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**Comparison Between Single-Touch and Multi-Touch Interfaces and Their Display Height for In-Vehicle
Information System Design**
Fatiha Widyanti, Ir.Fitri Trapsilawati, S.T., Ph.D., IPM. ASEAN.Eng.
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COMPARISON BETWEEN SINGLE-TOUCH AND MULTI-TOUCH INTERFACES AND THEIR DISPLAY HEIGHT FOR IN-VEHICLE INFORMATION SYSTEM DESIGN

THESIS

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YOGYAKARTA

2024

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PERBANDINGAN ANTARA ANTARMUKA SENTUH TUNGGAL DAN MULTI SENTUH DAN TINGGI LAYAR UNTUK DESAIN SISTEM INFORMASI PADA KENDARAAN

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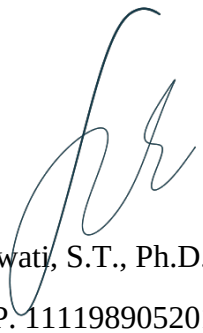
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PREFACE

This thesis entitled “Comparison between Single-Touch and Multi-Touch Interfaces and Their Display Height for In-Vehicle Information System Design” has been completed to fulfill the requirements for a master’s dual degree from Universitas Gadjah Mada, Indonesia and National Taiwan University of Science and Technology, Taiwan.

The study is organized into six chapters. Chapter one outlines the study's background, identifies the core issues, and describes how this research addresses these issues. Chapter two offers a comprehensive review of prior studies. Chapter three delves into the theoretical background about this research. Chapter four presents methodology. Chapter five provides a statistical result and discussion. Finally, chapter six concludes the study, summarizing the findings, implications, and directions for future research.

The author is aware of the limitations of this paper and invites constructive feedback and suggestions for improvement, with the aim of advancing the research and maximizing its value for readers and the broader public.

Yogyakarta, November 2024

Author

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I extend my heartfelt gratitude to my parents, whose unwavering support and encouragement have been a constant source of strength and motivation in pursuing my dreams. Their prayers and belief in me have always been a pillar of support.

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I am deeply grateful to my friends and participants who generously helped me with this study. A big thank you to my friends who accompanied me during my time in Taiwan, standing by me through both joy and sorrow, and offering both physical and mental support. Your camaraderie and support have made this research journey not only productive but also enjoyable.

The author acknowledges the limitations of this thesis and apologizes for any shortcomings. Thank you all for your support and encouragement.

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ABSTRACT

In-Vehicle Information Systems (IVIS) are increasingly integrated into modern vehicles, offering drivers enhanced convenience through various interactive touchscreens. However, the design and operation of these systems, particularly the type of touch scheme (single-touch vs. multi-touch) and the installation height of the display, can significantly influence driving performance, safety, and user experience. This study investigates the effectiveness of these touch schemes and displays heights in the context of typical driving tasks. Specifically, it compares drivers' performance using single-touch and multi-touch schemes while interacting with touchscreens installed at three different heights: low, middle, and high.

The research used a driving simulation to analyze the impact of the touch scheme and display height on several key factors, including driving performance, error rate, task completion time, accidents, and subjective responses. Participants performed tasks requiring interaction with IVIS screens under each combination of touch scheme and display height. The study employed objective measurements (task completion time, number of errors, accidents) and subjective evaluations (comfort, fatigue levels) to assess the influence of the independent variables on driver performance and safety. The statistical tests used include ANOVA, Friedman test, and Wilcoxon Signed Rank Test.

Touch scheme has a significant effect on objective measurement like task completion time. A p-value of less than 0.05 indicated significant relationships between these variables. However, participants preferred single-touch due to its ease of use, as reflected in the subjective questionnaire, where single-touch was rated as more comfortable with lower fatigue levels. Display height, however, had no significant effect on objective performance metrics such as task completion time, error rates, or accident frequency. However, subjective responses showed that display height influenced participant fatigue, with the middle installation yielding the lowest fatigue levels. The middle installation was also the most preferred by participants, requiring less hand movement to operate the screen.

Keywords: In-Vehicle Information System, Driving Simulator, Single-touch, Multi-touch, Display Height

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INTISARI

In Vehicle Information System (IVIS) semakin terintegrasi ke dalam kendaraan modern, menawarkan kenyamanan yang lebih baik bagi pengemudi melalui berbagai layar sentuh interaktif. Namun, desain dan pengoperasian sistem ini, khususnya jenis skema sentuh (sentuhan tunggal vs. multisentuhan) dan ketinggian pemasangan layar, dapat memengaruhi performa berkendara, keselamatan, dan pengalaman pengguna secara signifikan. Studi ini bertujuan untuk menyelidiki efektivitas skema sentuh dan ketinggian layar ini dalam konteks tugas mengemudi yang umum. Secara khusus, studi ini membandingkan kinerja pengemudi yang menggunakan skema sentuhan tunggal dan multisentuhan saat berinteraksi dengan layar sentuh yang dipasang pada tiga ketinggian berbeda: rendah, sedang, dan tinggi.

Penelitian ini menggunakan simulasi mengemudi untuk menganalisis dampak skema sentuh dan ketinggian layar pada beberapa faktor utama, termasuk performa mengemudi, tingkat kesalahan, waktu penyelesaian tugas, kecelakaan, dan respons subjektif. Peserta melakukan tugas yang memerlukan interaksi dengan layar IVIS di bawah setiap kombinasi skema sentuh dan ketinggian layar. Studi ini menggunakan pengukuran objektif (waktu penyelesaian tugas, jumlah kesalahan, dan jumlah kecelakaan) dan evaluasi subjektif (kenyamanan dan tingkat kelelahan) untuk menilai pengaruh variabel independen terhadap kinerja dan keselamatan pengemudi. Uji statistik yang digunakan antara lain ANOVA, *Friedman test*, dan *Wilcoxon signed rank test*.

Skema sentuhan memiliki pengaruh signifikan terhadap pengukuran objektif seperti waktu penyelesaian tugas. Nilai p kurang dari 0,05 menunjukkan hubungan signifikan antara variabel-variabel ini. Namun, partisipan lebih menyukai sentuhan tunggal karena kemudahan penggunaannya, sebagaimana tercermin dalam kuesioner subjektif, di mana sentuhan tunggal dinilai lebih nyaman dengan tingkat kelelahan yang lebih rendah. Namun, tinggi layar tidak memiliki efek signifikan pada metrik kinerja objektif seperti waktu penyelesaian tugas, tingkat kesalahan, atau frekuensi kecelakaan. Namun, tanggapan subjektif menunjukkan bahwa tinggi layar memengaruhi kelelahan peserta, dengan pemasangan di tengah menghasilkan tingkat kelelahan terendah. Pemasangan di tengah juga paling disukai oleh peserta, yang membutuhkan lebih sedikit gerakan tangan untuk mengoperasikan layar.

Keywords: Sistem Informasi Dalam Kendaraan, *Driving Simulator*, Sentuhan Tunggal, Multi Sentuhan, Ketinggian Layar

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CHAPTER 1
INTRODUCTION

1.1 Background

In present days, automobiles are essential for transportation, serving as a vital mode to commute both in regions well-served by public transit and those lacking in such infrastructure. Car manufacturers are now integrating more features into the In-Vehicle Information Systems (IVIS), such as radio, multimedia capabilities, vehicle controls, and even navigation applications. This expansion of functionality enhances the driving experience, providing convenience and efficiency at the driver's fingertips. Integration of IVIS, however, is worsening the issue of distracted driving because it enables overly distracting activities such as adjusting the navigation system, interacting with multimedia controls (selecting music or videos), responding to text messages, browsing the internet, or even using social media platforms while driving (Strayer et al., 2019).

IVIS are designed to provide a variety of information and entertainment services to drivers and passengers. Touchscreens have become ubiquitous interfaces. To operate applications, IVIS offered intuitive, direct manipulation methods that enhance user interaction and engagement such as video games, videos, and even social chatting (Lin et al., 2020). The design of touch operation can significantly impact its usability and safety. For example, single-touch allows the user to interact with the system using one finger at a time. It is commonly found in older touchscreens and is used for basic operations such as tapping and dragging. Multi-touch enables the use of multiple fingers simultaneously, allowing for more complex gestures like pinch-to-zoom and multi-finger swipes (Shen & Guodong, 2021). Single-touch mode, involving basic tapping and dragging with one finger, is easier to learn and more intuitive for users unfamiliar with advanced gestures but often requires more time to complete tasks due to its sequential nature. This mode can lead to higher driver distraction as it demands more frequent screen focus. In contrast, multi-touch mode supports advanced gestures like pinch-to-zoom and

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swipes, allowing for quicker and more efficient task completion by enabling multiple actions simultaneously. Although it may have a steeper learning curve, multi-touch interaction can reduce driver distraction by minimizing the need for prolonged screen glances.

However, optical parallax becomes a problem when we experience distortion or differences between visual perception of the object's location and the actual touch area where we interact with the object. The touch bias in Figure 1.1 is different when the object is viewed at different visual angles. Touch bias can cause users to miss their intended targets, resulting in higher error rates when interacting with touchscreens. This can be particularly problematic in applications requiring precise touch inputs, and its effects become more pronounced when the touchscreen is placed far away from the center of the visual field.

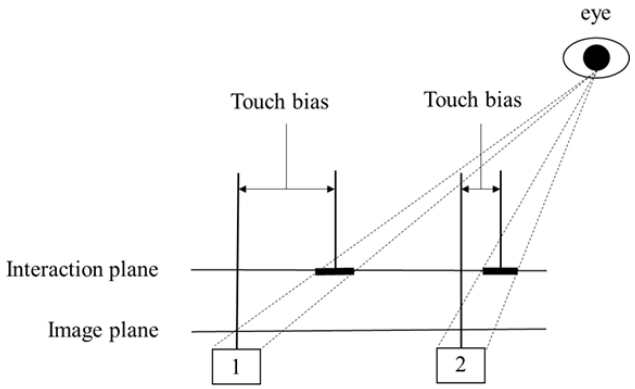


Figure 1.1 The Phenomenon of Optical Parallax (Faturohman, 2022)

The placement or installation of the IVIS touchscreens in different cars varies and can significantly affect drivers' experience and performance. The location of the IVIS should ideally minimize the need for excessive eye and hand movements, which can distract the driver and increase the risk of accidents. For instance, an installation at eye height can reduce the need for drivers to move their gaze up and down, which helps focus on the road. Conversely, a system installed in line with the steering wheel height minimizes the reach needed to operate the system, thereby reducing arm fatigue and keeping the hands closer to the steering wheel.

However, if the IVIS is placed too low, it might reduce the need to raise one's arms excessively but can cause drivers to look down frequently, which is not

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ideal for road safety as the driver's main focus should be on the road ahead. With the delay in screen operation causing the driver's eyes to look away from the road, there can be a sudden loss of speed control, leading to abrupt acceleration or sudden braking. Therefore, the placement of the screen should be carefully considered to ensure it is within the driver's visual limits, minimizing the time the driver's eyes are off the road. There are several examples of installation IVIS shown from Figure 1.2 until Figure 1.4 below.



Figure 1.2 BMW i7 23 (Edelstein, 2022)



Figure 1.3 Jaguar XF 2021 (Charlton, 2021)

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Figure 1.4 Lucid Air (Vincent, 2024)

The touchscreen IVIS is a critical component of what is known as the 'intelligent cabin'—a concept aimed at making the car's interior smart and more interactive. While the multifunctional nature of a touchscreen IVIS enhances the overall driving experience by integrating various controls and features into a single interface, it also presents challenges. The main concern is driving distraction. As drivers interact with an increasingly complex system, the potential for attention to be drawn away from the driving task increases significantly.

Therefore, while the IVIS offers numerous benefits, its design and placement require careful consideration to balance functionality and safety. Optimal placement that aligns with ergonomic principles is crucial to minimize distraction and maintain focus on the road, thus ensuring both enhanced driving experience and increased safety.

1.2 Research Statement

Given the background, this study aims to investigate the effectiveness of single-touch versus multi-touch operations of IVIS in a driving environment. Additionally, it compares the three different display height (low, middle, and high) for touchscreens to be operated in typical driving tasks. The variation in display height is expected to influence ergonomic factors, particularly hand movement,

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which can affect driver comfort and ease of use. Meanwhile, the touch scheme, specifically the comparison between single-touch and multi-touch, requires efficient screen operations to minimize driver distraction. Distraction during driving can compromise safety, emphasizing the need for an optimal interaction design.

1.3 Scope and Assumptions

Scope for this research can be listed as follows:

1. The participants were only Indonesian and Taiwanese.
2. Single type of screen not fully represent the variety of screens used across different vehicle brands.
3. The study used a driving simulator instead of actual on-road driving.

Assumption for this research can be listed as follows:

1. Driving simulation are sufficiently representative of real-world driving conditions on the road.
2. Participants followed the research instructions correctly and completed their tasks with consistent focus.
3. Participants are accustomed to using the left steering wheel.
4. The display height and touch scheme can be implemented in real vehicles without technical or ergonomic constraints.

1.4 Objective of Study

1. To determine the optimal interaction design for In-Vehicle Information Systems (IVIS) by comparing single-touch and multi-touch interfaces in terms of their impact on driver performance, safety, and user experience.
2. To evaluate the effects of different spatial locations or installation positions of IVIS on driver performance, safety, and experience, identifying the most effective placement for enhancing usability and minimizing driver distraction.

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The results of this study were expected to provide insights into the design of the touch-based IVIS system so that appropriate guidelines can be established.

1.5 Importance of Research

This research is important for understanding how different display heights in In-Vehicle Information Systems (IVIS) and touch schemes like single-touch or multi-touch affect driver performance, safety, and experience. Unlike previous studies, this research reflects the real-world driving context by examining how each touch interaction type interacts with various display heights, helping to identify the most effective configurations for minimizing driver distraction and enhancing usability. By providing insights into how display height and touch schemes impact drivers' responses, this study supports the development of IVIS designs that are safer and more user-friendly, contributing valuable knowledge for both automotive design and human-computer interaction fields.

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CHAPTER 2
LITERATURE REVIEW

2.1 Literature Review

In recent years, there has been a growing body of research investigating the design and operation of In-Vehicle Information Systems (IVIS). Additionally, many systems now integrate smartphones with IVIS to facilitate tasks such as making phone calls or listening to music. While certain IVIS features aim to enhance safety such as providing speed and collision alerts allowing access to all smartphone applications through an IVIS can distract drivers and increase the risk of accidents. (Starkey & Charlton, 2020) research further explores the behaviors of drivers using IVIS and their perceptions of its impact on driving performance and safety with a particular focus on the impact of touch-based interfaces and screen installation positions on driving performance and safety. While many studies have explored either single-touch or multi-touch modalities independently, there remains a lack of comprehensive analysis directly comparing these two interaction methods within the same driving context. Furthermore, prior research has largely overlooked the integration of real-world driving tasks in their assessments, which is critical for understanding the practical implications of these technologies in real-time driving scenarios. For instance, research conducted by Prabhakar et al (2022) investigates various interaction modalities within driving contexts to reduce disruptions in driving performance. The study introduces a novel interactive device combining a laser tracker and an eye gaze tracker for operating In-Vehicle Information Systems (IVIS). The findings revealed that the touch modality was more efficient, with faster response times compared to the laser modality. This research compares the touch and laser modalities. There is any research to evaluate two different prototype one based on multi-touch sliding gestures and a traditional touchscreen interface (Shen & Guodong, 2021). In terms of objective performance, Prototype 2 significantly reduced eye-off-road time, off-lane counts, and even completely eliminated accidents. Nearly all participants required only a short time (approximately 30

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seconds each) to learn and memorize its functionality, demonstrating that the system is intuitive and easy to use. Regarding subjective evaluation, the prototype utilizing multi-touch outperformed the traditional interface. These findings highlight the promising potential of multi-touch sliding gestures, especially given their adaptability for integration into existing IVI systems.

Previous studies have focused on either single-touch or multi-touch operations without directly comparing the two within the same context. Several studies, such as those by Lin & Chiang (2017) and Faturohman (2022), have explored the impact of different screen installation positions. However, these studies did not integrate driving tasks into their analyses. Lin & Chiang (2017) research concluded that middle installation is superior. The use of single-touch and multi-touch schemes is not exclusively suitable for younger drivers. Older drivers also interact with these touch schemes, which may present distinct usability challenges. For instance, research by Lepicard & Vigouroux (2012) on the comparison between single-touch and multi-touch interfaces for older individuals concluded that single-touch interfaces were generally more effective and user-friendly. The study emphasized that single-touch interfaces were preferable for older users, as multi-touch interfaces often posed difficulties in terms of precision and response times. As a result, the study recommended against using multi-touch interfaces for this demographic to avoid potential usability issues and distractions. Similarly, Faturohman (2022) study found that middle installation received the highest scores in subjective responses. However, these studies did not include driving tasks. On the other hand, Hagiwara's research focused only on multi-touch and screen installation with two types. Therefore, this study compares single-touch and multi-touch interfaces with different installation types in terms of operation time, errors, and accidents in vehicles. The shaded cells mean that the research addressed a combination of single-touch and multi-touch operation also the display position of screen with driving task. Additionally, Hagiwara et al., (2013) only examined two types of installations without considering a broader range of installation position variations. The study integrates both approaches by including subjective

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assessments through questionnaires and interviews, as well as objective evaluations of installation and operation.

2.2 Research Gap

The relevant studies associated with the research gap in this study are listed in Table 2.1 below. The research gap evident from the table highlights that previous studies have focused on specific aspects of In-Vehicle Information Systems (IVIS) usability, such as single-touch interactions, multi-touch gestures, voice input, or screen installation. However, these studies rarely integrated all these elements comprehensively or included realistic driving tasks. Furthermore, works such as Hagiwara et al., (2013) only partially addressed screen installations, as their study limited the analysis to two installation heights: middle and low. This leaves broader comparisons incomplete and fails to represent more comprehensive scenarios. This research addresses these gaps by simultaneously exploring single-touch and multi-touch schemes, screen installation variations (including low, middle, and high levels), and their collective impact on driving tasks.

Table 2.1 Research Gap

References	Focus						
	Voice Input	Single Touch	Multi Touch	Screen Installation			Driving Task
				High	Middle	Low	
Lepicard & Vigouroux, (2012)		✓	✓				
Choi, (2013)			✓				
Hagiwara et al., (2013)		✓	✓		✓	✓	✓
Lin & Chiang, (2017)		✓	✓	✓	✓	✓	

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References	Focus						
	Voice Input	Single Touch	Multi Touch	Screen Installation			Driving Task
				High	Middle	Low	
Starkey & Charlton, (2020)		✓	✓				
Cohen-Lazry & Borowsky, (2020)	✓						
Wu et al., (2020)		✓					✓
Jung et al., (2021)		✓					
Shen & Guodong, (2021)		✓	✓				
Faturohman, (2022)		✓	✓	✓	✓	✓	
This research		✓	✓	✓	✓	✓	✓

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CHAPTER 3
THEORETICAL BACKGROUND

3.1 Human Computer Interaction

The roots of Human Computer Interaction can be traced back to the innovative work of Douglas Englebart. Human-computer interaction (HCI) is the study of how to use and develop computer technology, with a particular emphasis on how users and computers interact with one another (Jyoti & Kaur, 2023). These systems are not limited to those installed on computers but also include those used in everyday life, such as cars and household appliances. In the current technological era, nearly all aspects of life rely on machines designed to simplify human tasks. Computers, for instance, are created to assist in various fields including banking, transportation, education, government, commerce, and the military can take the form of controllers and status visualization, either manually or through real-time computer visualization (Haryanto & Hidayat, 2016). To develop intelligent computers capable of performing desired tasks, it is essential for humans to understand how to formulate commands that computers can comprehend and how these commands are executed by the machines. The concept of the user interface, also known as the Human Computer Interaction, was introduced in the 1970s and quickly became a focus for researchers and system designers. By the mid-1980s, the term human-computer interaction (HCI) emerged as a new field of study, signifying a broader scope that extends beyond just the design of physical interfaces. In modern times, Human Computer Interaction (HCI) can be applied in various fields, including operating information systems in vehicles.

3.2 In Vehicle Information System

An In Vehicle Information System (IVIS) refers to a device that provides a variety of information and entertainment services. It includes a digital radio, built-in reversing camera, navigation system, music streaming, hands-free calling, voice

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commands, and a touchscreen display. IVIS interaction modes have expanded from traditional to multi-modal modes, combining visual, auditory, and tactile interaction. The use of touch interaction mode has increased significantly. IVIS also can connect with various smart automotive technologies, like sensors, smartphones, and Advanced Driver Assistance Systems (ADAS). The design of IVIS has been sensitive to human-centered concepts, taking the skills and limitations of the drivers into consideration. This will guarantee that IVIS reaches its goals of increasing mobility, boosting effectiveness, and elevating driving safety (Faturohman, 2022). As of right now, IVIS offers improved functions and information to make driving more enjoyable. As a result, drivers can now choose from a variety of in-car technologies, including music players, climate control, and route guiding, thanks to substantial technological developments. On the other hand, complicated operating processes and limited information delivery may be factors in accidents. Complex menus and the need to navigate through multiple screens can divert the driver's attention from the road. Also, the abundance of information and options available through IVIS can overwhelm drivers, leading to cognitive overload. The research findings emphasize the importance of designing IVIS interfaces that minimize cognitive load and support drivers in maintaining focus on the road (Reyes & Lee, 2008).

3.3 Single Touch

The touch screen was introduced around the 1960s by E.A. Johnson in England in 1965-1967. It uses the concept of the capacitance touch screen (Wicaksono, 2022). Then in 1968, he published an article about touch screens that could be used for air traffic control. The history of touch screen technology began with touch-sensitive synthesizers. According to the Canada Science and Technology Museum, the Electronic Sackbut created by Hugh Le Caine is considered to be the first musical synthesizer created (Marsh, 2024). The way to play this musical instrument is to play the keyboard in your right hand while the

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left hand is used for the controller board which is located above the keyboard on the left.

The single-touch technology (single-touch) can detect and respond to only one touch input at a time, e.g. tapping or dragging. Single-touch is commonly found in older devices and interfaces where single-point interaction suffices for basic operation. Single-touch is commonly used in touchscreens in vehicles. The first mass-produced vehicle to feature a touchscreen communication panel was The 1986 Buick Riviera (Dudziak et al., 2024). Meanwhile, BMW took the next bold step in revolutionizing infotainment with the introduction of iDrive in the 2002 model year 7 Series. This move was strategic for BMW, as it provided something new for traditionalists to focus on besides the aggressive styling. The 8.8-inch screen replaced all of BMW's conventional entertainment controls with a single operator-controlled knob (Quain, 2008). Initially, for two years, there was no Menu shortcut or Back key until BMW responded to the backlash and made the controls less minimalistic. The transition from single-touch to multi-touch interactions may improve task efficiency and reduce driver distraction, much like BMW's revisions aimed to enhance user experience.

3.4 Multi Touch

The multi-touch technology allows touch screens to be controlled by more than one finger simultaneously, unlike traditional touch screens that only allow control by one finger at a time. Multi-touch is commonly found in smartphones, tablets, and other modern devices, where it enables intuitive and efficient interactions with the device's interface. Users can perform actions like pinch-to-zoom and swiping. However, some applications may still require high precision in recognizing gestures.

Visual attention is the most critical aspect when driving vehicles (Bach et al., 2008). Ensuring that a driver's gaze remains undistracted is crucial for maintaining safety while driving. Introducing multi-touch interaction into IVIS holds potential because it can decrease operation time with less need for screen

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focus (Choi, 2013). A previous study (Shen & Guodong, 2021) yielded positive results that using swipe gestures, eye-off-road time was reduced by 87.3%, the number of off-lane occurrences decreased by 86.84%, and the accident rate dropped from 7.5% to 0% regarding the use of multi-touch in-vehicle information systems compared with traditional single-touch system. This approach minimized the necessity for dividing their visual attention between the central display and the road (Wu et al., 2020). Another benefit of multi-touch technology is its capacity to enhance collaboration between driver and vehicle system. This collaborative ability is particularly valuable as it can save time, especially in driving situations where maintaining focus on the road is essential.

Multitouch interaction systems offer a compelling advantage by providing a diverse range of inputs for interactive interfaces. These inputs can be used not only to manipulate data through natural gestures but also for controlling interface elements, such as activating commands and managing cursors. In multi-touch systems, command activation often relies on predefined gesture sets. However, recent research highlights the challenge of creating truly natural gestures that users can quickly learn. While gestures work well for a limited set of commands, developing a comprehensive library of gestures for applications with numerous commands becomes impractical. In such cases, menu-based systems appear more feasible (Lepinski et al., 2010). However, there remains a need for standardized icons and simple gestures.

3.5 Installation

The installation of screens in vehicles is a crucial aspect of automotive design, particularly concerning the safety and usability of In-Vehicle Information Systems (IVIS). The Japan Automobile Manufacturers Association (JAMA) guidelines emphasize several key principles for screen installation to minimize driver distraction and maintain visibility. According to the guidelines, display systems should not interfere with the operation of the steering device or obscure any part of the driver's necessary field of view. The screens must be positioned in such a way

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that the driver's posture remains stable during operation, avoiding the need for significant shifts in the driving position. This is critical to ensure that drivers can operate the display without diverting their attention from the road for prolonged periods. Ergonomic factors are also considered, particularly the impact of screen placement on driver comfort. The guidelines suggest that screens should be within easy reach and should not require drivers to perform excessive or awkward movements, which could lead to fatigue or distraction.

3.6 Driving Simulator

Driving simulators are valuable tools used for researching drivers' behavior, initially developed in the 1930s (Wynne et al., 2019). These simulators aim to replicate real-world conditions as closely as possible. This includes studying the impacts of technologies, devices, and road infrastructure, such as variable message signs. Driving simulators serve various purposes, such as training, research, and entertainment.

1. Training:
    - New drivers can use simulators to practice parking and improve their driving skills.
    - Simulators provide a safe environment for learners to gain experience without real-world risks.
2. Research:
    - Researchers use driving simulators to test new vehicle technologies or study driver reactions.
    - Simulators allow controlled experiments, enabling insights into driver behavior and safety.
3. Entertainment:
    - Video games and amusement parks often incorporate driving simulators to offer an immersive driving experience.
    - These systems engage users by replicating the feel of driving a real car.

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A simulator usually consists of the following components:

- Hardware: Simulators include components similar to those found in actual cars, such as steering wheels, pedals, gear shifters, and dashboard controls.
- Software: The software for a driving simulator can be custom-made or based on existing systems. For example, in a study conducted by (Schoenmakers et al., 2021) on car-following behavioral adaptation when driving next to automated vehicles in the Netherlands, actual Dutch roads were recreated using SketchUp Pro and exported to Unity. The driving simulator package utilized GreenDino's system, which provides scenario elements such as trees, buildings, and hills.
- Motion platforms: Some simulators even feature motion platforms, enhancing the sense of realism during simulation.

Driving simulators enable the evaluation of various driving performance metrics within a controlled, reasonably realistic, and safe driving environment. However, driving simulators differ significantly in their features, which can influence their realism and the validity of the obtained results (Papantoniou et al., 2017). Fidelity pertains to the level of realism present in the virtual environment. There are high-fidelity and low-fidelity simulators. Low-fidelity simulators offer basic visual and auditory feedback without motion cues, making them suitable for simple training and preliminary research. High-fidelity simulators provide immersive experiences with detailed graphics, realistic sounds, and motion feedback. They are used for advanced driver training and research on driver behavior and vehicle dynamics. For example, a study on a high-fidelity driving simulation platform focused on developing and validating advanced driver assistance systems (Grottoli et al., 2020). The more a simulator replicates real-world driving regarding the design and arrangement of controls, the realism of the visual scene, and its physical response characteristics, the higher the fidelity it is considered to have (Godley et al., 2002). Simulator validity usually refers to the extent to which behavior in a simulator matches behavior in real-world environments under comparable conditions (Kaptein & Theeuwes, 1996).

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3.7 Driving Performance

Driving performance refers to a driver's ability and effectiveness in operating a vehicle. Parameters for assessing driving performance include lateral control, longitudinal control, reaction time, gap acceptance, eye movement, and workload measures (Papantoniou et al., 2017). The potential for driver distraction rises as the number of functions and information services offered by multimodal IVIS (in-vehicle information systems) increases (Ma et al., 2022). Several factors influence driving performance, such as fatigue and physical condition. Distractions like mobile phones and lack of focus can also increase the risk of accidents. External conditions like road and weather conditions, as well as the state of the vehicle, can affect the driver. Additionally, driving skills and adherence to traffic regulations play a significant role in driving performance. The relationship between driving performance and safety is direct and significant. Improved driving performance generally correlates with enhanced safety, as it indicates better control of the vehicle and reduced driver distraction.

3.8 Device Assessment Questionnaire

The Device Assessment Questionnaire (DAQ) is included in ISO 9241-9 as part of the comprehensive qualitative evaluation. ISO 9241-9 provides requirements and recommendations for designing non-keyboard input devices that have sufficient published ergonomic information. This standard applies to various non-keyboard input devices for stationary use, such as mice, pucks, joysticks, trackballs, tablets and overlays, touch-sensitive screens, styli, and light pens, offering ergonomic design guidance for these devices used in typical office tasks. It takes into account users' limitations and capabilities (EN ISO 9241-9, 2000). The DAQ comprises 12 questions related to the comfort and effort levels involved in operating the system. It uses a 5-point interval scale to measure responses and is suitable for within-group or between-group comparisons (EN ISO 9241-9, 2000). The DAQ assesses several aspects, including operation, fatigue, comfort, and overall usability. It can evaluate a single input device or multiple devices being

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investigated simultaneously, with users rating each scale item to determine which device performs better than the others (Faturohman, 2022).

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CHAPTER 4
METHODS

4.1 Participant

The experiment involved 15 participants, consisting of 13 Indonesians and 2 Taiwanese, with a gender distribution of 7 males and 8 females. They came from different majors, including computer science, electric engineering, and industrial management, and their ages were between 22 and 30 years old (mean of age 24.7 ± 1.9 years old). Participants were required to have a valid driver's license, experience in driving, and familiarity with the use of the In-Vehicle Information System. All participants are used to driving and have had a driving license for more than two years. All participants were experienced drivers and had held a driving license for more than four years (mean of driving experience was 4.4 ± 2 years). Familiarity meant understanding IVIS features and functions like navigation and entertainment, and being able to distinguish basic icons such as music logos. Participants who were familiar with IVIS were identified based on a questionnaire that asked whether they were accustomed to using IVIS or not. It also included understanding touchscreen gestures like tapping and swiping. Participants provided information about their age, gender, experiences with touch-screen devices, and driving experience. Based on the statistical power calculation using a within-subject design with six measurements, the analysis determined that a minimum total sample size of 8 participants is sufficient. This sample size achieves an actual statistical power greater than 95%, ensuring a high likelihood of detecting significant effects if they exist within the data.

4.2 Environment and Devices

The use of driving simulators including car seats, seat belts, supporting devices for the screen are shown in Figure 4.1. The driving simulator utilized a city scenario and its parameter settings are listed in Figure 4.2. The type of car used was

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a Fiat 500 (city car), and the traffic conditions were shown in Figure 4.3, featuring traffic lights but no pedestrians. Accidents were primarily triggered by collisions between cars, especially when turning.

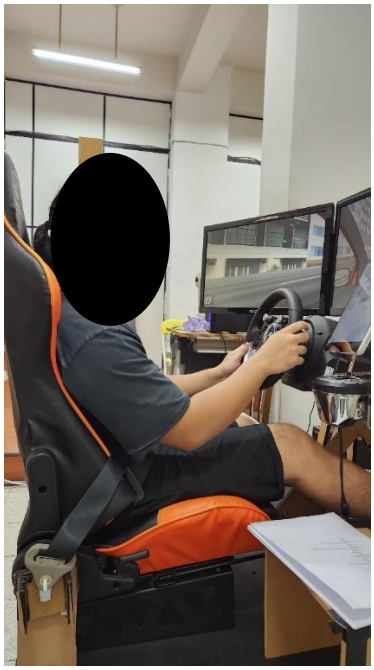


Figure 4.1 Driving Simulator Environment



Figure 4.2 Selected View in Driving Simulator

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Figure 4.3 City View in Driving Simulator

Figure 4.4 shows the interface displayed on a Surface notebook used as the simulated IVIS. The single-touch operation for the air conditioner is illustrated. At the top, a fan icon with levels (e.g., Fan 2) indicates the speed of the air conditioner fan, with higher numbers representing higher fan speeds. Below the fan icon, the "+" and "-" buttons serve as fan controls to adjust the fan level, with "+" increasing and "-" decreasing the fan speed. Below these buttons, a display shows the current temperature. At the bottom, a temperature slider allows the user to drag or tap to adjust the temperature setting. This slider has already been used in papers published by (Lin & Chiang, 2017; Faturohman, 2022). On the right, airflow direction icons for "Head", "Body", and "Feet" direct the airflow to specific parts of the car. Selecting "Head" directs air to the upper vents, "Body" to the mid-level vents, and "Feet" to the lower vents.

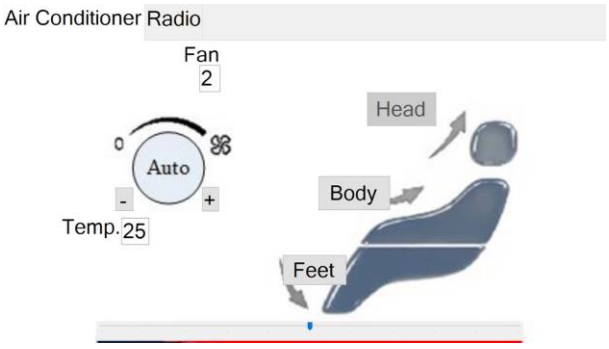


Figure 4.4 Interface Display of Air Conditioner Setting in Single-touch

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In Figure 4.5, the radio interface for single-touch operation is shown. The frequency slider above the "FM" and "AM" buttons allows the user to drag or tap to adjust the radio frequency. This slider has already been used in papers published by (Lin & Chiang, 2017; Faturohman, 2022). The frequency display (e.g., 96 MHz) with buttons labeled "FM" and "AM" enables the user to switch between FM and AM radio bands and set the desired frequency. Volume control buttons labeled "Vol. Up" and "Vol. Down" adjust the radio volume, with "Vol. Up" increasing and "Vol. Down" decreasing the volume. Preset buttons labeled "1", "2", "3", and "SET" allow the user to set and select preset radio stations for quick access.



Figure 4.5 Interface Display of Radio Setting in Single-touch

In Figure 4.6, the multi-touch operation on the air conditioner interface was shown. At the top, there was a display fan icon with levels (e.g., Fan 5) which indicated the current fan speed. Higher numbers indicated higher fan speeds. This could be controlled using a multi-touch gesture, such as pinching to reduce the speed or expanding to increase the speed with two fingers. There was also a temperature display that showed the current temperature setting of the air conditioner (e.g., Temp 25). A circular button labeled "Auto" automatically adjusted the fan speed and temperature settings based on the desired climate control conditions when the center of the red circular feedback was located inside the “Auto” area. On the right, there were airflow direction icons for "Head," "Body," and "Feet," which directed the airflow to specific parts of the car. Using multi-touch gestures, users could select the desired airflow direction. For example, pinching or

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spreading fingers on the "Head," "Body," or "Feet" icons directed air to the upper vents, mid-level vents, or lower vents, respectively.

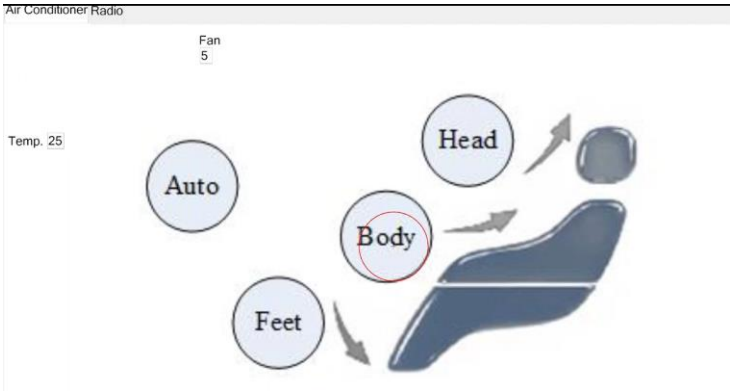


Figure 4.6 Interface Display of Air Conditioner Setting in Multi-touch

In Figure 4.7, the multi-touch operation on the radio interface was displayed. At the top, there was a frequency display (e.g., 105 MHz) which showed the current radio frequency. Then, there was a volume display level (e.g., Volume 4) which indicated the current volume level of the radio. The multi-touch interaction area consisted of a blank space (highlighted by the circle) and was used for multi-touch gestures to control the radio frequency and volume. Top for Mhz bands and bottom for Khz bands. For example, if the user wanted to increase the frequency, they would slide the pinch to the right. Similar gestures could be used to adjust the volume level. The larger the pinch, the greater the volume.

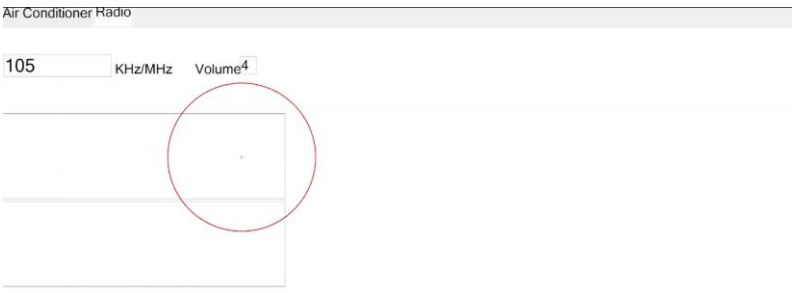


Figure 4.7 Interface Display of Radio Setting in Multi-touch

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4.3 Experimental Design

The experimental design for this study involves testing the effects of two independent variables, touch scheme (single-touch and multi-touch) and display height (low, middle, and high), on multiple dependent variables: task completion time, driving safety (accident rate), error rate, and subjective responses (comfort and fatigue indices). A within-subject design was employed, where each participant experienced all combinations of the independent variables like shows in Table 4.x. Participants performed representative IVIS tasks, such as change temperature of air conditioner and radio frequency, in a controlled driving simulation to replicate real-world conditions. Quantitative data, including task duration, error rates, and accident occurrences, were recorded, while qualitative data were gathered through post-task questionnaires. The analysis focused on identifying both the main effects of each independent variable and their interaction effects, ensuring insights into usability and safety outcomes for different touch schemes and display heights.

Table 4.1 Experimental Design

Touch Scheme	Display Height		
	Low	Middle	High
Single-touch	✓	✓	✓
Multi-touch	✓	✓	✓

4.4 Experimental Task

Participants were required to drive according to a given route while performing air conditioner and radio setting operations. The route consisted of driving on main roads, with requirement to follow traffic regulations such as stopping at red traffic lights, using turn signals before turning, and staying within lane boundaries. The route included several specific scenarios. Participants began by driving straight and crossing an intersection. At the first T-junction, they turn right and immediately perform the first operation on the screen. Continuing straight, they reach another intersection, turn right again, and perform the second screen operation. If they encounter a red traffic light, participants must stop; once the light

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turns green, they proceed to cross the intersection. After crossing the intersection, they turn left at another T-junction and perform the third screen operation. Finally, participants encounter another T-junction, turn left, and immediately perform the fourth screen operation after the turn. This structured route ensured that participants experience a variety of driving scenarios while interacting with the IVIS, providing a comprehensive assessment of how these tasks impact driving performance and compliance with traffic regulations. Participants did 4 screen operations in one route. Two single-touch (AC and radio) and two multi-touch (AC and radio). For the experimental model shows in Figure 4.8 below.

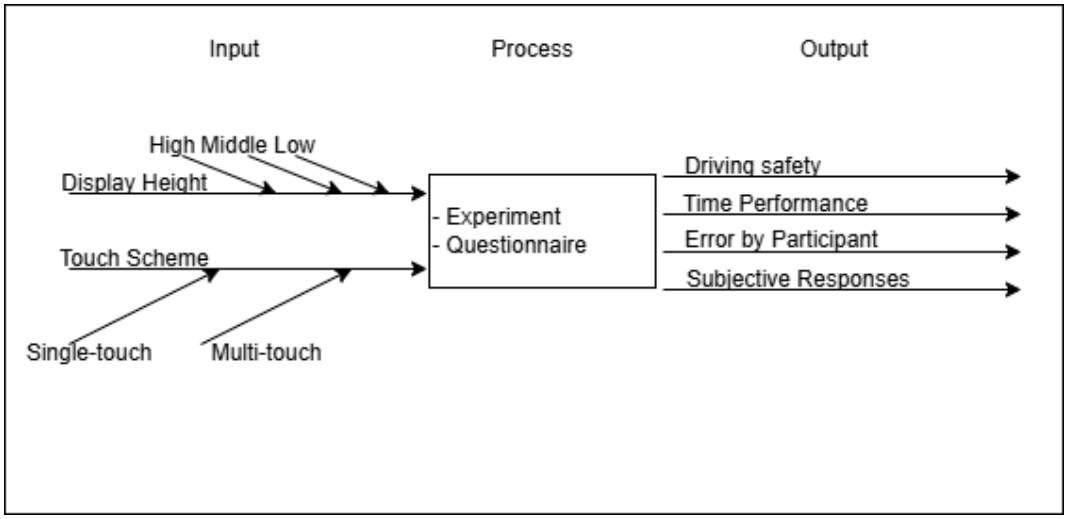


Figure 4.8 Experimental Model

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4.4.1 Type of Display Height

Figure 4.9 until 4.12 shows an illustration of three display height, an explanation of the installations is below.

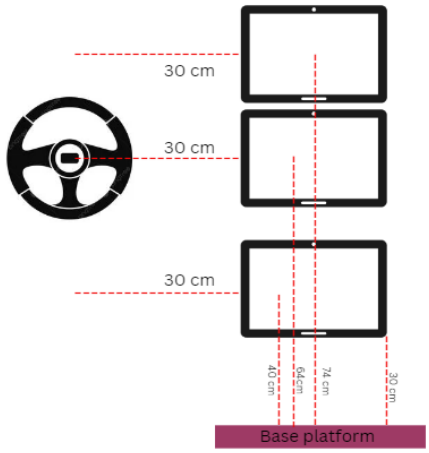


Figure 4.9 Graph Illustrating of Display Height



Figure 4.10 High Installation 3D



Figure 4.11 Middle Installation 3D

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Figure 4.12 Low Installation 3D

1. High Installation

The highest installation was aligned with the driver's eye level when seated, because the participants from Indonesia and Taiwan so the average of eye level based on Indonesia and Taiwan. According to the Japan Automobile Manufacturers Association (JAMA) Guidelines for installing display screens in vehicles, a display system must not interfere with the operation of the steering mechanism or obscure the driver's view of essential meters. Additionally, the display system should not obstruct any part of the driver's visual field necessary for safe driving. The control section of a display system should not be positioned in a way that significantly disrupts the driver's posture when operating it.

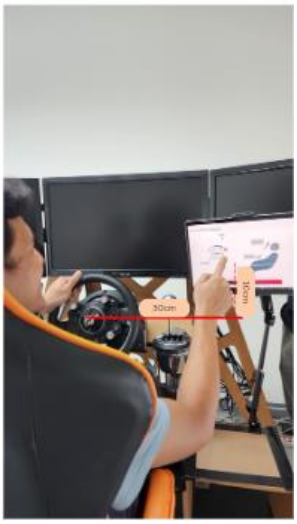


Figure 4.13 High Installation

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2. Middle Installation

This installation was located centrally, aligned with the steering wheel. According to the JAMA Guidelines for In-Vehicle Display Systems, the placement of the display screen in a vehicle should be within the limit between eye level and the line connecting the eye to the center of the display screen, with an inclination of less than 30º.

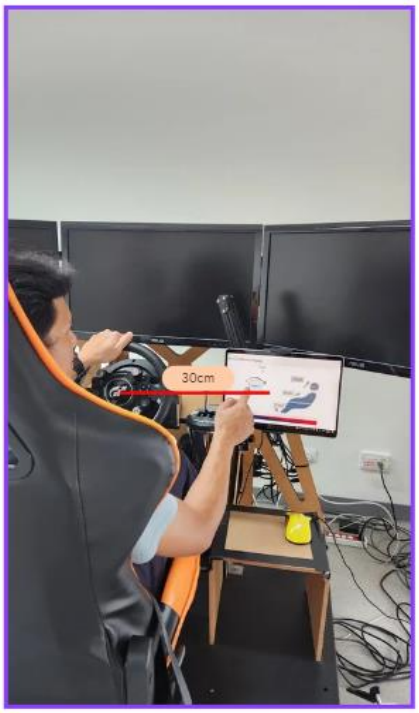


Figure 4.14 Middle Installation

3. Low Installation

This installation was positioned at the lowest point, aligned with the gear shift. For the low installation, the measurement was based on the average seated elbow height. Participants were from Indonesia and Taiwan, the anthropometric data used were the averaged value from both countries. The anthropometric data based on (Indonesia, 2013) and (Wang et al., 2002). The purpose of this low installation was to minimizing biomechanical effort by eliminating shoulder and arm elevation, allowing the driver to keep one hand resting or on the gear shift.

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Figure 4.15 Low Installation

4.4.2 Type of Touch Scheme

The experimental task was intended to study the impact of using touchscreens to operate air conditioner and radio systems in driving because, in modern vehicles, these functions are ubiquitous and frequently used. Thus their operation is essential to understand how screen-based interfaces affect driver behavior and safety. The display of single-touch scheme is shown in Figure 4.16 and Figure 4.17 below.

1. Single-touch Scheme

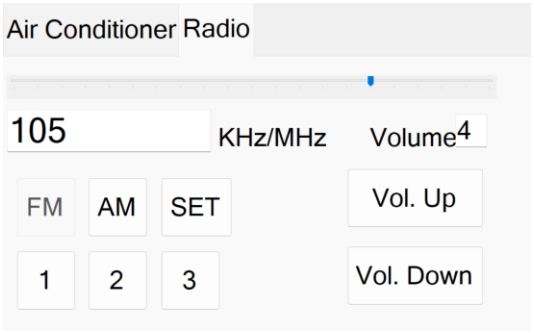


Figure 4.16 Air Conditioner for Single-touch Scheme

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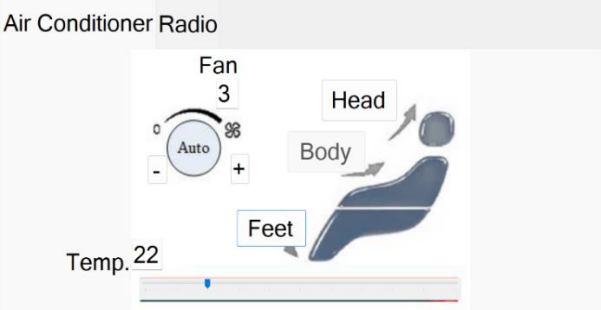


Figure 4.17 Radio Setting for Single-touch Scheme

In Figure 4.18 the steps for operating the radio with a touch screen are as follows: First, select FM/AM as instructed. Then, choose the radio frequency by dragging with one finger on the available frequency dots. To increase or decrease the volume, click on "vol up" or "vol down"; each click changes the volume by one unit, so to increase the volume by two units, you need to click "vol up" twice. For operating the air conditioner with a single-touch, click once on the area you want to select (head/body/feet). Then, choose the air conditioner temperature by dragging with one finger on the available temperature dots. To increase or decrease the fan level, click the "+" or "-" sign; each click changes the fan level by one unit, so to decrease the fan level by two units, you need to click the "-" sign twice.

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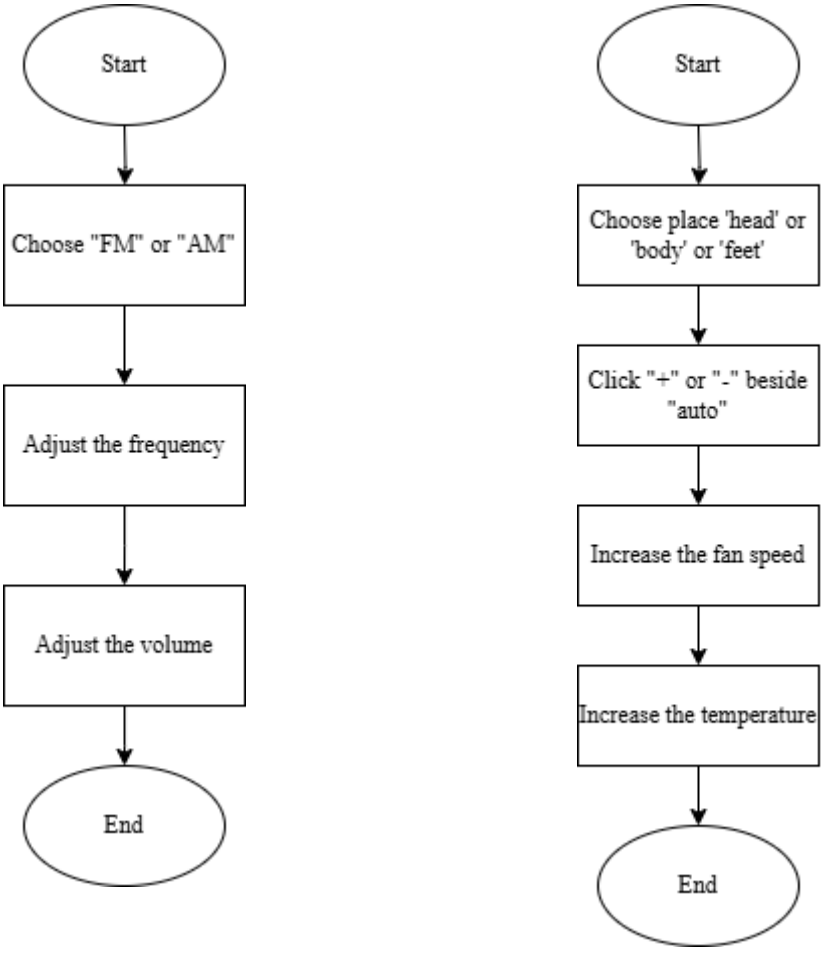


Figure 4.18 Flowchart for Radio and Air Conditioner Scheme of Single-touch

2. Multi-touch Scheme

The next operation was multi-touch. Figures 4.19 and 4.20 showed the display of multi-touch scheme for the air conditioner and radio.



Figure 4.19 Radio Setting for Multi-touch Scheme

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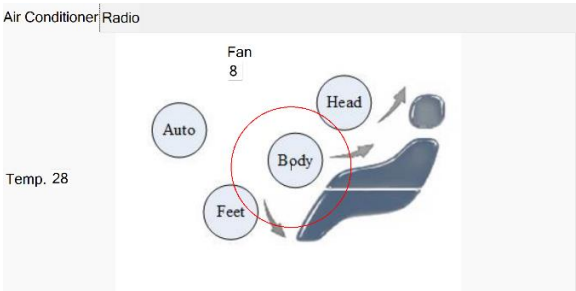


Figure 4.20 Air Conditioner Setting for Multi-touch Scheme

In Figure 4.21 the steps for operating the radio with multi-touch were as follows: First, use a pinch gesture with two fingers in the designated box area (top for FM, bottom for AM). Moving to the left decreases the frequency, while moving to the right increases it. For volume control, also use a two-finger pinch gesture; the smaller the circle, the lower the volume. If you want to change to a lower frequency but have a higher volume, make a pinch gesture to the left with a larger circle. For operating the air conditioner with multi-touch, make a pinch gesture with two fingers in the designated area (head/body/feet). The larger the circle, the higher the temperature and fan level. If the circle is smaller, the temperature and fan level will be lower. The difference between the flow in Figure 4.18 and Figure 4.21 is that single-touch scheme requires sequential steps to individually adjust each setting. Overall, the multi-touch scheme is designed for efficiency, allowing simultaneous adjustments and reducing the time required to complete tasks.

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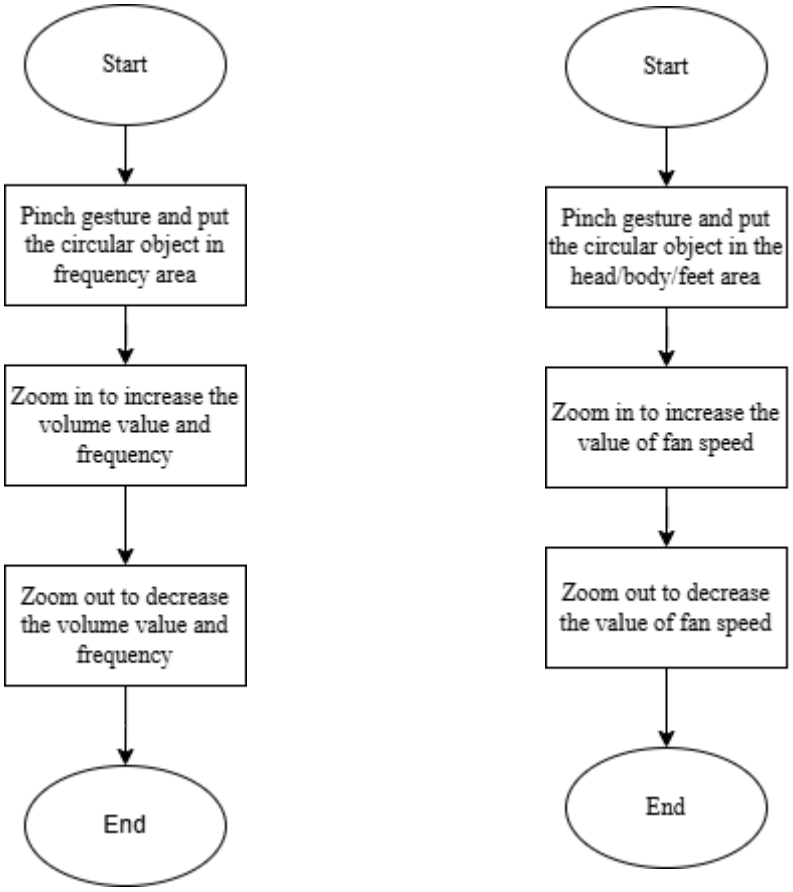


Figure 4.21 Flowchart for Radio and Air Conditioner Scheme of Multi-touch

4.5 Driving Safety

Driving safety is a crucial metric for evaluating driving performance. It is measured by counting the number of errors committed by the driver, including incidents such as collisions with other vehicles, driving off the road, or failing to obey traffic signals. The assessment was conducted manually using a screen recorder to tally the number of accidents participants experienced along the route, particularly during screen operations. Drivers are provided with instructions and a route map to follow.

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4.6 Time Performance

Time performance measured the duration required for drivers to operate the touch screen according to the instructions given by the researcher. The shorter the time taken to complete the tasks, the higher the efficiency. Time performance was calculated from the moment the driver or participant touched the screen to when they lifted their finger after completing the final task. For instance, in a single-touch operation, a participant might be instructed to set the air conditioner to body area mode, with a fan speed of 4 and a temperature of 25. This involves steps such as clicking the "body" button, pressing the "+" button until the fan speed reads 4, and sliding the temperature bar to 25.

4.7 Error by Participants

Errors by participants are counted to measure the number of mistakes made while interacting with the screen. For example, if a participant was instructed to set the air conditioner to body area mode with a fan speed of 4 and a temperature of 25 in a single-touch operation, but instead set it to the "head" area with a fan speed of "6", this would be recorded as an error. Errors are calculated based on actions or clicks that do not match the given instructions.

4.8 Subjective Responses

Subjective responses were measured by user satisfaction and perceived ease of use. To gather these subjective responses, this study employed the DAQ and conducted interviews. The subjective response data utilized in this study includes the following:

4.8.1 Device Assessment Questionnaire Data

The DAQ was used to collect subjective response data. All participants were asked to complete the questionnaire as a subjective response to the experiments.

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4.8.2 Interviews

To strengthen subjective responses from participants, preference interviews were conducted to collect qualitative opinions in depth from participants. Questions I asked participants:

1. Which one do you choose for the type of touch scheme? Why?
2. Which one do you choose for display height of screen? lim?

Figure 4.22 shows the research step of this study. Start from identify the problem research. After that, write for the proposal research and prepare all of equipment like the driving simulator (check the application of simulator, and record application). The screen is also thing that needs to be prepared, the UI is already available from previous research but it still needs to be ensured that the scale is appropriate. After ensuring that everything is in accordance, a pilot test is conducted by the researcher. If the pilot test is good enough, then the experiment and data collection are continued. However, if during the pilot test there is something lacking in the equipment, then improvements are made to the equipment. After data collection, calculations or data testing are carried out using statistical tests of normality, ANOVA, Chi Squared, Wilcoxon Test, and Friedman Test and then included in the results and discussion.

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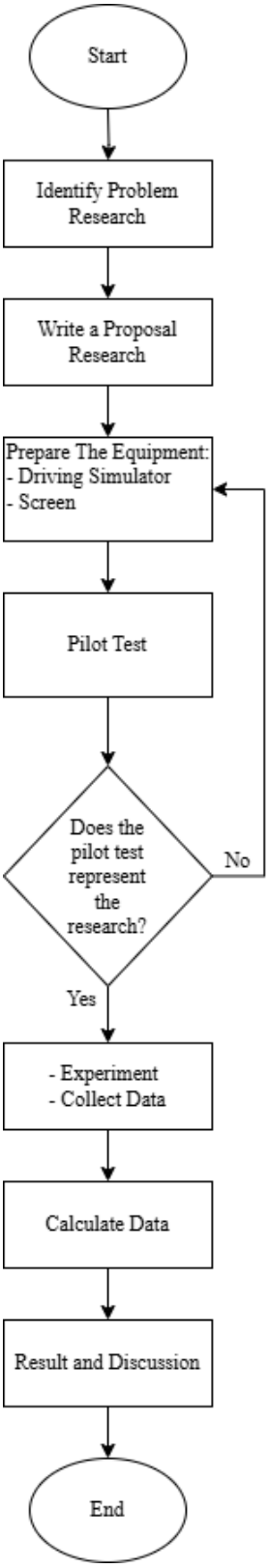


Figure 4.22 Research Step

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Figure 4.23 shows the experimental procedure beginning with an introduction and trial session for the participants, ensuring familiarity with the setup. Following this, a pre-questionnaire was administered. Participants then engaged in the first driving task, which involved interacting with the screen across three different display height (low, middle, and high), each requiring two IVIS tasks on a touchscreen. This was followed by a second driving task, replicating the same structure. After completing both rounds of driving tasks, participants filled out a device assessment questionnaire and performance metrics were recorded, including accident rate, performance time, and error rate. The procedure concluded with data collection for analysis, aiming to evaluate the impact of the display height and the touch scheme on user comfort and task efficiency.

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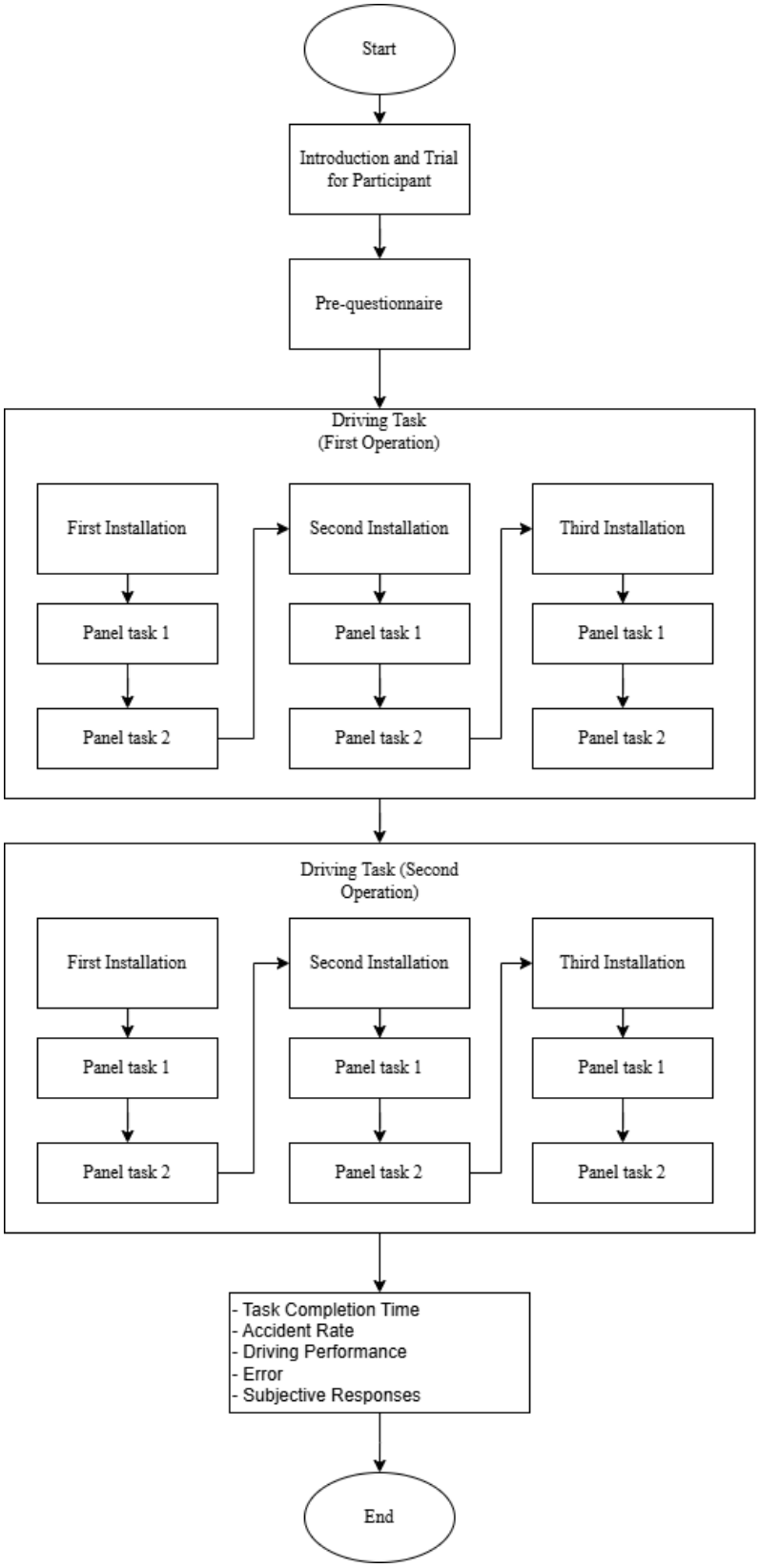


Figure 4.23 Experiment Flowchart

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CHAPTER 5
RESULT AND DISCUSSION

5.1 Task Completion Time

With 15 participants, all of them operated the screen either single-touch or multi-touch, as well as with different display heights. A shorter time required by participants to complete the task indicates higher efficiency, reducing the time spent on tasks such as interacting with an In-Vehicle Information System (IVIS) minimizes the distraction from primary activities, like keeping eyes on the road and hands on the wheel. Figure 5.1 shows the main effect plot of the display height and task operation device on task completion time.

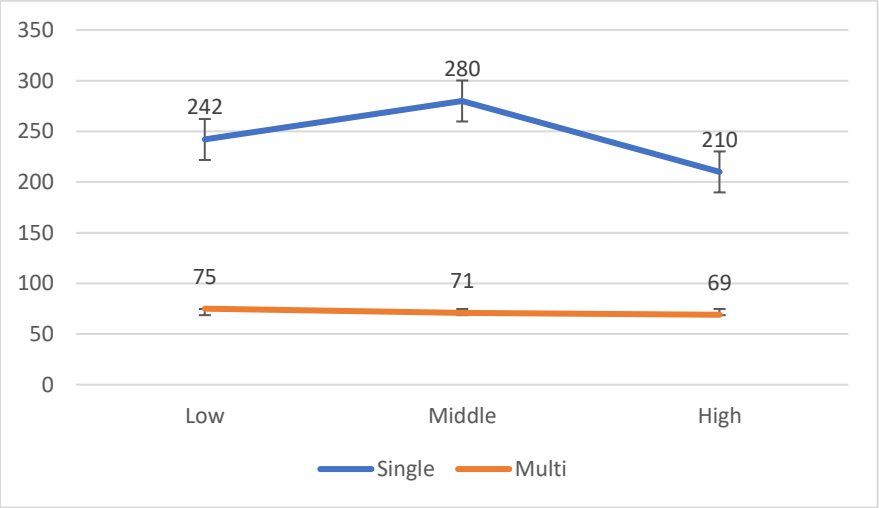


Figure 5.1 Time of Task Completion Time

The task completion time was analyzed using an ANOVA (Analysis of Variance), taking into factors of touch scheme types, installation levels. As presented in Table 5.1 ANOVA Result in Task Completion Time. It is shown that the p-value is less than 0.05, indicating that the differences in touch scheme have a significant effect on task completion time. Also for the p-value's of task is less than 0.05, indicating that the differences in task operation device (air conditioner and radio) have a significant effect on task completion time. But for the display height the p-value is more than 0.05, indication that the differences in display height level no significant effect. For interaction, p-value more than 0.05 indicating combination

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of touch scheme and display height does not significantly affect task completion time.

Table 5.1 ANOVA Result in Task Completion Time

Source	DF	F-Value	P-Value
Touch Scheme	1	207.69	<0.001
Display Height	2	2.28	0.106
Touchscheme*height	2	2.1	0.120

5.2 Errors by Participants

Participant error was assessed by the number of errors committed when carrying out screen operations as instructed. The number of errors by participants were analyze a using Wilcoxon Signed Rank Test for touch scheme and Friedman Test for display height level. The result is shown at Table 5.2 below. All p-values are more than 0.05, indicating there is no significant effect of touch scheme type and display height level on errors by participant. For interaction, p-value more than 0.05 indicating combination of touch scheme and display height does not significantly affect error by participants.

Table 5.2 Result of Error by Participant

Source	Test	DF	Sig
Touch Scheme	Wilcoxon Signed Rank Test	1	0.307
Display Height	Friedman Test	2	0.918
Low Installation * Single touch	Wilcoxon Signed Rank Test	1	0.502
Low Installation * Multi touch	Wilcoxon Signed Rank Test	1	0.491
Middle Installation * Single touch	Wilcoxon Signed Rank Test	1	0.870
Middle Installation * Multi touch	Wilcoxon Signed Rank Test	1	0.402

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Source	Test	DF	Sig
High Installation * Single touch	Wilcoxon Signed Rank Test	1	0.588
High Installation * Multi touch	Wilcoxon Signed Rank Test	1	0.726

5.3 Number of Accidents

The number of accidents by participants were also analyzed using Wilcoxon Signed Rank Test for touch scheme and Friedman Test for display height level. The result is shown at Table 5.3 below. All p-values are more than 0.05 so indicating there is no significant effect of touch scheme type and display height level on number of accidents. For interaction, p-value more than 0.05 indicating combination of touch scheme and display height does not significantly affect number of accidents.

Table 5.3 Result Number of Accident

Source	Test	DF	Sig
Touch Scheme	Wilcoxon Signed Rank Test	1	0.131
Display Height	Friedman Test	2	0.401
Low Installation * Single touch	Wilcoxon Signed Rank Test	1	1.000
Low Installation * Multi touch	Wilcoxon Signed Rank Test	1	0.180
Middle Installation * Single touch	Wilcoxon Signed Rank Test	1	0.134
Middle Installation * Multi touch	Wilcoxon Signed Rank Test	1	1.000
High Installation * Single touch	Wilcoxon Signed Rank Test	1	0.317

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Source	Test	DF	Sig
High Installation * Multi touch	Wilcoxon Signed Rank Test	1	0.617

5.4 Driving Performance

In Table 5.4 ANOVA for driving time is shown. The p-value of the installation factor was greater than 0.05 so this indicates no significant effect between different display height levels on driving time.

Table 5.4 ANOVA Driving Time

Source	DF	F Value	p-value
Display Height	2	0.2	0.821

5.5 Subjective Responses

5.5.1 The Device Assessment Questionnaire

The Device Assessment Questionnaire is a tool used to evaluate the device in terms of comfort and the fatigue it causes. The following are the results of the questionnaire for general comfort and fatigue.

5.1.1.1 General Comfort

Figure 5.2 shows the average scores of general comfort from a subjective questionnaire evaluating single-touch and multi-touch interactions across three different display height levels (low, middle, and high). Table 5.5 shows the results of the non-parametric test on the effect of the type of touch scheme and display height on the general comfort. The significance values for touch scheme were less than 0.05, indicating that there was a significant difference between the single-touch and multi-touch operations on the general comfort but for the display height were more than 0.05 so that indicating that there was no significant different between the display height level on the general comfort. For p-value less than 0.05 there is only interaction between low installation and single touch indicating there is any

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interaction. In addition, the results of the interaction are more than 0.05 which means it does not show interaction.

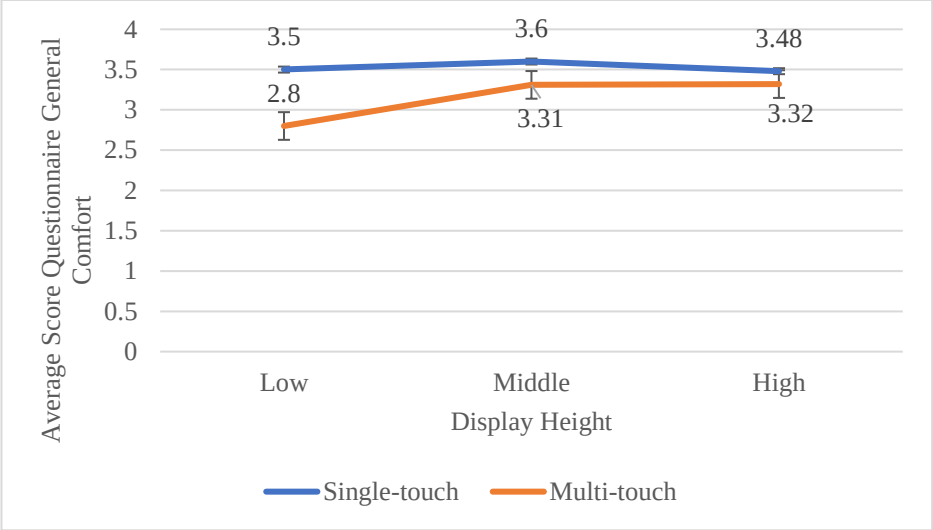


Figure 5.2 Average Score of Questionnaire for General Comfort

Table 5.5 Non-Parametric Test for General Comfort Questionnaire

Source	Test	DF	Sig
Touch Scheme	Wilcoxon Signed Rank Test	1	<0.001
Display Height	Friedman Test	2	0.371
Low Installation * Single touch	Wilcoxon Signed Rank Test	1	0.045
Low Installation * Multi touch	Wilcoxon Signed Rank Test	1	1.000
Middle Installation * Single touch	Wilcoxon Signed Rank Test	1	0.327
Middle Installation * Multi touch	Wilcoxon Signed Rank Test	1	0.267
High Installation * Single touch	Wilcoxon Signed Rank Test	1	0.267

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Source			Test		DF	Sig
High Multi touch	Installation	*	Wilcoxon Rank Test	Signed	1	0.690

5.5.1.2 Fatigue

Figure 5.3 shows the average scores of fatigue from a subjective questionnaire evaluating single-touch and multi-touch interactions across three different display height levels (low, middle, and high). Table 5.6 shows the results of the non-parametric test on the effect of the type of touch scheme and display height on the fatigue score. The significance values for touch scheme and display height were less than 0.05, indicating that there was a significant difference between the single-touch and multi-touch operations and different display height level on fatigue level. For p-value less than 0.05 there is interaction between low installation with single touch, middle installation with multi touch and high installation with single touch indicating there is any interaction. In addition, the results of the interaction are more than 0.05 which means it does not show interaction.

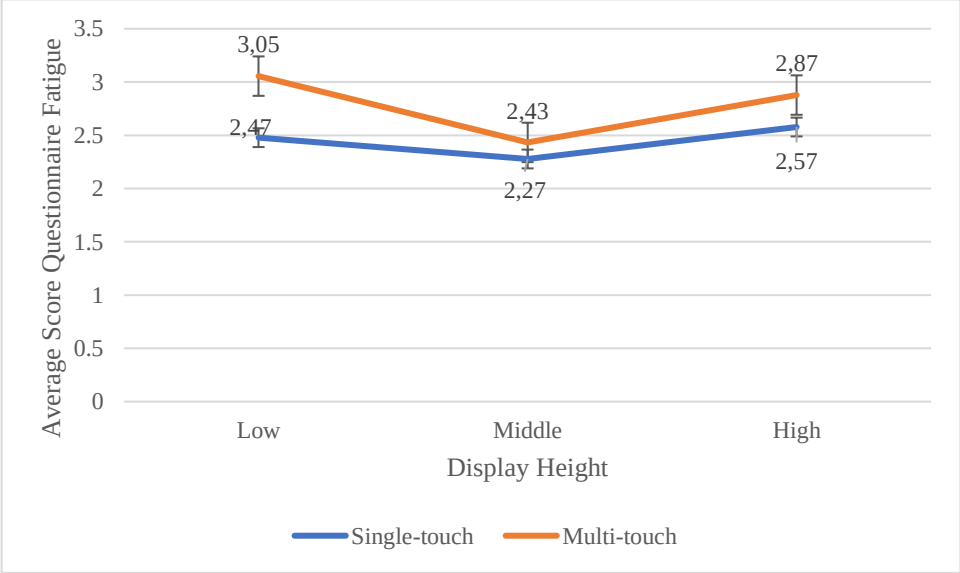


Figure 5.3 Average Score of Questionnaire for Fatigue Level

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Table 5.6 Non-Parametric Test for Fatigue Questionnaire

Source	Test	DF	Sig
Touch Scheme	Wilcoxon Signed Rank Test	1	<0.001
Display Height	Friedman Test	2	0.002
Low Installation * Single touch	Wilcoxon Signed Rank Test	1	0.038
Low Installation * Multi touch	Wilcoxon Signed Rank Test	1	0.424
Middle Installation * Single touch	Wilcoxon Signed Rank Test	1	1.000
Middle Installation * Multi touch	Wilcoxon Signed Rank Test	1	<0.001
High Installation * Single touch	Wilcoxon Signed Rank Test	1	<0.001
High Installation * Multi touch	Wilcoxon Singed Rank Test	1	0.523

5.5.2 Interview

a. Which one do you choose for the type of touch scheme?

Figure 5.4 shows a total of 10 participants preferred single-touch operation compared to multi-touch. They chose it because it was familiar and could be done without looking, no need to guess whether the desired temperature or radio frequency was appropriate even though it took longer. Meanwhile, 5 other participants chose multi-touch considering the shorter time required. The results of the goodness of fit test are shown in Table 5.7 below. The Chi-square test results indicate that the type of touch scheme (single-touch and multi-touch) does not have a statistically significant impact on the participant's choices. In other words, the

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participants' preferences are not significantly influenced by the different touch scheme types, as evidenced by the high p-value of 0.197.

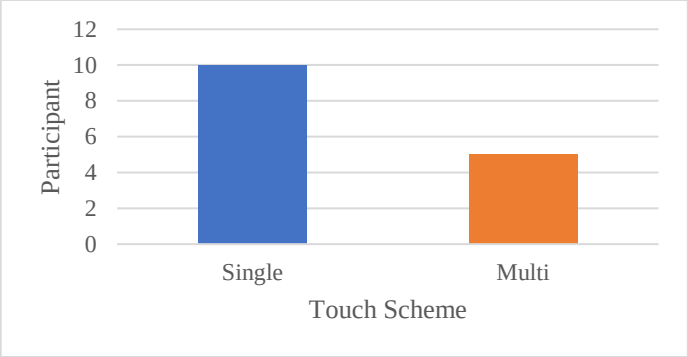


Figure 5.4 Subjective Response by Interview based on Touch Scheme

Table 5.7 X^2 Goodness of Fit Test Interview of Touch Scheme

Chi-square Test	Value
Chi-square	1.667
df	1
Sig	0.197

b. Which one do you choose for display height of screen?

In Figure 5.5 display height, participants rated the middle installation slightly higher than the high and low installations, but the differences are not substantial. This suggests that while there might be minor preferences, the overall experience provided by each installation level is relatively similar. The middle installation is at an optimal position where it is easily accessible without requiring significant hand movement. The reason why they did not like the other two were that high installation needs more hand movement and that low installation could be difficulty to view or reaching the control of the screen. The results of the goodness of fit test can be found in Table 5.8 below. The Chi-square test results indicate that the display height type (high, middle, low) does not have a statistically significant impact on the participants' choices. In other words, the participants' preferences are not significantly influenced by the different display height types, as evidenced by the high p-value of 0.819.

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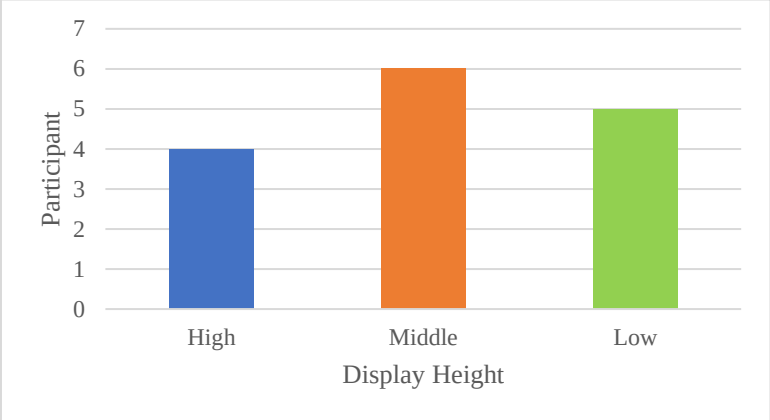


Figure 5.5 Subjective Response by Interview Based on Display Height

Table 5.8 X^2 Goodness of Fit Test Interview of Display Height

Chi-square Test	Value
Chi-square	0.400
df	2
Sig	0.819

5.6 Discussion

Based on the results obtained from several response variables such as task completion time, number of error by participant, number of accidents, and driving time, the type of display height did not significantly impact any of them. Similarly, the mode of screen operation did not have any significant effects on operation error, number of accidents, and driving despite suspicious interaction Figure 4.1. However, the mode of screen operation had a significant effect on operation time, with participants operating the multi-touch screen much faster comparing to the single-touch one. As found in previous research (Cohen-Lazry & Borowsky, 2020), multi-touch interfaces demanded less visual attention from drivers, enabling them to complete tasks more quickly and with fewer distractions. This increased speed was due to the ability of multi-touch to perform multiple actions simultaneously. For example, when operating the air conditioner, participants could adjust both temperature and fan speed at the same time by pinching. The same applied to radio

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operation, where participants could change frequency and volume simultaneously. If a higher frequency is needed, a pinch to the right is used, and to increase volume, the pinch circle is made larger. Therefore, if a driver wants a higher frequency but a lower volume, they should pinch more to the right with a smaller circle. This demonstrates that multi-touch operation is significantly more efficient for time performance, particularly for tasks requiring simultaneous adjustments. However, it should be noted that the task given for multi-touch was simpler compared to single-touch. For example, in single-touch, participants were instructed to increase the frequency band by 5 and the volume by 2, whereas in multi-touch, they were only instructed to increase the frequency. Therefore, the advantage of multi-touch in time efficiency should be concluded with caution that precision requirements could affect performance in multi-touch operations.

Subjective responses were obtained from a questionnaire regarding general comfort and fatigue, followed by brief interviews with the participants. For general comfort, participants predominantly preferred single-touch operation, stating it was more comfortable and did not cause fatigue in the fingers, wrists, arms, shoulders, neck, or eyes. Similarly, in the interviews, 10 out of 15 participants favored single-touch operation, explaining that they were more accustomed to it and did not need to estimate the extent of gestures required on the screen to change the temperature or frequency, as they would with multi-touch. However, the 5 participants who preferred multi-touch cited that it was simpler and saved time because it could do tasks at the same time.

The research findings the installation type (high, middle, low) and device type did not significantly impact the number of errors, number of accidents, or overall driving performance. These results contrast with previous studies, such as (C.-J. Lin & Chiang, 2017), which found significant differences based on installation and device type. Participants in the current study may have been more familiar with the IVIS interfaces used because they got the trial, while a brief practice session might help participants familiarize themselves with the controls, it does not fully replicate the long-term use and adaptation that might occur in everyday driving. Leading to less variation in performance and subjective ratings across different installation

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types and devices. Familiarity with the system can mitigate the impact of installation height and device complexity. The driving task and IVIS designed to be straightforward. In a real-world driving context, where visual attention is paramount. The driving tasks likely increased the visual demand, making the top installation more advantageous because it aligns better with the driver's natural line of sight, thereby reducing the frequency and duration of eye movements away from the road.

Based on the subjective and objective evaluations, the results reveal differing preferences and performance outcomes. In the objective testing, one indicator that task completion time showed that the multi-touch scheme was more efficient than single-touch. However, subjective responses from three categories indicated a clear preference for single-touch. Participants favored single-touch, citing it as more user-friendly, likely because they were less accustomed to using multi-touch interfaces. Therefore, while multi-touch may offer faster task completion, single-touch remains more favorable overall due to participants' familiarity and comfort with the interface.

This study has several limitations that should be acknowledged. One key limitation is the lack of comparison between the display height levels (low, middle, high) and those used in actual vehicle models from various car brands. Consequently, the application of the "high" display height may not accurately reflect existing In-Vehicle Information System (IVIS) designs. In the real world, several brands place IVIS systems above the centre of steering wheel, and this study considers the area of vision. This study used the left steer on the vehicle, it was assumed that participants were accustomed to using the left drive because they had been given a trial, but there was no performance measurement during the trial using the left steer. Additionally, there is a disparity in the UI button designs for single-touch and multi-touch schemes, where single-touch uses a square design, and multi-touch uses a circular one because adopting screen designs based on prior studies. In this research, driving performance measurement is only on the difference in display height because one route only covers one height or installation. In one route, participants undergo all touch schemes. Likewise, the slider feature for changing

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the temperature and radio frequency is not yet standard for real cars. Future research should aim to establish consistency in screen design to ensure more reliable comparisons across different touch schemes and consider for the real measure of high installation.

Additionally, the tasks assigned to participants, such as adjusting the air conditioner and radio, may not cover the full range of interactions that drivers typically engage in with In-Vehicle Information Systems. IVIS tasks can vary widely, including navigation, phone calls, messaging, and entertainment controls, each of which may pose different levels of cognitive and visual demands on the driver.

In addition, the controlled environment in which this research was conducted may not fully reflect real-world driving conditions, where drivers face dynamic and unpredictable scenarios such as pedestrians, even though the driving scenarios currently used by researchers relate to conditions on the road city but there are only cars. In this study, both single-touch and multi-touch operations were utilized on the same screen (rather than using examples of single-touch operations like the buttons on the steering wheel commonly found in current vehicles) due to limitations in the research, time constraints, and available devices.

5.7 Research Benefit

The research offers significant benefits for both academic exploration and practical application in the design and management of in-vehicle infotainment systems. For research, the study enhances understanding of IVIS interactions by providing valuable insights into how different types of screen operations and installation positions affect driver performance and safety. This contributes to the existing body of knowledge on human-computer interaction within vehicle systems. Additionally, the findings offer empirical data that can inform the design of more efficient and user-friendly IVIS, setting the groundwork for future studies focused on optimizing interface design and considering user familiarity and physical ergonomics. For examples a study could involve testing different screen placements

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(e.g., dashboard, center console, head-up display) to determine the most ergonomic positions for reducing neck and eye strain. Also personalize driver interface layout (e.g., positioning of frequently used controls) impacts their driving performance and comfort. For managerial purposes, the research can improve product development by guiding the creation of IVIS products that enhance customer satisfaction. It informs strategic decision-making regarding feature prioritization in new IVIS models, emphasizing that multi-touch interfaces can improve time performance without significantly increasing errors or accidents. The research also aids in ensuring safety and compliance with standards and regulations, advocating for the adoption of multi-touch interfaces to reduce operational time and potential distractions.

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CHAPTER 6
CONCLUSION

6.1 Conclusion

This study compares single-touch and multi-touch operations as well as screen installations (high, middle, and low) in vehicles. Using a driving simulator equipped with realistic features like a driver's seat, shift gear, and seatbelt, the research simulates urban driving conditions. The prototype interface, developed in C# using Visual Studio, includes two versions: single-touch and multi-touch, each with air conditioner and radio tasks. Results show a significant impact of operation type on task performance time: multi-touch averaged 2 seconds per task, while single-touch took almost 10 seconds. Despite the longer operation times for single-touch compared to multi-touch, participants still preferred single-touch in the subjective responses due to its ease of use. In the questionnaire results, single-touch was rated as more comfortable and had lower fatigue levels than multi-touch. Collectively, the results from both objective and subjective evaluations indicate that single-touch better than multi-touch.

Display height did not have a significant effect on task completion time, the number of errors by participants, the number of accidents, or driving performance. However, in the subjective questionnaire responses, display height had a significant impact on the fatigue experienced by participants. The lowest fatigue was reported with the middle installation, which was also the most preferred by participants, with six choosing it. The middle installation required less hand movement to operate the screen. Future improvements with standardized icons and simpler gestures could enhance the appeal of multi-touch, reducing the time drivers need to look away from the road.

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6.2 Suggestion for Future Research

There are several things that can be improve for future research, such as:

1. Future studies should employ driving scenarios that closely resemble real-world road conditions, including varying traffic densities, weather conditions, and road layouts.
2. Since the study was conducted using a single type of screen, future research should incorporate a variety of screen designs, sizes, and interaction types used in different vehicle brands and models. This would overcome the limitation of limited screen representation and improve the generalizability of findings to various IVIS implementations.
3. To address the limitation of focusing on limited tasks, future studies should evaluate a broader spectrum of IVIS functionalities, such as navigation systems, multimedia control, and vehicle system settings. This would provide a more comprehensive understanding of how drivers interact with IVIS in diverse contexts.

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APPENDIX

Appendix 1 Pre-Questionnaire

To:

Dear Sir/Madam/Brother/Sister,

I am Fatiha Widyanti, a dual degree master's student in the Department of Mechanical and Industrial Engineering at Gadjah Mada University and the Department of Industrial Management at the National Taiwan University of Science and Technology. I am currently working on my final project and kindly request your participation in completing the attached questionnaire. The information you provide in this questionnaire means a lot to me in completing research entitled "Comparison between Single-touch and Multi-touch Interfaces and Their Installation for In-Vehicle Information System Design"

There are no right or wrong answers in this questionnaire, so please respond truthfully and accurately. Before you begin, please read the provided instructions carefully to ensure proper completion. Based on the applicable code of ethics, this questionnaire is only used for study purposes, all participant information will remain confidential.

Thank you for your time, cooperation, and assistance. I apologize in advance for any errors during the data collection process. Should you have any questions about this research, please feel free to contact me at fatihawidyanti26@gmail.com.

Sincerely,

Fatiha Widyanti

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Appendix 2 Personal Data

Participants' name: _____

Gender: Male/Female

Age: _____ years old

1. How long have you been driving?
    - < 1 year
    - 2 – 5 years
    - > 5 years
2. Do you have a legal drivers' license?
    - Yes
    - No
3. How long have you possessed a driving licence?
    - < 1 year
    - 2 – 5 years
    - > 5 years
4. How often do you drive?
    - Often
    - Sometimes
    - Seldom
5. Do you have any experience using a touch-screen-based interface?
    - Yes
    - No
6. Do you have any experience using a computer?
    - Yes
    - No

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Appendix 3 The Devices Assessment Questionnaire

The Devices Assessment Questionnaire

1. DAQ for single-touch operation
    a. General comfort

No	Question	Scale				
1	The smoothness during the operation of this interface was	Very Rough	Rough	Neutral	Smooth	Very Smooth
2	The effort required for the operation of this interface was	Very High	High	Neutral	Low	Very Low
3	Accurate touching of this interface was	Very Difficult	Difficult	Neutral	Easy	Very Easy
4	Operation speed of this interface was	Very Slow	Slow	Neutral	Fast	Very Fast
5	The general comfort of this interface was good	Very Disagree	Disagree	Neutral	Agree	Very Agree
6	The overall rating of this interface was good	Very Disagree	Disagree	Neutral	Agree	Very Agree

b. Fatigue indices

No	Question	Scale				
1	This interface caused finger fatigue	Very Agree	Agree	Neutral	Disagree	Very Disagree
2	This interface caused wrist fatigue	Very Agree	Agree	Neutral	Disagree	Very Disagree

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No	Question	Scale				
3	This interface caused arm fatigue	Very Agree	Agree	Neutral	Disagree	Very Disagree
4	This interface caused shoulder fatigue	Very Agree	Agree	Neutral	Disagree	Very Disagree
5	This interface caused neck fatigue	Very Agree	Agree	Neutral	Disagree	Very Disagree
6	This interface caused eye fatigue	Very Agree	Agree	Neutral	Disagree	Very Disagree

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The Devices Assessment Questionnaire

2. DAQ for multi-touch operation

   a. General comfort

No	Question	Scale				
1	The smoothness during the operation of this interface was	Very Rough	Rough	Neutral	Smooth	Very Smooth
2	The effort required for the operation of this interface was	Very High	High	Neutral	Low	Very Low
3	Accurate touching of this interface was	Very Difficult	Difficult	Neutral	Easy	Very Easy
4	Operation speed of this interface was	Very Slow	Slow	Neutral	Fast	Very Fast
5	The general comfort of this interface was good	Very Disagree	Disagree	Neutral	Agree	Very Agree
6	The overall rating of this interface was good	Very Disagree	Disagree	Neutral	Agree	Very Agree

   b. Fatigue indices

No	Question	Scale				
1	This interface caused finger fatigue	Very Agree	Agree	Neutral	Disagree	Very Disagree
2	This interface caused wrist fatigue	Very Agree	Agree	Neutral	Disagree	Very Disagree

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No	Question	Scale				
3	This interface caused arm fatigue	Very Agree	Agree	Neutral	Disagree	Very Disagree
4	This interface caused shoulder fatigue	Very Agree	Agree	Neutral	Disagree	Very Disagree
5	This interface caused neck fatigue	Very Agree	Agree	Neutral	Disagree	Very Disagree
6	This interface caused eye fatigue	Very Agree	Agree	Neutral	Disagree	Very Disagree

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Appendix 4 Route Scenario

1. Go straight until the first intersection and still go straight
2. Still go straight
3. T-junction and turn right
4. **Do the first operation –** right after turning into
5. Intersection and turn right
6. **Do the second operation –** right after turning into
7. Traffic light go straight
8. Intersection go straight
9. Traffic light and turn left
10. **Do third operation –** right after turning into
11. T-junction and turn left
12. **Do the fourth operation –** right after passing the T-junction

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Appendix 5 Instruction for Participants

Step for participants:

- Trial driving 5 minutes for all signs and directions.
- Trial screen single-touch and multi-touch (AC dan radio)
- Car type: Fiat500 with motion 20%

Instruction single-touch Air Conditioner:

- Click the head/body/feet box according to the command
- To increase the fan level, click the + sign, to decrease the fan, click the – sign
- To set the temperature, click on one of the places on the bottom line or drag

Instruction single-touch Radio:

- Drag to determine the frequency according as requested
- Click FM/AM as requested
- Hold number 1/2/3 to set
- Click volume up/down to adjust volume as requested

Instruction multi-touch Air Conditioner:

- Pinch to get the temperature and the area (head/body/feet) as requested
- The bigger the circle that is pinched, the bigger the fan level

Instruction multi-touch Radio:

- The bigger the circle that is pinched, the bigger volume
- The further to the right the circle is pinched, the greater the frequency

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Appendix 6 Antropometric Scale

No	Information	Scale
1.	Eye height in sitting position	71,5cm
2.	Elbow height in sitting position	30cm
3.	Reach arm	60cm