraged, irritated, stressed, and annoyed were you?	
P1	9	81	100	100	10	79	10	75
P2	11	80	100	80	7	80	10	85
P3	20	50	75	100	20	75	5	20
P4	40	40	100	66	40	50	40	10
P5	77	62	100	82	81	70	60	78
P6	9	66	100	65	10	65	5	78
P7	60	21	55	85	50	5	30	10
P8	5	10	100	91	5	10	5	70
P9	50	90	100	35	60	90	34	100
P10	20	70	100	66	10	70	10	60
P11	47	77	17	30	85	81	65	49
P12	10	15	100	90	5	15	5	15
P13	80	70	66	66	75	95	79	79
P14	70	50	66	66	70	45	65	65
P15	20	87	100	66	20	100	3	100
P16	16	68	100	69	35	63	25	63
P17	25	50	100	100	25	70	10	80
P18	10	70	100	100	10	80	10	100
P19	35	70	100	66	35	80	20	85
P20	10	50	100	82	16	70	15	51
P21	7	40	100	100	15	18	7	6
P22	64	61	100	100	61	65	61	60
P23	50	30	100	100	50	45	40	35
P24	80	40	100	100	80	40	50	40
Average (Mean)	34.37	56.16	90.79	79.38	36.46	60.86	27.67	58.92

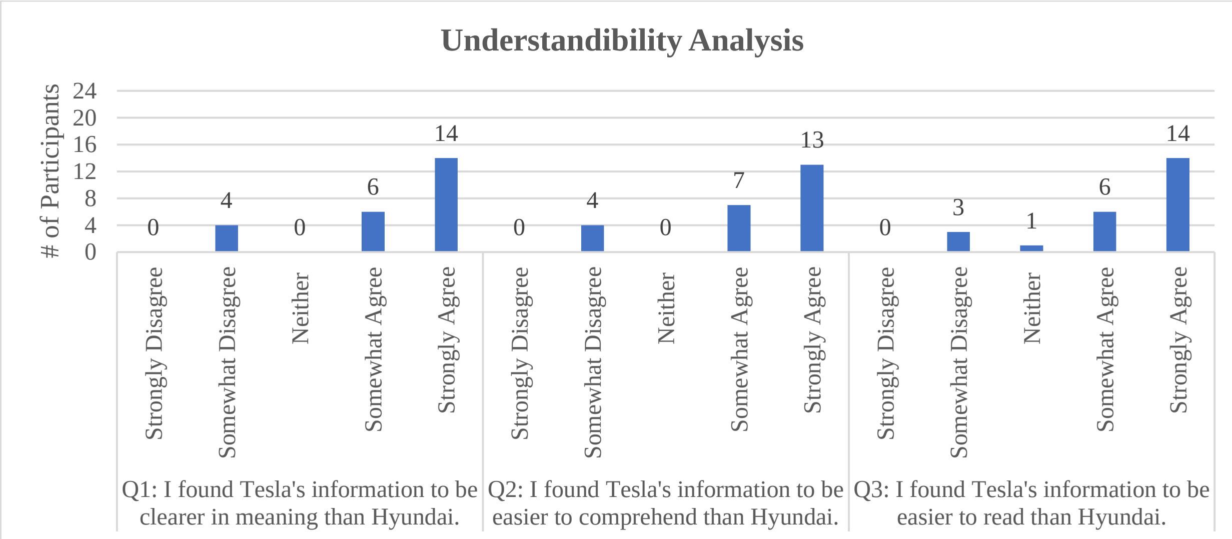
To assess cognitive load, we adapted the NASA-TLX questionnaire after each vehicle's experiment to identify which interface required less effort. Table 6 will illustrate that the majority of this study's participants have identified Tesla's single-screen interface with an average reading of 34.37/100 of mental capacity to accomplish all tasks, while Hyundai's multi-screen interface averaged a reading of 56.16/100.

Figure 5: Summary of Level of Effort



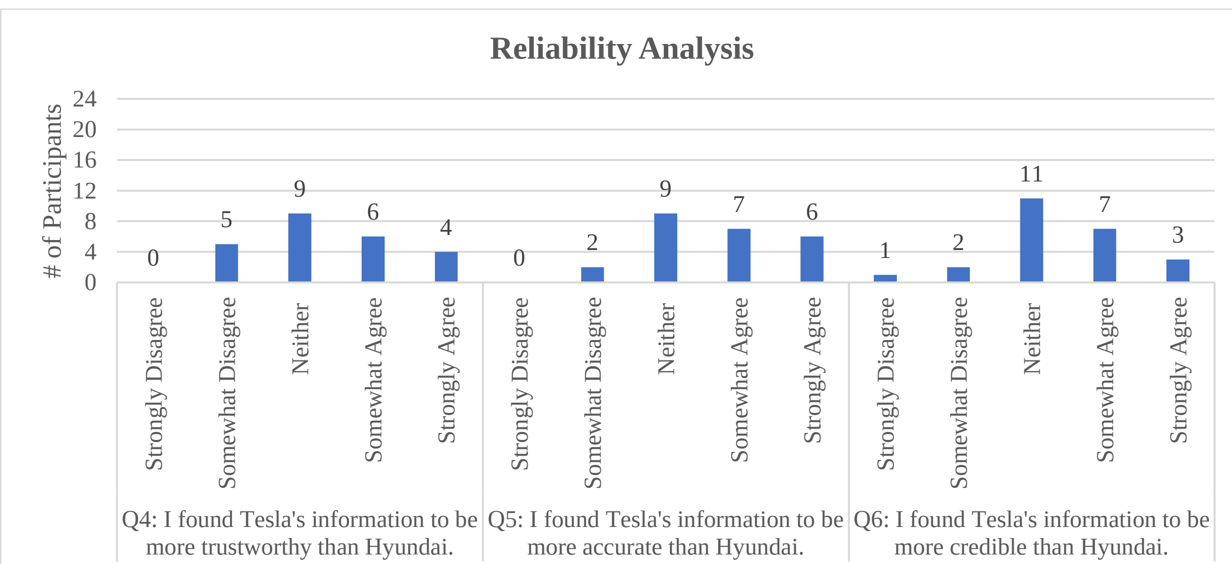
Additionally, participants were also asked to summarize their level of effort required to complete each task using the 5-point Likert Scale, illustrated in Figure 5 (*Summary of Level of Effort*). Through bilateral Exact Wilcoxon signed rank t-test, at a significance level of 5% (p-value = 0.833), there is no statistical significance. Therefore, *H1 – "Participants interacting with a multi-screen interface will report lower cognitive load than those using a single-screen interface*" is rejected.

Figure 6: Summary of Understandability Analysis



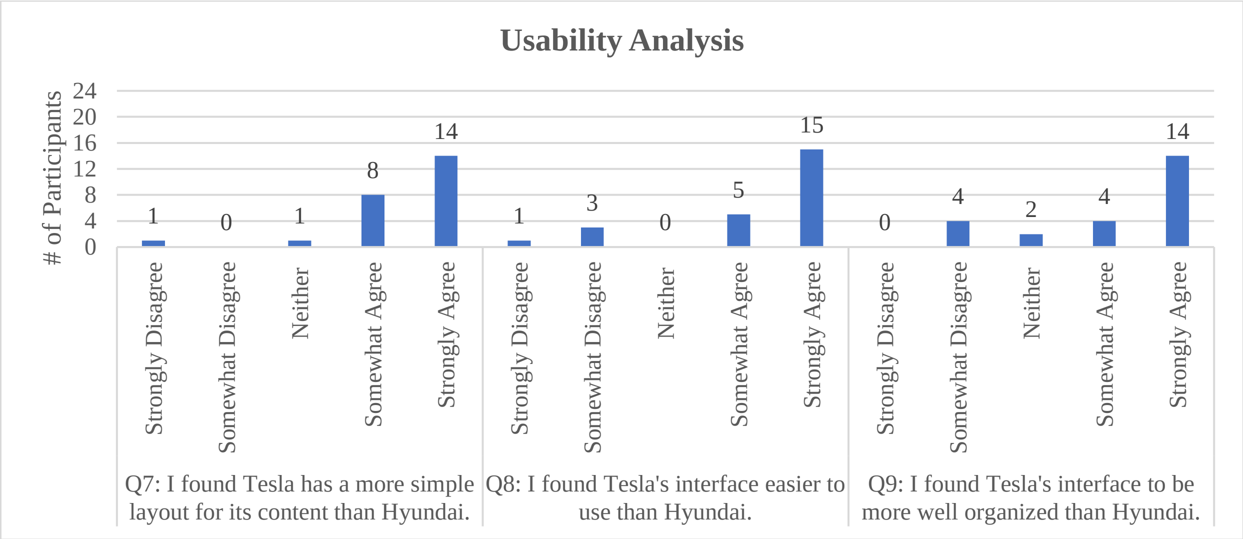
Using a 5-point Likert Scale, Figure 6 (*Summary of Understandability Analysis*) provides this study with the results for Understandability, determining that Tesla's single-screen interface is rated far higher, leaving little-to-no opportunity to challenge Tesla.

Figure 7: Summary of Reliability Analysis



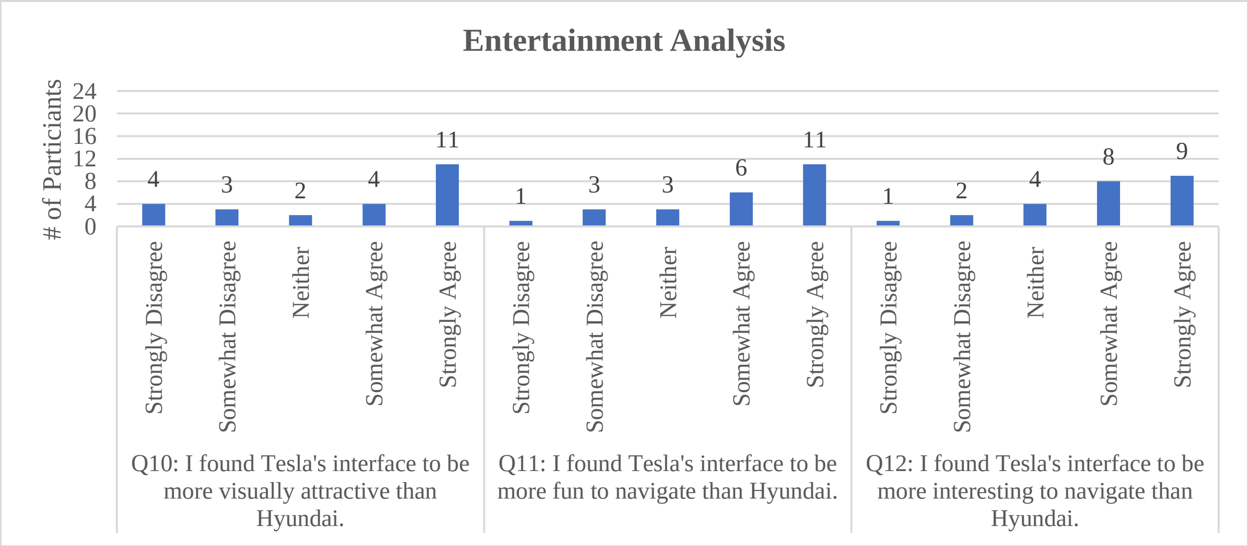
Using a 5-point Likert Scale, Figure 7 (*Summary of Reliability Analysis*) provides this study with the results for Reliability, determining that Tesla's single-screen interface is rated higher. However, we notice that participants have been heavily reliant on selecting neither Tesla nor Hyundai. As a result, we can determine that the reliability of the information for both a single-screen interface and a multi-screen interface, once found, is still reliable, nevertheless.

Figure 8: Summary of Usability Analysis



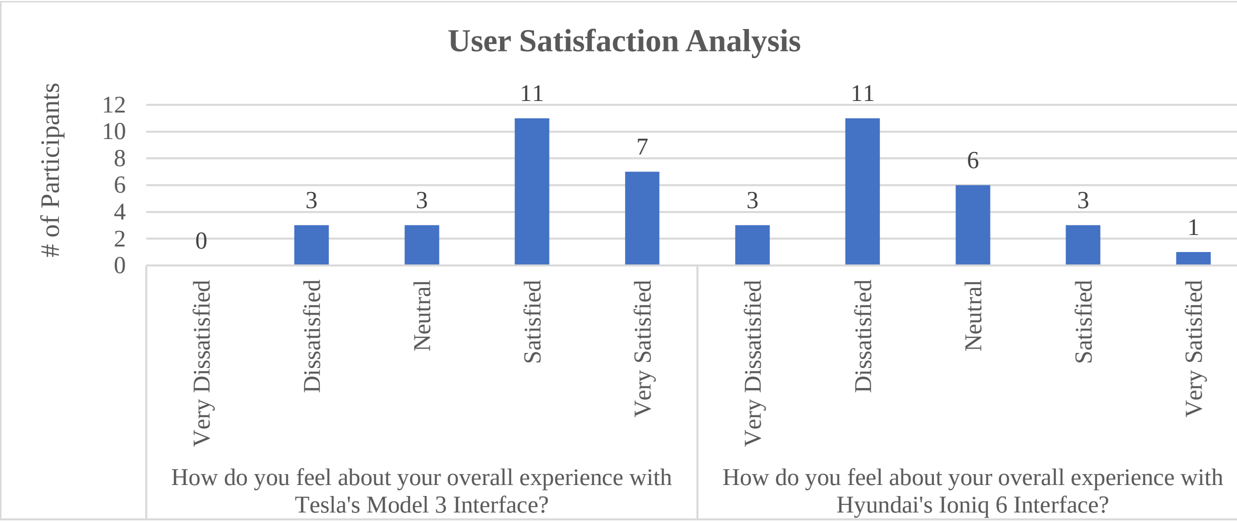
Using a 5-point Likert Scale, Figure 8 (*Summary of Usability Analysis*) provides this study with the results for Usability, determining that Tesla's single-screen interface is rated far higher, leaving little-to-no opportunity to challenge Tesla.

Figure 9: Summary of Entertainment Analysis



Using a 5-point Likert Scale, Figure 9 (*Summary of Entertainment Analysis*) provides this study with the results for Entertainment, determining that Tesla's single-screen interface is rated higher. However, we can observe that several participants have challenged Tesla, see Chapter 5 for full details.

Figure 10: Summary of User Satisfaction Analysis



This study requested each participant to summarize their overall experience when completing their experiment with each interface using the 5-point Likert Scale. Figure 10 (*Summary of User Satisfaction Analysis*) provides the summarized results. Through bilateral Exact Wilcoxon signed rank t-test, at a significance level of 5% (p-value = 0.042), there is statistical significance.

4.2 Mediation Analysis

This section will note that the mediation analysis identifies "Number of Screens" as this study's independent variable (X) and "User Satisfaction" as this study's dependent variable (Y) to recognize any potential indirect and direct effect on the following mediating variables. For full statistical data, refer to Appendix H – Mediation Analysis.

Table 7: Mediation Statistics using Understandability on User Satisfaction

	Coefficient (β)	Standard Error	t-value	p-value	[0.025	0.975]
Intercept	3.5000	0.205	17.074	0.000	3.085	3.915
# of Screens (X)	0.2500	0.183	1.364	0.180	-0.121	0.621
Understandability	0.5000	0.222	2.255	0.030*	0.051	0.949

* P-value is significant at the 0.05 level.

The coefficient for # of Screens (X) is 0.2500 but is not statistically significant (p = 0.180), suggesting that the direct effect of the number of screens on user satisfaction is not significant when controlling for understandability. The coefficient for Understandability (Mediator) is 0.5000 and is statistically significant (p = 0.030), suggesting that understandability has a significant effect on user satisfaction even when controlling for the number of screens. This model, illustrated in Table 7 (*Mediation Statistics using Understandability on User Satisfaction*) suggests that understandability partially mediates the relationship between the number of screens and user satisfaction. Increasing the number of screens leads to higher understandability, which in turn leads to higher user satisfaction. However, the direct effect of the number of screens on user satisfaction becomes non-significant when controlling for understandability, highlighting the importance of the mediator in this relationship. Testing for significance, the Sobel test shows a statistically significant indirect effect (p = 0.025), supporting the presence of mediation. Therefore, *H7 – "Participants who report higher levels of understandability will report a higher level of user satisfaction"* is supported.

Table 8: Mediation Statistics using Reliability on User Satisfaction

	Coefficient (β)	Standard Error	t-value	p-value	[0.025	0.975]
Intercept	3.5000	0.183	19.116	0.000	3.130	3.870
# of Screens (X)	0.2500	0.163	1.532	0.132	-0.080	0.580
Reliability	0.5000	0.183	2.730	0.009*	0.130	0.870

* P-value is significant at the 0.05 level.

The coefficient for # of Screens (X) is 0.2500 but is not statistically significant (p = 0.132), suggesting that the direct effect of the number of screens on user satisfaction is not significant when controlling for reliability. The coefficient for Reliability (Mediator) is 0.5000 and is statistically significant (p = 0.009), suggesting that reliability has a significant effect on user satisfaction even when controlling for the number of screens. This model, illustrated in Table 8 (*Mediation Statistics using Reliability on User Satisfaction*) suggests that reliability partially mediates the relationship between the number of screens and user satisfaction. Increasing the number of screens leads to higher reliability, which in turn leads to higher user satisfaction. Testing for significance, the Sobel test shows a statistically significant indirect effect (p = 0.025), supporting the presence of mediation. Therefore, *H8 – "Participants who report higher levels of reliability will report a higher level of user satisfaction"* is supported.

Table 9: Mediation Statistics using Usability on User Satisfaction

	Coefficient (β)	Standard Error	t-value	p-value	[0.025	0.975]
Intercept	3.5000	0.183	19.116	0.000	3.130	3.870
# of Screens (X)	0.2500	0.163	1.532	0.132	-0.080	0.580
Usability	0.5000	0.183	2.730	0.009*	0.130	0.870

* P-value is significant at the 0.05 level.

The coefficient for # of Screens (X) is 0.2500 but is not statistically significant (p = 0.132), suggesting that the direct effect of the number of screens on user satisfaction is not significant when controlling for usability. The coefficient for Usability (Mediator) is 0.5000 and is statistically significant (p = 0.009), suggesting that usability has a significant effect on user satisfaction even when controlling for the number of screens. This model, illustrated in Table 9 (*Mediation Statistics using Usability on User Satisfaction*) suggests that usability partially mediates the relationship between the number of screens and user satisfaction. Increasing the number of screens leads to higher usability, which in turn leads to higher user satisfaction. However, the direct effect of the number of screens on user satisfaction becomes non-significant when controlling for usability, highlighting the importance of the mediator in this relationship. Testing for significance, the Sobel test shows a statistically significant indirect effect (p = 0.025), supporting the presence of mediation. Therefore, *H9 – "Participants who report higher levels of usability will report a higher level of user satisfaction"* is supported.

Table 10: Mediation Statistics using Entertainment on User Satisfaction

	Coefficient (β)	Standard Error	t-value	p-value	[0.025	0.975]
Intercept	3.5000	0.183	19.116	0.000	3.130	3.870
# of Screens (X)	0.2500	0.163	1.532	0.132	-0.080	0.580
Entertainment	0.5000	0.183	2.730	0.009*	0.130	0.870

* P-value is significant at the 0.05 level.

The coefficient for # of Screens (X) is 0.2500 but is not statistically significant (p = 0.132), suggesting that the direct effect of the number of screens on user satisfaction is not significant when controlling for entertainment. The coefficient for Entertainment (Mediator) is 0.5000 and is statistically significant ($p = 0.009$), suggesting that entertainment has a significant effect on user satisfaction even when controlling for the number of screens. This model, illustrated in Table 10 (*Mediation Statistics using Entertainment on User Satisfaction*) suggests that entertainment partially mediates the relationship between the number of screens and user satisfaction. Increasing the number of screens leads to higher entertainment, which in turn leads to higher user satisfaction. However, the direct effect of the number of screens on user satisfaction becomes non-significant when controlling for entertainment, highlighting the importance of the mediator in this relationship. Testing for significance, the Sobel test shows a statistically significant indirect effect ($p = 0.025$), supporting the presence of mediation. Therefore, *H10 – "Participants who report higher levels of entertainment will report a higher level of user satisfaction"* is supported.

Table 11: Mediation Statistics using Cognitive Load on User Satisfaction

	Coefficient (β)	Standard Error	t-value	p-value	[0.025	0.975]
Intercept	3.5000	0.205	17.074	0.000	3.085	3.915
# of Screens (X)	1.2500	0.183	6.816	0.000	0.879	1.621
Cognitive Load	0.0200	0.005	3.758	0.001*	0.009	0.031

* P-value is significant at the 0.001 level.

The model shows that both the number of screens and cognitive load significantly influence "User Satisfaction" with $p < 0.001$. The positive coefficient for # of Screens (X) suggests that increasing the number of screens generally leads to higher user satisfaction. Additionally, the positive coefficient for Cognitive Load (Mediator) indicates that higher cognitive load tends to be associated with lower user satisfaction. This model, illustrated in Table 11 (*Mediation Statistics using Cognitive Load on User Satisfaction*) suggests a direct relationship between the number of screens and user satisfaction, as well as an indirect effect mediated through cognitive load.

Based on the above evidence, we can infer the following:

Cognitive load and understandability have a direct negative relationship. An increase in the number of screens leads to an increase in cognitive load, however a decrease in understandability. Therefore, *H3 – "Participants who report a lower cognitive load will report a higher level of understandability"* is supported.

The coefficient for the mediator “Reliability” is not significant in this model. The direct effect of the number of screens on user satisfaction becomes non-significant when controlling for reliability, highlighting the importance of the mediator in this relationship. Therefore, *H4 – “Participants who report a lower cognitive load will report a higher level of reliability”* is rejected.

Cognitive load and usability have a direct negative relationship. An increase in the number of screens leads to an increase in cognitive load, however a decrease in usability. Therefore, *H5 – “Participants who report a lower cognitive load will report a higher level of usability”* is supported.

Cognitive load and entertainment have a direct negative relationship. An increase in the number of screens leads to an increase in cognitive load, however a decrease in entertainment. Therefore, *H6 – “Participants who report a lower cognitive load will report a higher level of understandability”* is supported.

4.3 Moderation Analysis

This section will note that the moderation analysis identifies “Number of Screens” as this study’s independent variable (X) and “Age Group/Gender” as this study’s moderating variable to recognize any potential indirect and direct effects on the following dependent (Y) variables. For full statistical data, refer to Appendix I – Moderation Analysis.

Table 12: Moderation Statistics using Age Group on Cognitive Load

	Coefficient (β)	Standard Error	t-value	p-value	[0.025	0.975]
Intercept	39.3750	6.631	5.937	0.000	26.003	52.747
# of Screens (X)	16.5104	5.942	2.781	0.008*	4.437	28.584
AgeGroup_C	37.0417	7.933	4.671	0.000	21.033	53.050
Screens_AgeGroup	-18.6875	8.930	-2.095	0.042*	-36.707	-0.668

* P-value is significant at the 0.05 level.

The p-value for the Screens_AgeGroup interaction, illustrated in Table 12 (*Moderation Statistics using Age Group on Cognitive Load*) is 0.042 ($p = 0.042$). This suggests that the interaction effect is statistically significant at the 0.05 level and that the relationship between the number of screens and cognitive load is moderated by age group. As a result, the impact of screen usage on cognitive load is not uniform across all individuals but varies depending on their age. The negative coefficient from the interaction (β = -18.6875) suggests that the effect of # of screens on Cognitive Load is weaker for the 50+ age group compared to the 18-35 age group.

Table 13: Moderation Statistics using Age Group on Understandability

	Coefficient (β)	Standard Error	t-value	p-value	[0.025	0.975]
Intercept	3.5000	0.205	17.074	0.000	3.085	3.915
# of Screens (X)	1.2500	0.183	6.816	0.000	0.879	1.621
AgeGroup_C	2.0000	0.258	7.749	0.000	1.477	2.523
Screens_AgeGroup	-1.0000	0.290	-3.452	0.001*	-1.591	-0.409

* P-value is significant at the 0.001 level.

The p-value for the Screens_AgeGroup interaction, illustrated in Table 13 (*Moderation Statistics using Age Group on Understandability*) is 0.001 ($p = 0.001$). This suggests that the interaction effect is statistically significant at the 0.001 level and that the relationship between the number of screens and understandability is moderated by age group. As a result, the effect of screen usage varies depending on the age group. The negative coefficient from the interaction (β = -1.000) suggests that the effect of # of screens on Understandability is weaker for the 50+ age group compared to the 18-35 age group.

Table 14: Moderation Statistics using Age Group on Reliability

	Coefficient (β)	Standard Error	t-value	p-value	[0.025	0.975]
Intercept	3.0000	0.249	12.063	0.000	2.500	3.500
# of Screens (X)	0.5000	0.222	2.255	0.030*	0.051	0.949
AgeGroup_C	1.0000	0.313	3.193	0.002*	0.368	1.632
Screens_AgeGroup	-0.5000	0.351	-1.426	0.161	-1.209	0.209

* P-value is significant at the 0.05 level.

The model, illustrated in Table 14 (*Moderation Statistics using Age Group on Reliability*) shows that both the number of screens and age group significantly influence "Reliability" ($p < 0.05$). However, the interaction term ($p = 161$) is not statistically significant in this model, suggesting that the effect of screen usage on "Reliability" does not vary significantly between the “Age Group 50+” and the Age Group 18-35”.

Table 15: Moderation Statistics using Age Group on Usability

	Coefficient (β)	Standard Error	t-value	p-value	[0.025	0.975]
Intercept	3.5000	0.205	17.074	0.000	3.085	3.915
# of Screens (X)	1.2500	0.183	6.816	0.000	0.879	1.621
AgeGroup_C	2.0000	0.258	7.749	0.000	1.477	2.523
Screens_AgeGroup	-1.0000	0.290	-3.452	0.001*	-1.591	-0.409

* P-value is significant at the 0.001 level.

The p-value for the Screens_AgeGroup interaction, illustrated in Table 15 (*Moderation Statistics using Age Group on Usability*) is 0.001 ($p = 0.001$). This suggests that the interaction effect is statistically significant at the 0.001 level and that the relationship between the number of screens and usability is moderated by age group. As a result, the effect of screen usage varies depending on the age group. The negative coefficient from the interaction ($\beta = -1.000$) suggests that the effect of # of screens on Usability is weaker for the 50+ age group compared to the 18-35 age group.

Table 16: Moderation Statistics using Age Group on Entertainment

	Coefficient (β)	Standard Error	t-value	p-value	[0.025	0.975]
Intercept	3.5000	0.205	17.074	0.000	3.085	3.915
# of Screens (X)	1.2500	0.183	6.816	0.000	0.879	1.621
AgeGroup_C	2.0000	0.258	7.749	0.000	1.477	2.523
Screens_AgeGroup	-1.0000	0.290	-3.452	0.001*	-1.591	-0.409

* P-value is significant at the 0.001 level.

The p-value for the Screens_AgeGroup interaction, illustrated in Table 16 (*Moderation Statistics using Age Group on Entertainment*) is 0.001 ($p = 0.001$). This suggests that the interaction effect is statistically significant at the 0.001 level and that the relationship between the number of screens and Entertainment is moderated by age group. As a result, the effect of screen usage varies depending on the age group. The negative coefficient from the interaction ($\beta = -1.000$) suggests that the effect of # of screens on Entertainment is weaker for the 50+ age group compared to the 18-35 age group.

Table 17: Moderation Statistics using Age Group on User Satisfaction

	Coefficient (β)	Standard Error	t-value	p-value	[0.025	0.975]
Intercept	3.5000	0.205	17.074	0.000	3.085	3.915
# of Screens (X)	1.2500	0.183	6.816	0.000	0.879	1.621
AgeGroup_C	2.0000	0.258	7.749	0.000	1.477	2.523
Screens_AgeGroup	-1.0000	0.290	-3.452	0.001*	-1.591	-0.409

* P-value is significant at the 0.001 level.

The p-value for the Screens_AgeGroup interaction, illustrated in Table 17 (*Moderation Statistics using Age Group on User Satisfaction*) is 0.001 ($p = 0.001$). This suggests that the interaction effect is statistically significant at the 0.001 level and that the relationship between the number of screens and User Satisfaction is moderated by age group. As a result, the effect of screen usage varies depending on the age group. The negative coefficient from the interaction ($\beta = -1.000$) suggests that the effect of # of screens on User Satisfaction is weaker for the 50+ age group compared to the 18-35 age group.

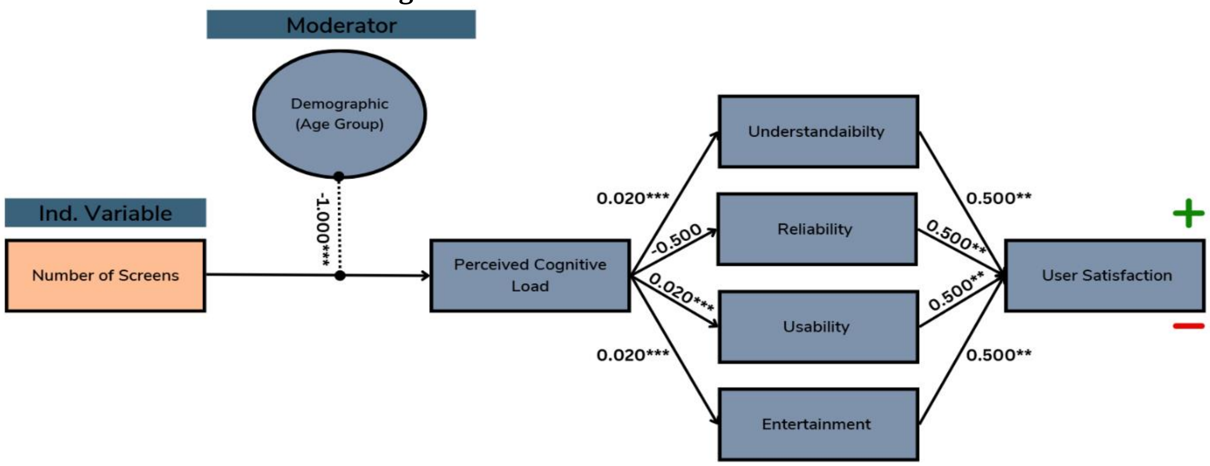
Therefore, the collective evidence indicates that "*MF1: age groups significantly influence overall satisfaction when comparing a single-screen interface to a multi-screen interface"* is supported.

The following table represents the summary of this study's hypotheses:

Table 18: Summary of Hypotheses Testing Results

Hypothesis	Result
H1 *– "Participants interacting with a multi-screen interface will report lower cognitive load than those using a single-screen interface."*	Rejected
H2 *– "Participants interacting with a multi-screen interface will report higher task success rates than those using a single-screen interface."*	Rejected
H3 *– "Participants who report a lower cognitive load will report a higher level of understandability."*	Supported
H4 *– "Participants who report a lower cognitive load will report a higher level of reliability."*	Rejected
H5 *– "Participants who report a lower cognitive load will report a higher level of usability."*	Supported
H6 *– "Participants who report a lower cognitive load will report a higher level of entertainment."*	Supported
H7 *– "Participants who report higher levels of understandability will report a higher level of user satisfaction"*	Supported
H8 *– "Participants who report higher levels of reliability will report a higher level of user satisfaction"*	Supported
H9 *– "Participants who report higher levels of usability will report a higher level of user satisfaction"*	Supported
H10 *– "Participants who report higher levels of entertainment will report a higher level of user satisfaction"*	Supported
MF1 *– Age groups significantly influence overall satisfaction when comparing a single-screen interface to a multi-screen interface*	Supported

Figure 11: Validated Research Model



Chapter 5: Discussion

5.1 Main Findings and General Discussion

In this thesis, we explored the mental efforts required to complete several NDRTs among two user profiles, in order to identify the significance among the number of screens to overall satisfaction.

First, the results from the performance analysis reveal an inverted trend across the experiment. This suggests that, rather than one system consistently outperforming the other, their performance diverged in opposite directions depending on the task.

Specifically, task one (1) and task three (3) showed statistically significant differences in task completion times between the two vehicles, with mean differences of 73 and 59, respectively. These time gaps indicate a consistent and reliable disparity in user efficiency for those tasks. However, task two (2), which showed a smaller mean difference of just 11, did not reach statistical significance, implying that any observed difference in performance for that task could be due to chance.

Interestingly, participants using the Hyundai Ioniq 6's multi-screen interface consistently took longer to complete tasks compared to those using the Tesla Model 3's single-screen interface. This contradicts the original hypothesis (H2), which proposed that a multi-screen interface would facilitate higher task success rates. Not only did this anticipated advantage not manifest, but the effect was reversed, indicating a potential usability disadvantage with the multi-screen setup.

As a result, the findings suggest that a multi-screen interface does not necessarily enhance user performance and may in fact hinder task efficiency.

When discussing overall effort, the results show a positive relationship between the number of screens and cognitive load. Evidence highlights a significant positive relationship for tasks one (1) and three (3). This indicates that as the number of screens increases, the cognitive load required to complete the tasks also increases, contradicting the hypothesis (H1).

To further discuss, the post-task questionnaire was designed to identify which interface required less effort. To further expand on the descriptive statistics, the majority of this study's participants have identified Tesla's single-screen interface with an average reading of 34.37/100 of mental capacity to accomplish all tasks, while Hyundai's multi-screen interface averaged a reading of 56.16/100, despite the influence among Baby Boomers. Ironically, Baby Boomers did not influence the performance reading high enough in order to compete with Tesla's Model 3. This data highlights that most participants have successfully completed each task when testing Tesla's Model 3, suggesting that Baby Boomers still had a relatively easy time learning how to navigate a single-screen interface when compared to younger generations learning how to navigate a multi-screen interface.

Given the learning curve to both age groups, Tesla's single-screen interface highlights far less difficulty with an average reading of 36.46/100, almost half the level of difficulty when compared to Hyundai's multi-screen interface, in which, provides an average reading of 60.86/100. Despite the qualitative data captured during each task among our pool of participants aged fifty (50) and above, it did not provide significant impact towards the collective scoring for perceived cognitive workload. Consequently, Tesla's single-screen interface scored a lower average rating of 27.67 for overall frustration given that all other ratings favoured the Tesla's Model 3.

Additionally, participants were also asked to summarize their level of effort required to complete each task. The results show that despite familiarity with traditional design, Tesla's single-screen interface prevailed. 14/24 participants have identified a lowered level of effort for Tesla's single-screen interface, with nine (9) participants who believe it neither required low or high levels of effort. However, 13/24 participants have a identified higher levels of effort required while testing Hyundai's multi-screen interface. Ironically, only three (3) participants believed the multi-screen interface required low effort.

In combination to the available qualitative analysis, the participants' impressions and comments were recorded after the study. The majority of our participants aged 18-to-35 years (N=8/12) have argued that Hyundai's Ioniq 6 multi-interface does not provide additional value, rather, an elevated level of confusion and frustration**.** Participants in this age group, are inherently more adaptive and understanding of new technology **(**Jianan et al. 2020). However, when asked to perform three (3) common in-vehicle tasks, many of the participants were unable to intuitively direct their attention to the correct interface when locating primary and secondary information, which in turn, validates the results of increased failure rates and increased cognitive load.

For our pool of participants aged fifty years and above (50+), several participants have had a direct opposite affect (N=7/12). The participants in this age group are not intuitively tech savvy yet have had a significantly different reaction and were intuitively capable to locate the PSI rating, and the odometer reading, regardless of how much time it took them. Why? Baby Boomers tend to be familiar with a more traditional style of the vehicle cockpit. Historically, vehicles produced during the height of their driving years (1960s through the 1990s) often featured more analog controls, such as buttons, knobs, dials, and levers. This generation is generally accustomed to straightforward, tactile controls for functions like climate control, audio, and other in-car systems, which are often separated and directly accessible, both above and on the steering wheel **(**Monika et al., 2015).

In contrast, modern vehicles, particularly newer models, tend to feature more digital interfaces, such as touchscreens, digital displays, and multi-function control systems. While many Baby Boomers have adapted to newer technology, studies suggest several may prefer more intuitive, tactile controls that feel familiar compared to fully digital dashboards (Owens et al., 2015). Automakers often consider these preferences in vehicles targeted to this demographic by blending traditional controls with newer technologies to ensure ease of use and comfort for all generations (Chelsea et al., 2024).

In comparison to Tesla's Model 3, participants aged 18-to-35 years of age have stated that their in-system experience is far simpler, yet far more intuitive. Yet we may observe that some participants aged fifty and over (50+) have had a direct opposite effect. Since the majority of this study's Baby Boomer participants are not quite adaptive to a dramatically new cockpit, it was observed that the time needed to complete the task had increased. Not only were they faced with three (3) tasks, they automatically compared Tesla's Model 3 to their own current cockpit, if not, with Hyundai's Ioniq 6 if they had started this study with this vehicle first. In most cases, their experience had become very different from their own current vehicle. Therefore, to satisfy this study's mediating factor of demographic age group, the results indicate that the age group 18-to-35 are more receptive towards a single-screen interface.

Additionally, several participants, including both age groups (N=11/24), have identified a design flaw in Hyundai's multiscreen interface, specifically in task #1, when a user requires immediate information. As mentioned in chapter 3, section 3.3 experimental procedure, the user of this vehicle must identify the current Pound per Square Inch (PSI) reading for the vehicle's tires. This task identifies relevant information and determines if the vehicle is safe to operate. If we were to make an assumption and envision a new scenario, let's say, you have an upcoming road trip, the vehicle must be able to provide this critical piece of information before your departure to evaluate the health of your tires. The task evaluated whether or not the participate is capable to take the necessary steps to locate the PSI reading, however, once they found how to navigate the allocated section of the screen to display the PSI, several after the successful time recorded, participants would indicate, "Not Available – Drive to Display", leaving participants extremely frustrated and determined to continue their investigation, contributing to the overall time taken during the task.

This study has additionally evaluated the mediating and moderating variables, the results of the mixed models indicate the following:

(1) The results reveal that the predictor to mediator (# of screens to cognitive load) was expected to hold a significant positive relationship. Increasing the number of screens would increase *cognitive load* due to factors gathered from the interview sessions, like increased information processing demands, and attentional resources required to navigate multiple screens. However, the interaction from cognitive load to user satisfaction possess a significant negative relationship. High cognitive load was associated with decreased user satisfaction due to factors like frustration, confusion, and mental effort required from the participants. Therefore, the direct effect of the number of screens on user satisfaction becomes non-significant when controlling for cognitive load, indicating that a significant portion of the effect of the number of screens on user satisfaction is mediated by cognitive load. In other words, the number of screens primarily influences user satisfaction by increasing cognitive load.

(2) The results reveal that the number of screens influences user satisfaction indirectly by first affecting how well users *understand* the system. The model could express a direct relationship between the number of screens and user satisfaction due to factors like Hyundai's perceived innovation, novelty, or the feeling of having access to more information. However, when controlling for understandability, the direct effect of the number of screens on user satisfaction becomes non-significant. This indicates that the initial direct relationship was likely due to the influence of understandability.

The finding that the direct effect becomes non-significant when controlling for understandability emphasizes the crucial role of understandability in the relationship between the number of screens and user satisfaction. It suggests that the primary way the number of screens influences user satisfaction is by impacting how well users can understand and interact with the system. In essence, the analysis suggests that while the number of screens can offer certain advantages, their impact on user satisfaction hinges on how well users can understand and interact with the system.

(3) The results reveal a positive relationship between the number of screens and system *reliability*. This suggests that, increasing the number of screens tends to be associated with higher system reliability. This could be due to various factors; one observed during the experiment is the ability to isolate specific screens for specific information. Multiple screens could enable the system to function even if one or more screens fail, enhancing overall system robustness.

The analysis demonstrates a strong positive relationship between system reliability and user satisfaction. This is intuitive; participants generally responded positively when systems were consistent, free from errors or questionable data.

The key finding is that the indirect effect of the number of screens on user satisfaction through system reliability is significant. This indicates that a substantial portion of the impact of the number of screens on user satisfaction is channeled through its influence on system reliability. However, when the effect of reliability is controlled for Model c, the direct effect of the number of screens on user satisfaction becomes non-significant. This indicates that the direct impact of the number of screens on user satisfaction is relatively weak compared to the indirect effect mediated by reliability.

(4) The results reveal that *usability* plays a crucial role in mediating the relationship between the number of screens and user satisfaction. While increasing the number of screens might have some direct impact on user satisfaction, the majority of its influence seems to be channeled through its positive effect on system usability.

The increase in the number of screens is associated with the increase in system usability. This implies that, in this model, adding more screens generally leads to a system that is easier to use. Therefore, an increase in system usability is strongly associated with an increase in user satisfaction. This aligns with expectations and observations, as systems that are easier to use are generally more enjoyable and satisfying for the participants.

(5) The results reveal a significant indirect effect of # of screens on user satisfaction through *entertainment*. This indicates that a substantial portion of the impact of the number of screens on user satisfaction is channeled through its influence on entertainment. While the number of screens might have some direct impact on user satisfaction, the analysis suggests that this direct effect is less pronounced when controlling for the mediating effect of entertainment.

Increasing the number of screens is positively associated with increased entertainment. This suggests that more screens can potentially offer a richer and more engaging entertainment experience. This could be due to factors such as an increased content variety, more specifically, more screens can allow for the simultaneous display of different content types (e.g., movies and TV shows) providing users with a wider range of entertainment options. An improved user interaction, multiple screens can enable more interactive entertainment experiences, such as multi-player gaming or collaborative viewing. Participants have mentioned that Hyundai’s multi-interface design resembled an android where its robust interface encourages user engagement and customization, as opposed to Tesla’s “Apple-like” design with design restrictions.

Higher levels of entertainment are positively associated with increased user satisfaction. This aligns with expectations as enjoyable entertainment experiences contribute significantly to a positive user experience. Users are more likely to be satisfied when they are engaged and entertained.

Therefore, the analysis underscores the crucial role of entertainment in driving user satisfaction in this context. The number of screens itself doesn't directly and strongly influence satisfaction. Instead, it's the increase in entertainment options and experiences enabled by those screens that primarily drives user satisfaction.

(6) The results reveal that *age group* is a significant predictor of *cognitive load*. This suggests that different age groups may experience varying levels of cognitive load when interacting with multiple screens. The adults aged 50+ may experience age-related cognitive decline, leading to increased cognitive load when processing information from multiple screens. Younger generations may be more familiar with technology and have better multitasking abilities, potentially leading to lower cognitive load when interacting with multiple screens, despite Hyundai's Ioniq 6 similarity to traditional design.

The significant interaction term between # of Screens and AgeGroup_c suggests that the relationship between the number of screens and cognitive load differs across age groups. The observations during the experiment would suggest that the increase in cognitive load associated with each additional screen might be more pronounced in certain age groups compared to others. For example, adults 50+ might experience a steeper increase in cognitive load with each additional screen compared to younger adults.

(7) The results reveal that *age group* is a significant predictor of *understandability*. The interaction term is significant, but negative. This means that the positive relationship between the number of screens and understandability becomes weaker (or even negative) as the age group increases (older participants). Therefore, while the number of screens generally enhances understandability, the benefit depends on the age group.

(8) the results reveal that *age group* is not a significant predictor of *reliability*. The coefficient suggests that as age increases, the positive effect of the additional screen on reliability decreases. However, this effect was not statistically significant, so the evidence for this relationship is weak. The negative trend could indicate that older participants might not benefit as much from additional screens, potentially due to cognitive overload. Observations were made during the experiment and found that more screens had seemed to overwhelm several older users, especially if they are less tech-savvy.

Adding screens may enhance reliability, but it's crucial to avoid overloading users, especially older participants. A balance should be struck between providing sufficient information and maintaining simplicity. Older users might prefer systems with simpler layouts, fewer screens, or interfaces designed to minimize cognitive load. Younger users might appreciate more dynamic and information-rich interfaces.

(9) The results reveal that *age group* is a significant predictor of *usability*. The negative coefficient indicates that the positive effect of an additional screen on usability decreases. Statistically significant, the diminishing effect of additional screens for older participants may result from a cognitive overload. Older users might struggle with managing information across multiple screens. They might find a single screen easier to navigate and understand.

For younger users, additional screens likely provide greater usability benefits as they are more accustomed to multitasking and managing complex interfaces.

(10) These results reveal that *age group* is a significant predictor of *entertainment*. The positive effect of an additional screen on entertainment decreases. Statistically significant, the interaction term indicates that age modifies the relationship between screen count and entertainment.

Younger users derive greater entertainment value from additional screens compared to older users. Older users may experience diminishing returns with more screens, potentially due to cognitive overload, less familiarity with multitasking, or different preferences for simpler setups. Younger users may thrive with more screens, potentially due to higher familiarity with multitasking and a preference for richer multimedia experiences. Older users may prefer simpler setups or find too many screens distracting or difficult to manage.

(11) These results reveal that *age group* is a significant predictor of *user satisfaction.* The positive effect of additional screens on user satisfaction decreases. Statistically significant, the interaction term indicates that age moderates the relationship between the number of screens and satisfaction.

Younger users derive more satisfaction from additional screens compared to older users. Older users may experience diminishing returns or even find an additional screen overwhelming, highlighting the importance of designing interfaces that cater to age-related preferences.

Considering the regression results across the different variables, *age group* (as captured by the centered age group variable, AgeGroup_c) emerges as a significant factor influencing the dependent variables. The consistent significance of AgeGroup_c and the interaction term across models indicates that age group not only directly influences satisfaction but also shapes how other factors (e.g., the number of screens) impact the user experience. Understanding this moderation is essential for creating inclusive designs that accommodate different age groups. That said, the next section will include several recommendations to further improve in-vehicle systems.

5.2 Practical Implication

Human factors in HMI design focus on understanding and accommodating human capabilities and limitations in the context of interacting with automotive user interfaces, essentially everything the driver engages with while in their vehicle (Jianan & Abas, 2020).

This discipline integrates principles of ergonomic design, cognitive psychology, and UX research to craft interfaces that are user-friendly, enhance safety and performance, and make vehicle operation intuitive and enjoyable. The objective is to design systems that align with natural human behaviors and cognitive processes, reducing the likelihood of errors and maximizing overall usability (Kukkamalla et al., 2021).

A key aspect of automotive HMI design and expressed several times in this paper, is managing the driver's cognitive load, the mental effort required to process information in real-time. Human factors experts aim to create interfaces that streamline information processing, reducing cognitive load to avoid confusion or overload, thereby minimizing the risk of dangerous situations.

This involves presenting information in a logical, intuitive manner, eliminating unnecessary complexity, and using visual and interactive hierarchies to prioritize essential functions. Therefore, the following section will provide actionable recommendations for automotive stakeholders.

5.2.1 Designer Recommendations

Prioritize User-Centered Design: The very core of human factors lies in the principle of user-centered design, which focuses on involving users throughout the design and development process to create more effective and intuitive interfaces. This methodology prioritizes usability, ensuring systems are easy to learn, efficient to operate, and enjoyable to use (Aljaroodi et al., 2023). By incorporating iterative testing and accommodating real users of all ages, technical skill levels, and physical abilities, designers can continuously refine the interface based on direct feedback and insights gained from observing user interactions.

Implement a Multimodal Interaction: Discussed in previous sections, ensuring seamless interaction between vehicle occupants and AI in-car features has become a top priority for automaker designers and researchers (Jianan & Abas, 2020). OEMs are increasingly embracing the multimodal approach in designing automotive HMIs. This multimodal strategy incorporates various input and feedback methods, such as voice, touch, gestures, and gaze to provide flexible interaction options, catering to diverse user preferences and driving conditions (Zhang & Wang, 2021).

Incorporate Adaptive AI: Utilize AI to adapt interfaces based on individual user behaviors and preferences. Personalization plays a crucial role in enhancing user engagement, with models tailored to individual preferences could prove to be more attractive to users (Xu et al., 2023). From an interface design perspective, basic elements like color schemes, icons, typography, and fonts could be thoughtfully combined with AI-driven automatic optimization. This approach would enable personalized designs that adapt seamlessly to the user's driving context and preferences, creating a more intuitive and satisfying interaction, offering greater flexibility and improving the overall user experience. For instance, Mercedes have made promising advancements in this domain with their recent introduction to the MBUX (Mercedes-Benz User Experience) system to enhance the in-car experience. The MBUX system, powered by NVIDIA technology, introduces a groundbreaking Hyper-screen, a wide, curved display spanning from the cockpit to the passenger seat, providing seamless access to essential functions at a glance. Utilizing a unique user interface, the system prioritizes situationally and contextually relevant applications on the top level, minimizing the need for menu navigation or voice commands (Washabaugh, 2021).

Mercedes-Benz leverages deep neural networks to analyze data such as vehicle position, cabin temperature, and time of day, enabling context-sensitive awareness. This intelligent system dynamically presents the most relevant functions at the right moment, delivering a personalized and optimized user experience tailored to both environmental conditions and user behavior (Washabaugh, 2021).

This advanced infotainment system represents the foundation to improved user experience, it is designed to adapt to driver preferences, offering a more intuitive and personalized driving environment by learning and adjusting settings to meet individual needs, a system that could be the new norm of driving experiences.

5.2.2 OEM Recommendations

Focus on Safety: Ensuring adherence to functional safety goals and standards is critical for the safe and reliable operation of automotive HMIs, including advanced digital cockpits, instrument clusters, and telematics systems. Modern digital cockpits are quickly evolving to integrate multiple displays managed by a single domain controller, which handles instrument clusters, infotainment, connectivity, HUD, and driver monitoring functionalities (NHTSA, 2013).

The domain controller consolidates electronic control units (ECU), delivering enhanced Computer processing units (CPU) and graphics processing units (GPU) computing power to elevate the driving experience while maintaining safety. This streamlined approach reduces system costs, simplifies software updates, and minimizes weight and power consumption, all key considerations for the design of electric vehicles (Washabaugh, 2025).

In-vehicle multi-display HMI environments support features such as digital voice assistants, instrument clusters, infotainment, cloud connectivity, advanced security, and telematics (Zhang & Wang, 2021). Whether guiding users to the nearest coffee shop or providing optimal navigation routes, these next-generation digital cockpits, driven by domain controllers, ensure safe, efficient, and seamless vehicle operation.

Improve Support and Educate Users on AI Capabilities and Limitations: New innovative in-car functionalities bring new complexities, navigating next generation's infotainment systems will remain a priority. Therefore, it will be crucial to any user to provide clear information and training resources to help users understand what new AI systems can and cannot do, setting realistic expectations and promoting safe usage for the next generation of consumers.

Collaborate with Third-Party Developers to Accelerate Innovation: Automakers stand to gain significantly by developing open, standardized platforms that invite third-party developers to create innovative apps and features for in-car systems. Providing software development kits (SDKs) and application programming interfaces (APIs) can foster a vibrant developer ecosystem, driving the creation of diverse solutions tailored to evolving user needs (Kukkamalla et al., 2021). This strategy mirrors the success of smartphone app stores, where external developers play a pivotal role in enhancing user experiences.

Collaborating with third-party developers allows automakers to integrate specialized applications that elevate the usability and entertainment value of in-vehicle systems. Examples include: (1) Navigation Apps like Waze, offering real-time, crowd-sourced traffic updates; (2) Music and Podcast Platforms such as Spotify and Audible for personalized audio entertainment and (3) AI-Powered Personal Assistants for managing tasks like scheduling, email, and home automation seamlessly from the car (Aalbers & Whelan, 2021).

This variety ensures that users can access their favorite tools directly within the vehicle, eliminating the need for additional devices. Tesla exemplifies this approach by incorporating features like gaming, streaming, and advanced navigation, underscoring the benefits of integrating third-party solutions. Through such partnerships and a robust software ecosystem, automakers can keep users engaged while maintaining a competitive edge in the market.

5.2.3 Policy Recommendations

Develop Comprehensive Regulations: Regulators must implement stringent safety guidelines to ensure AI-driven systems are designed to prevent accidents, reduce driver distractions, and maintain operational reliability. These guidelines should include requirements for real-time hazard detection, fail-safe mechanisms, and redundancy in critical functions, providing layers of protection against system failures (McLachlan et al., 2022).

Set clear benchmarks for creating intuitive user interfaces that balance manual and automated controls effectively. At the root of this paper, these standards should account for human factors such as cognitive load, accessibility, and ease of learning, ensuring the interfaces are user-friendly and inclusive for diverse user groups.

Develop robust policies governing the collection, storage, and usage of vehicle-generated data (McLachlan et al., 2022). Automakers should implement strong encryption measures, adhere to global privacy regulations such as GDPR or CCPA, and provide users with control over their personal information, building trust and transparency into AI systems (Krstačić et al., 2024). By enforcing these standards and promoting transparency, the safety, usability, and trustworthiness of AI-driven interfaces can be significantly enhanced, paving the way for widespread adoption and improved user experiences.

Promote Research and Development: Going beyond comprehensive studies to analyze how AI-driven interfaces affect driver focus, reaction times, and decision-making processes. Financial incentives such as tax benefits, grants, or subsidies can motivate automakers to prioritize eco-friendly and inclusive design in vehicle interfaces. Examples include (1) Developing energy-efficient displays that reduce power consumption in electric vehicles. (2) Using recycled or biodegradable materials for hardware components. (3) Creating interfaces that cater to users with disabilities, including, adjustable font sizes for improved readability, text-to-speech features for visually impaired users and gesture-recognition systems tailored for individuals with limited mobility (Zhou et al., 2019).

Such incentives can accelerate innovation, ensuring that in-car systems are not only technologically advanced but also environmentally responsible and universally accessible. This holistic approach fosters a future where vehicle interfaces meet diverse user needs while supporting sustainability goals (Zhou et al., 2019).

As vehicles become increasingly autonomous, the significance of HMI design in facilitating seamless interaction between humans and machines continues to grow. These innovations will create a future where vehicles evolve from mere modes of transportation into collaborative partners, enhancing human capabilities and ensuring greater safety on the road.

5.3 Limitations and Further Research

Our study has several limitations. Despite extensive research on in-vehicle displays, several critical gaps remain to be addressed, particularly focusing on enhancing the user experience of NDRTs. This study aimed to investigate whether an optimal number of in-vehicle display configurations exists. However, we suggest that a deeper underlying factor, cognitive load, may play a role. To assess perceived cognitive load, we relied on self-reported measures, which have limitations as subjective tools. Self-report measures rely on participants' perceptions and introspection, which can be influenced by personal biases, emotions, or misunderstanding of the scale. Participants may underreport or overreport their cognitive load based on how they interpret the questions or their willingness to provide accurate responses. (Sweller et al., 2011). Therefore, we strongly recommend that future studies incorporate neurophysiological methods, such as EEG or eye-tracking, to collect objective cognitive load data and further explore its effect on the number of screens.

Additionally, the user experience observed in the two cars cannot be solely attributed to differences in screen configuration, because the systems in each car are fundamentally different in other important ways. These differences include not just the layout or number of screens, but also deeper aspects of system design, such as how information is organized and accessed (i.e., the information architecture), how features are grouped and labeled, the visual design, interaction patterns, and even system responsiveness. These factors can all significantly influence how users perceive and interact with the system. As a result, any comparison of user experience between the two vehicles must account for these potential confounding variables, rather than assuming that screen configuration is the only relevant factor.

However, and more importantly, this study was limited to an in-vehicle, stationary experiment, while a in-vehicle evaluation offered a controlled, risk-free environment ideal for isolating specific factors, they may not fully replicate the complexity and variability of real-world driving and its ability to distract the user, regardless on the vehicle’s user experience. An on-road study requires more resources, including, insurance, and adherence to road safety regulations, which can limit study size and frequency. On-road experiments provide higher ecological validity but are constrained by safety, ethical concerns, and logistical challenges (Young et al., 2007). To further address this research, a hybrid approach combining both methods can provide complementary insights into cognitive load and task performance.

Lastly, task performance metrics could provide a more comprehensive evaluation. Due to technical constraints, our experiment did not capture the metric, number of screen clicks, which likely affected the precision of our results. We encourage future research to include this metric to enhance the accuracy and understanding of task performance.

Chapter 6: Conclusion

This thesis was inspired by the rapid growth of new innovative electric vehicles, which primarily offer a multi-screen interface. By evaluating the number of screens in new vehicles, manufacturers can design systems that enhance usability, and driver satisfaction while minimizing risks associated with distraction and cognitive overload (Lee et al., 2004). It also ensures vehicles remain compliant with safety standards and aligned with evolving consumer expectations from different age groups (Young et al., 2007).

The literature review suggest controversy, while multi-screen interfaces, especially those incorporating HUDs and independent systems, have the potential to reduce cognitive load by presenting information within the driver's natural line of sight, yet single-screen interfaces like Tesla's Model 3 may increase cognitive demands due to the necessity of navigating through various controls on a single display. (Zhu et al., 2023). Ultimately, these studies underscore the importance of thoughtful design in multiscreen vehicle interfaces to manage cognitive load effectively. Properly designed interfaces can enhance driving performance and safety, while poorly implemented systems may increase distraction and cognitive strain. Therefore, this study’s results from 24 participants have identified both positive and negative significance, identifying that the number of screens has a direct correlation with cognitive load: as the number of screens increase, the higher cognitive load is required to complete the tasks. Additionally, as the number of screen increases, the level of satisfaction decreases.

The results provide some key insights into improving practical implications. This study has identified the age matters in design choices, that the system is perceived differently by users of varying ages. The positive intercept across models indicates that the baseline experience with the system is generally favorable, regardless of the number of screens or the user's age group. Although, the number of screens has a positive and significant effect across all models, indicating that multi-screen setups enhance usability, entertainment, reliability, and overall satisfaction. This suggests that users generally find the multi-screen design beneficial. Additionally, age (centered as AgeGroup_c) positively influences all outcomes, with older users reporting higher satisfaction, usability, entertainment, and reliability scores. This highlights that older users, as a group, perceive the system more favorably overall, potentially due to their preferences for simpler, practical features on the expected designated screens. However, and more importantly, the interaction term (Screens_AgeGroup) reveals that the positive effect of an additional screen diminishes for older users. Younger users can benefit more from multi-screen setups, as they are likely more accustomed to multitasking or navigating complex interfaces. Older users experienced challenges with the multi-screen setups, emphasizing the need for designs that reduce cognitive load or provide simplified options for this demographic.

Despite limited research, the available evidence will suggest that the design and configuration of multi-screen vehicle interfaces play a crucial role in user satisfaction. Aligning these interfaces with user preferences can enhance engagement and the overall experience.

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Appendix A: Demographic Information Table

Table 19: Demographic Information Table

	Options	Frequency	% of Sample
Gender	Male	11	45.8%
	Female	13	54.2%
Age	18-35	12	50%
	50+	12	50%

HEC MONTRÉAL

Retrait d'une ou des pages pouvant contenir des renseignements personnels

Appendix C – Scenario Provided to Participants

You are in the market for a new vehicle and have been looking to upgrade your vehicle to an all-electric vehicle and have arrived at a Tesla/Hyundai Dealer to educate yourself on the 2024 Tesla Model 3 and the Hyundai Ioniq 6. You enter the vehicle and begin to test the interface to evaluate your level of comfort with its dashboard. In order to evaluate its usability, you will engage in the following tasks: (1) when understanding the health of the vehicle, locate the vehicle's tire pressure and determine the PSI reading. (2) Another inscrutable piece of important information is your odometer reading, locate the vehicles odometer and determine its reading and (3) identify if the vehicle's software is update to date with the most recent version or if an update is required. I, the moderator of this study, will remain outside the vehicle in the designated waiting area once you are ready to begin, to limit the possibility of including any additional stress factors. A recording device will be present in order to capture your overall performance, to be used in the final evaluations and discarded once the data has been analyzed. Please do not hesitate to notify me if you have any questions or concerns before and during this exercise. You may now proceed to your assigned tasks with your first vehicle. Goodluck!

Appendix D – Tasks Provided to Participants

Question 1: When understanding the health of the vehicle, using the vehicle's controls, locate the vehicle's tire pressure and determine the tires' PSI (pressure) reading.
**If no numerical value is available, in the text below, indicate what is displayed.*

Question 2: Another inscrutable piece of important information is your odometer reading, locate and determine the vehicles odometer.
**Odometer: an instrument for measuring the distance travelled by a vehicle, in KM or Miles*

Question 3: Locate the vehicle's software update portal and identify if the vehicle is available for a new update.
**In the text below, if the vehicle is available for an update, indicate, "Update is available", if no update is available, indicate, "No update is available".*

Appendix E – NASA-TLX Questionnaire

Post Task Questionnaire

What is your participant number?

Which electric vehicle did you test?

- ○ Tesla Model 3
- ○ Hyundai Ioniq 6

What level of effort did you have to expend to complete task using Tesla's interface?
Please give an answer from 1 to 5 (where 1 = very low effort; 5 = very high effort).

1 very low	2	3	4	5 very high effort
○	○	○	○	○

What level of effort did you have to expend to complete task using Hyundai's Interface?
Please give an answer from 1 to 5 (where 1 = very low effort; 5 = very high effort).

1 very low	2	3	4	5 very high effort
○	○	○	○	○

How mentally demanding was the task?

Low — High

0 10 20 30 40 50 60 70 80 90 100

How successful were you in accomplishing the task?

Low — High

0 10 20 30 40 50 60 70 80 90 100

How hard did you have to work to complete the task?

Low — High

0 10 20 30 40 50 60 70 80 90 100

How insecure, discouraged, irritated, stressed, and annoyed were you?

We thank you for your time spent taking this survey.
Your response has been recorded.

The following page will automatically redirect you back to the Landing Page in order to evaluate the 2nd vehicle. Please select the vehicle you were not initially assigned to. If you wish to take a small break, you may do so now before clicking on the next arrow key.

If you have evaluated both vehicles at this time, you may notify me of completion, a final Post-Study Survey will be provided momentarily.

Appendix F – Post-Study Questionnaire + Interview (Part 1)

Thank you for completing the Post-Task Questionnaire, the following section is designed to identify your preferences around four (4) unique constructs, we will evaluate the interface's Understandability, Reliability, Usability and Entertainment. Please refer to the following questions.

Post-Study Questionnaire

I found Tesla's information to be clearer in meaning than Hyundai.

Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
○	○	○	○	○

I found Tesla's information to be easier to comprehend than Hyundai.

Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
○	○	○	○	○

I found Tesla's information to be easier to read than Hyundai.

Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
○	○	○	○	○

I found Tesla's information to be more trustworthy than Hyundai.

Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
○	○	○	○	○

I found Tesla's information to be more accurate than Hyundai.

Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
○	○	○	○	○

found Tesla's information to be more credible than Hyundai.

Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
○	○	○	○	○

I found Tesla has a more simple layout for its contents than Hyundai.

Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
○	○	○	○	○

I found Tesla's interface easier to use than Hyundai.

Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
○	○	○	○	○

I found Tesla's interface to be more well organized than Hyundai.

Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
○	○	○	○	○

I found Tesla's interface to be more visually attractive than Hyundai.

Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
○	○	○	○	○

I found Tesla's interface to be more fun to navigate than Hyundai.

Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
○	○	○	○	○

I found Tesla's interface to be more interesting to navigate than Hyundai.

Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
○	○	○	○	○

Post Study Interview (Part 1)

Almost done!
Thank you for completing the Post-Study Questionnaire. Now that you have completed your tasks, and evaluated both vehicles, let's take this opportunity together to summarize your final thoughts, two (2) questions will be recorded on your mobile device, and two (2) questions will be asked verbally.

Post Study Interview (Part 1)

How do you feel about your overall experience with Tesla's Model 3 interface?

Very Dissatisfied	Dissatisfied	Neutral	Satisfied	Very Satisfied
○	○	○	○	○

How do you feel about your overall experience with Hyundai's Ioniq 6 interface?

Very Dissatisfied	Dissatisfied	Neutral	Satisfied	Very Satisfied
○	○	○	○	○

Appendix G – Post-Study Interview (Part 2)

P#	Overall Comments/Observations/Opinions
P1	Tesla: I liked navigating the Tesla system. It was easy and self explanatory. I didn't feel like I didn't know what I was doing and that resulted in me feeling comfortable in driving the car if I wanted to one day. Feeling safe behind the wheel has to do with many aspects but for me a key aspect is feeling like I can rely on and know my car. I need to feel comfortable, and I was comfortable in the Tesla and navigating it's system. Hyundai: I did not like the navigation system on the Hyundai. It was very complicated and wordy for no reason. It made me feel like I wouldn't be safe in driving the car. They should make the search options easier so that we can easily find what we are looking for. I really would not consider purchasing this car.
P2	Tesla: Tesla's model 3 interface was modern and easy to use. Information was easily accessible and comprehensible. Visuals were also well presented and ultimately made me feel at ease. The "test" did not take long for me to complete which made me feel confident and safe. Without ever having set foot in a Tesla before, the interface somehow already felt familiar. Overall great experience. Hyundai: Hyundai's Ioniq 6 interface was complicated and stressful. I felt out of place and frustrated. Information was difficult to find and took quite some time. As frustrations escalated, I ended up clicking several unnecessary buttons such as the lights and wipers of the car. Additionally, when having "found" the tire pressure, it never gave a straight answer as the vehicle needed to be in motion to see an actual number. Do not recommend :)
P3	Tesla: I found the general interface very user friendly and easy to navigate. I would compare it the iPhone; dummy-proof (simple and easy to use). Hyundai: I found the general interface was more complex and challenging to navigate. I would compare it to the Android, where it only becomes easy once you have become familiar with the interface.
P4	Tesla: Finding the information on the Tesla was easier to find than on the Hyundai. There is one screen and everything you need is there. Hyundai: Finding information on the Hyundai was a little more complicated. Already having a Kia which is similar helped, however, I do not find that it is a simple process or user friendly.
P5	Tesla: I did not like the look of 1 interface, But I found it easier and more clear. The topic and subject were all in the right categories and was easier to find answer Hyundai: I enjoyed the look but it was more confusing trying to find the information I was looking for - you didn't know which interface to look at and which categories the information would be under.
P6	Tesla: easy to use. Abyone can get into the car and be comfortable with it. Hyundai: would need a long time to get use to its system.
P7	Tesla: I like the big screen in the middle but it was a bit difficult to manage and understand as a first time user. Hyundai: he Hyundais 2 interface was a nice touch and I find it easier to manage than the teslas.
P8	the interface reassembles a lot to the iphone interface, which most people are used to, so theres less search time and easy access to information while driving. Hyundai: The fact that there is 2 screen makes it harder to determine where the information you're looking for is located, which made me impatient after a while and got me to use the "search bar" to find the information I was looking for, which can easily be a distraction while driving. The interface is a bit more complicated to understand in the beginning. Overalllike any other technology, it takes a bit of time of adaptation but once you get to understand the way the interface works it is as easy to use as the Tesla.
P9	Tesla: Being "Techy", I am able to adapt, so navigating through tesla's interface felt like confirguring my Iphone. Hyundai: I actually drive a much older, much more analoque Hyundai, that aside, they have defiently upgraded, however, I found it more complex to use the new, all touch interface than my current vehicle.
P10	Tesla: I feel like the interface is somewhat user friendly when the car isn't moving. However, i feel like it would be very difficult to navigate through the interface while driving because, unlike regular cars, everything is flat which makes it hard to differentiate by touch the different settings (heating, music, maps, etc). Certain things on the screen appeared as if they were tappable but they weren't (ex: the tires on the 3d render of the car). Hyundai: I thought it was horrible. Random values were show on both screens with no label mentioning whag the value was representing. There were 2 screens but the one behind the steering wheel was not a tap screen and was quite distracting. The screen was smaller and less appealing visually due to the dull color choice. I had a very hard time locating informations because of how unorganized the buttons were.

P11	understand and find. I think the Hyundai's overall interface was complicated to use and things weren't clear to understand. I have no concerns with the Tesla but in the other hand for the Hyundai I do. I think that if it's that complicated to use then imagine if something bad happens when you are driving or in an emergency it will be very hard to figure out what to do especially if you are already stressed.
P12	The Tesla model 3 interface is much more customers friendly. In a sense that I could really see the main screen as an iPhone and it is really easy for me to go through information. On the other hand, the Hyundai is still good but i feel like its it's own software. So for Tesla the comparison of the software with an Iphone is pretty easy and noticable but Hyundai is more its own thing. To finish, the Hyundai is a bit harder to use because of the fact that you dont know what information is on what screen but the Tesla since its only one scren you are sure to find what you need in one place.
P13	Tesla: Im not used to a design where all the information is shoved into one screen. I felt uncomfortable. Hyundai: Feels like my current vehicle where I have information over the steering wheel and the rest in the middle.
P14	Tesla: Maybe it's my older age, but I don't use an Ipad at home, I prefer not to use one in my vehicle Hyundai: Although more familiar, I worked too hard to get simple information about the vehicle's health
P15	
P16	
P17	Tesla: My brother had the first gen Tesla, the UI now feels better so it didn't take me too much remembering to fiqure out the overall design. Hyundai: Attractive design but I felt overwhealmed, despite being surrounded around technology these days.
P18	Tesla: Simple, fast and to the point, it feels like my iphone. Hyundai: I have 3 screens in my office and I felt the ioniq 6 was more complex to navigate simple commands.
P19	Tesla: very responsive. The screen moves into another screen so theres enough space to display all the "relevent" info. Hyundai: I feel neutral about the design, its attractive but busy.
P20	Tesla: I found that the simplicity of the one screen interior allowed me to focus and retrieve the information in a more efficient way. The way the information was given and its accessibility was very convenient in regards to the interface and/or computer aspect. Hyundai: I found the screen's appearance to be somewhat more confusing, due to the complexities of the multiple options
P21	Tesla: My general thoughts about the Tesla interface is that it is a simpler interface to navigate. All the relevant information is under the same menu and then organized in well defined subcategories that are easy to navigate. Although I did find it strange to have the tire pressure in that subcategory, I would have liked to have it grouped up with maybe the range. Hyundai: My first opinion about the Hyundai is that the separation of information between the two screens is not as intuitive as expected. My first instinct was to search for the tire pressure under maintenance and service on the center screen, a category that was not easy to find. The sub categories in the main screen are not well defined, for example the software updates are under software, which is under general, which is in the settings and those are only on the center screen.
P22	I like the Hyundai better than the Tesla model. I find the Hyundai more attractive (exterior and Interior)
P23	Tesla: Simple design, I guess more suited for a person with minimal design Hyundai: Familiar design so I was able to navigate a litte easier in this vehicle
P24	Tesla: The Tesla's interface was much more simple and well designed in my opinion. I personally really like the simple layout without a bunch of buttons. I was able to find what i needed to find relatively quickly. Was definitely my favorite out of the 2. Hyundai: The Hyundai's interface was a lot more complex for me. It had a bunch of buttons everywhere and i did not know how to operate it. Took me a while just to find my tire pressure which i couldn't even see after all since it wont tell you unless the vehicle is moving.

Appendix H – Mediation Analysis

**********************************8Run statsmodel for Python*******************************

Table 20: OLS Regression Mediation Results using Cognitive Load on User Satisfaction

```
                            OLS Regression Results
==============================================================================
Dep. Variable:      User Satisfaction (Y)   R-squared:                   0.946
Model:                             OLS   Adj. R-squared:                 0.942
Method:                  Least Squares   F-statistic:                    154.6
No. Observations:                   48   Prob (F-statistic):          1.90e-18
Df Residuals:                       44   Log-Likelihood:               -16.930
Df Model:                            3   AIC:                            40.86
Covariance Type:             nonrobust   BIC:                            49.66
==============================================================================
                 coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------
Intercept      3.5000      0.205     17.074      0.000       3.085       3.915
# of Screens (X)  1.2500      0.183      6.816      0.000       0.879       1.621
Cognitive Load (Mediator)  0.0200      0.005      3.758      0.001       0.009
```

Table 21: OLS Regression Mediation Results using Understandability on User Satisfaction

```
                            OLS Regression Results
==============================================================================
Dep. Variable:      User Satisfaction (Y)   R-squared:                   0.946
Model:                             OLS   Adj. R-squared:                 0.941
Method:                  Least Squares   F-statistic:                    154.6
No. Observations:                   48   Prob (F-statistic):          1.90e-18
Df Residuals:                       44   Log-Likelihood:               -16.930
Df Model:                            3   AIC:                            40.86
Covariance Type:             nonrobust   BIC:                            49.66
==============================================================================
                 coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------
Intercept      3.5000      0.205     17.074      0.000       3.085       3.915
# of Screens (X)  0.2500      0.183      1.364      0.180      -0.121       0.621
Understandability (Mediator)  0.5000      0.222      2.255      0.030       0.051
```

Table 22: OLS Regression Mediation Results using Reliability on User Satisfaction

OLS Regression Results

Dep. Variable:	User Satisfaction (Y)	R-squared:	0.946
Model:	OLS	Adj. R-squared:	0.942
Method:	Least Squares	F-statistic:	309.1
No. Observations:	48	Prob (F-statistic):	3.81e-20
Df Residuals:	45	Log-Likelihood:	-16.930
Df Model:	2	AIC:	40.86
Covariance Type:	nonrobust	BIC:	47.66

	coef	std err	t	P>|t|	[0.025	0.975]
Intercept	3.5000	0.183	19.116	0.000	3.130	3.870
# of Screens (X)	0.2500	0.163	1.532	0.132	-0.080	0.580
Reliability (Mediator)	0.5000	0.183	2.730	0.009	0.130	[illegible]

Table 23: OLS Regression Mediation Results using Usability on User Satisfaction

OLS Regression Results

Dep. Variable:	User Satisfaction (Y)	R-squared:	0.946
Model:	OLS	Adj. R-squared:	0.942
Method:	Least Squares	F-statistic:	309.1
No. Observations:	48	Prob (F-statistic):	3.81e-20
Df Residuals:	45	Log-Likelihood:	-16.930
Df Model:	2	AIC:	40.86
Covariance Type:	nonrobust	BIC:	47.66

	coef	std err	t	P>|t|	[0.025	0.975]
Intercept	3.5000	0.183	19.116	0.000	3.130	3.870
# of Screens (X)	0.2500	0.163	1.532	0.132	-0.080	0.580
Usability (Mediator)	0.5000	0.183	2.730	0.009	0.130	[illegible]

Table 24: OLS Regression Mediation Results using Entertainment on User Satisfaction

OLS Regression Results

Dep. Variable:	User Satisfaction (Y)	R-squared:	0.946
Model:	OLS	Adj. R-squared:	0.942
Method:	Least Squares	F-statistic:	309.1
No. Observations:	48	Prob (F-statistic):	3.81e-20
Df Residuals:	45	Log-Likelihood:	-16.930
Df Model:	2	AIC:	40.86
Covariance Type:	nonrobust	BIC:	47.66

	coef	std err	t	P>|t|	[0.025	0.975]
Intercept	3.5000	0.183	19.116	0.000	3.130	3.870
# of Screens (X)	0.2500	0.163	1.532	0.132	-0.080	0.580
Entertainment (Mediator)	0.5000	0.183	2.730	0.009	0.130	

Appendix I – Moderation Analysis

********************************Run statsmodel for Python*********************************

Table 25: OLS Regression Moderation Results using Age Group on Cognitive Load

OLS Regression Results

Dep. Variable:	Cognitive Load (Y)	R-squared:	0.571
Model:	OLS	Adj. R-squared:	0.533
Method:	Least Squares	F-statistic:	15.35
No. Observations:	48	Prob (F-statistic):	1.90e-06
Df Residuals:	44	Log-Likelihood:	-166.05
Df Model:	3	AIC:	342.1
Covariance Type:	nonrobust	BIC:	350.9

	coef	std err	t	P>|t|	[0.025	0.975]
Intercept	39.3750	6.631	5.937	0.000	26.003	52.747
# of Screens (X)	16.5104	5.942	2.781	0.008	4.437	28.584
AgeGroup_c	37.0417	7.933	4.671	0.000	21.033	53.050
Screens_AgeGroup	-18.6875	8.930	-2.095	0.042	-36.707	-0.668

Table 26: OLS Regression Moderation Results using Age Group on Understandability

OLS Regression Results

Dep. Variable:	Understandability (Y)	R-squared:	0.946
Model:	OLS	Adj. R-squared:	0.941
Method:	Least Squares	F-statistic:	154.6
No. Observations:	48	Prob (F-statistic):	1.90e-18
Df Residuals:	44	Log-Likelihood:	-16.930
Df Model:	3	AIC:	40.86
Covariance Type:	nonrobust	BIC:	49.66

	coef	std err	t	P>|t|	[0.025	0.975]
Intercept	3.5000	0.205	17.074	0.000	3.085	3.915
# of Screens (X)	1.2500	0.183	6.816	0.000	0.879	1.621
AgeGroup_c	2.0000	0.258	7.749	0.000	1.477	2.523
Screens_AgeGroup	-1.0000	0.290	-3.452	0.001	-1.591	-0.409

Table 27: OLS Regression Moderation Results using Age Group on Reliability

```
                            OLS Regression Results
==============================================================================
Dep. Variable:      Reliability (Y)   R-squared:                       0.914
Model:                          OLS   Adj. R-squared:                  0.907
Method:               Least Squares   F-statistic:                     102.6
No. Observations:                48   Prob (F-statistic):           1.91e-16
Df Residuals:                    44   Log-Likelihood:                -20.519
Df Model:                         3   AIC:                             49.04
Covariance Type:          nonrobust   BIC:                             57.84
==============================================================================
                 coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------
Intercept      3.0000      0.249     12.063      0.000       2.500       3.500
# of Screens (X)  0.5000      0.222      2.255      0.030       0.051       0.949
AgeGroup_c      1.0000      0.313      3.193      0.002       0.368       1.632
Screens_AgeGroup -0.5000      0.351     -1.426      0.161      -1.209       0.209
```

Table 28: OLS Regression Moderation Results using Age Group on Usability

```
                            OLS Regression Results
==============================================================================
Dep. Variable:      Usability (Y)   R-squared:                       0.946
Model:                          OLS   Adj. R-squared:                  0.941
Method:               Least Squares   F-statistic:                     154.6
No. Observations:                48   Prob (F-statistic):           1.90e-18
Df Residuals:                    44   Log-Likelihood:                -16.930
Df Model:                         3   AIC:                             40.86
Covariance Type:          nonrobust   BIC:                             49.66
==============================================================================
                 coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------
Intercept      3.5000      0.205     17.074      0.000       3.085       3.915
# of Screens (X)  1.2500      0.183      6.816      0.000       0.879       1.621
AgeGroup_c      2.0000      0.258      7.749      0.000       1.477       2.523
Screens_AgeGroup -1.0000      0.290     -3.452      0.001      -1.591      -0.409
```

Table 29: OLS Regression Moderation Results using Age Group on Entertainment

OLS Regression Results

Dep. Variable:	Entertainment (Y)	R-squared:	0.946
Model:	OLS	Adj. R-squared:	0.941
Method:	Least Squares	F-statistic:	154.6
No. Observations:	48	Prob (F-statistic):	1.90e-18
Df Residuals:	44	Log-Likelihood:	-16.930
Df Model:	3	AIC:	40.86
Covariance Type:	nonrobust	BIC:	49.66

	coef	std err	t	P>|t|	[0.025	0.975]
Intercept	3.5000	0.205	17.074	0.000	3.085	3.915
# of Screens (X)	1.2500	0.183	6.816	0.000	0.879	1.621
AgeGroup_c	2.0000	0.258	7.749	0.000	1.477	2.523
Screens_AgeGroup	-1.0000	0.290	-3.452	0.001	-1.591	-0.409

Table 30: OLS Regression Moderation Results using Age Group on User Satisfaction

OLS Regression Results

Dep. Variable:	User Satisfaction (Y)	R-squared:	0.946
Model:	OLS	Adj. R-squared:	0.941
Method:	Least Squares	F-statistic:	154.6
No. Observations:	48	Prob (F-statistic):	1.90e-18
Df Residuals:	44	Log-Likelihood:	-16.930
Df Model:	3	AIC:	40.86
Covariance Type:	nonrobust	BIC:	49.66

	coef	std err	t	P>|t|	[0.025	0.975]
Intercept	3.5000	0.205	17.074	0.000	3.085	3.915
# of Screens (X)	1.2500	0.183	6.816	0.000	0.879	1.621
AgeGroup_c	2.0000	0.258	7.749	0.000	1.477	2.523
Screens_AgeGroup	-1.0000	0.290	-3.452	0.001	-1.591	-0.409