The Effects of Icon Features on In-Vehicle Infotainment Systems on Drivers' Performance, Distraction and Satisfaction

by

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Dedication

I dedicate this thesis to God, whose endless grace and strength have been my guiding light throughout this academic endeavor. To my family, mom, dad, and Laeon. Your infinite love and support have been the pillars of my life. I am eternally grateful for the sacrifices you've made and the encouragement you've provided.

A heartfelt thank you to Dr. Sang-Hwan Kim, my mentor and advisor, whose support, insight, and encouragement have been vital to my success. Dr. Kim has been more than an adviser; he has been a rock, an academic father guiding me on this path.

To all the friends in Korea, Handong Global University, your support and companionship made triumphs more joyful and obstacles easier to overcome. I couldn't have made it through this without you guys. To all the friends I've met in the U.S., InterVarsity, Korean Presbyterian Church of Metro Detroit, I cannot express how grateful I am for your kindness, compassion, empathy, and generosity in accompanying me on this academic, spiritual journey with me. I also wouldn't have been able to get through this process without you guys.

To all the members of the Human-System Integration Lab, your impact has been profound, shaping my academic journey in ways I could not have imagined.

Reflecting on almost two years as Jubilee in the U.S., with a name I chose for myself, I embarked on a journey of self-discovery. I faced the challenges of navigating a new culture, striving to fit in while staying true to myself, filled with self-doubt and questioning.

Nevertheless, I firmly believe that this is a place where I can overcome, learn, and ultimately thrive with walking with God and I am grateful all the process he has given to me.

May God help me to be faithful stewards of gifts you have given me to bring your life and love to others, give me the vision to see the path you set before me today, grant me courage to follow your way.

I am convinced that without all of these, this would not have been done. Thank you so much.

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Abstract

The Icons are important in Human-Machine Interface elements in-vehicle infotainment systems regarding usability and driving safety. The study is to examine the effects of different characteristics of icons in in-vehicle infotainment systems on performance, distraction, and satisfaction, including while prior studies have mainly concentrated on investigating variables such as icons' color and symbols. The current study attempted to find the effects of the border of shape (Square, Circle) and the color of icons (Color, Monochrome) on driving performance and experience. A total of twenty-four participated in a driving simulator experiment, during which they were exposed to different prototypes of infotainment systems that included varying icon designs. The experiment was conducted using a driving simulator, a controller, a tablet PC, software, and video-recording tools to investigate dependent variables, including task performance, eye attention profiles, driving performance, subjective workload, and subjective satisfaction. The results revealed the color of icons marginally improves task completion time, driving performance factors, lowers workload, and increases confidence in subjective workload assessments. On the other hand, the shape of borders generally exhibits no significant differences in most variables; however, it contributes to higher satisfaction in subjective assessments. The findings of the study provide practical recommendations for optimizing the design of touch buttons and color combinations to improve the efficiency of information display and input, aiming to enhance driving safety and overall driver satisfaction.

Chapter 1. Introduction

1.1 In-Vehicle Infotainment System

In recent times, in-vehicle information systems (IVIS) have become increasingly significant in the realm of transportation technology. (Horrey et al., 2006; Feng, Liu, & Chen, 2017). IVIS includes Infotainment Systems such as AVN: audio, video, navigation and Clusters and Head-Up Displays (HUD), which commonly found in most vehicles and collectively defined to as IVIS (Beck et al., 2019; Guo et al., 2014; Feng et al., 2018; Pampel et al., 2019; Kula et al., 2017; Platten et al., 2013). Clusters are a type of instrument panels that shows specific information about a vehicle's status while it is being driven (Bauerfeind et al., 2017; Broy, Zierer et al., 2014). Head-Up Displays (HUD) use augmented reality to show extensive vehicle information inside the driver's visual range and field of vision (Merenda et al., 2018; Villalobos-Ziga et al., 2016).

Furthermore, an infotainment system serves as a versatile device that covers the entertainment demands of the car, including capabilities such as in-vehicle music, multimedia, and navigation, etc. (Gupte & Askhedkar, 2018; Strayer et al., 2011). When compared to traditional dashboards, the purpose of IVIS is to increase productivity and satisfy the driving experience by enabling seamless interaction while offering information to drivers (Feng et al., 2018; Horrey et al., 2006). To provide a seamless interface between the driver and the vehicle, it is necessary to conduct usability tests on the way the In-Vehicle Information System (IVIS) delivers information. Technologies such as Apple CarPlay and Android Auto have revolutionized the way drivers and passengers interact with their vehicles. These systems enable seamless integration of smartphones with the vehicle's infotainment system. Users can mirror their phone's interface on the vehicle's screen, providing access to their favorite apps, music, maps, and other functions in a familiar and convenient way. This integration enhances safety by reducing the need for drivers to fumble with their phones while on the road and ensures a more enjoyable and connected driving experience (Dobres et al.,2014; Becker, Hanna, & Wagner, 2014).

1.2 Components of In-Vehicle Infotainment System and Icon

The user interface of IVIS consists of background, menu, buttons, icon, layout, symbols, label, text, colors, etc (Bigelow & Matteson, 2011). Menus provide an organized structure in the infotainment system, offering users a hierarchy of options for intuitive navigation. Icons are for users to identify, interact, and select desired features as visual representations of functions. (Kim et al., 2015; Bigelow & Matteson, 2011). Icons are important in Human-Machine Interface elements in-vehicle infotainment systems regarding usability and driving safety (Kim et al., 2015). The improvement of the user experience, which means more comfort and safety while driving or riding, depends on how well these signs are understood and used. This is made possible by smart design and buttons that are easy to understand, so drivers can safely use the entertainment features even while they are driving (Lee, Gibson, & Lee, 2015). This makes sure that people can quickly get to the information and features they need without putting safety at risk (Gaffar & Kouchak, 2017).

Studies have explored the use of symbols, colors, shapes, and spatial organization to optimize icon recognition and interpretation. Feng et al. (2018) performed a usability assessment of IVIS, concentrating on three different square touch button sizes (14, 24, and 33 mm) and three touch button quantities (4, 8, and 15). Their findings recommended a touch button size of over 24 mm and a range of 4 to 6 touch buttons, with participants searching for and pressing buttons. Suh and Ferris (2019) assessed IVIS usability by comparing two square touch button sizes (15 mm, 25 mm) and the size of 25 mm generally exhibited better usability. Kim et al. (2014) conducted a usability assessment, considering different driving speeds and five distinct square touch button sizes (7.5, 12.5, 17.5, 22.5, and 27.5 mm) and the touch button size should be at least 17.5 mm. Crundall et al. (2016) evaluated IVIS usability with five font sizes (4, 5, 6.5, 8, and 9 mm), with participants tasked with reading text. It led that minimum font size of 8 mm or larger was optimal size to use.

Multiple studies have investigated the impact of different shapes of icon borders on the effectiveness of visual search. Huang and Chiu (2007) investigated the impact of four different icon shape of border forms on the ability to visually search for objects (Circles, Squares, equilateral triangles facing, Diamonds). Fleetwood and Byrne (2002) conducted an experiment to ascertain the impact of icon border shape on the pace at which users perform searches.

Several research (Chi & Dewi, 2014) have explored the significance of color in interface design components, including size. Huang (2012) explored the aesthetic preferences' consistency of color combinations of icon and background. Color-related properties significantly impact the effectiveness of interfaces, especially in automobiles (Singh, 2006). While using colors in IVIS can aid differentiation, an excess of colors can lead to confusion (Park & Park, 2019). According to the findings of Li, Qu et al. (2017), it is advisable to use black and gray as background colors for the dashboard, focusing on the effectiveness of different dashboard colors for a cluster display. Through these research efforts, the field of IVIS has continuously evolved, demonstrating ongoing and active research interests.

1.3 Problem Definition

For the design of conventional car controls, like knobs and buttons, and push buttons, the automobile industry has established numerous guidelines and regulations (Stevens, 2002). Nevertheless, the fact that touchscreens are becoming increasingly popular in the field of IVIS, there is still a lack of standardized criteria and regulations that belong to in-vehicle touchscreens. (Feng, Liu, & Chen, 2017) (Figure 1).

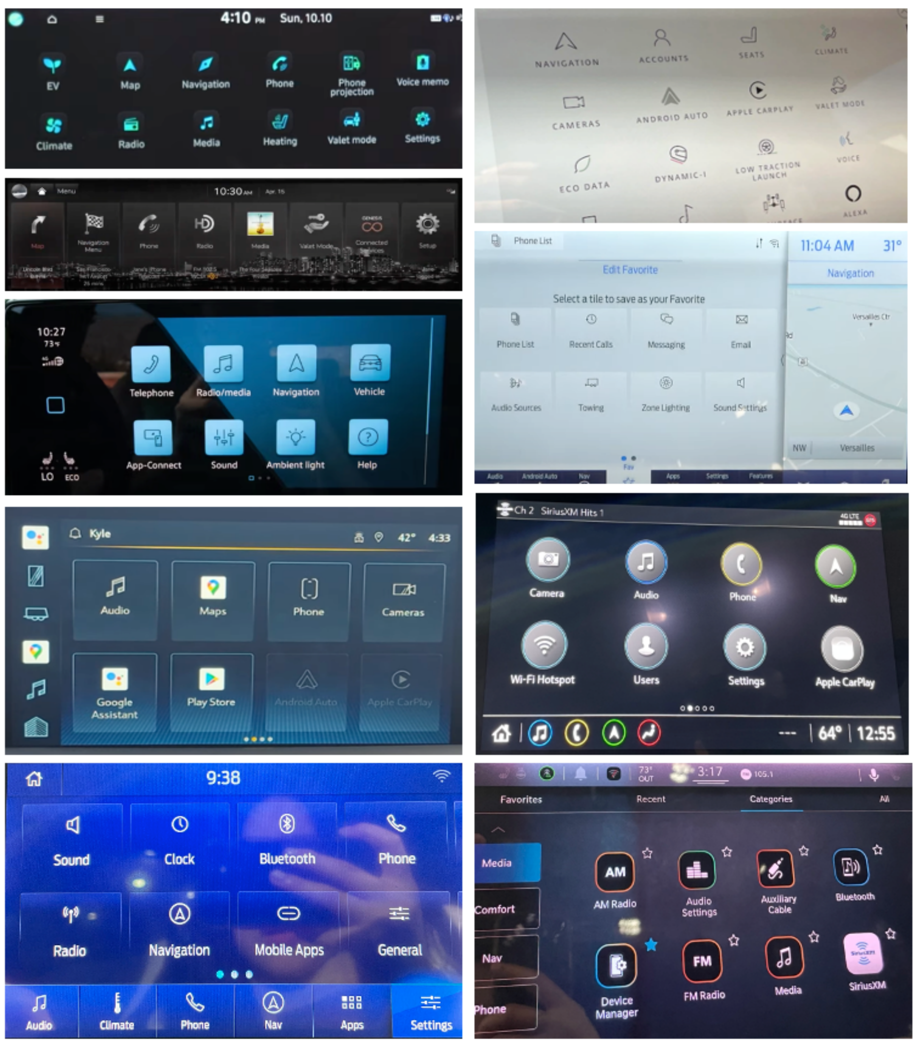


Figure 1 The Need for Standardizing In-Vehicle Touchscreens

1.3.1 Distraction and Safety Issues

Infotainment systems affect driver distraction and safety while driving (Guo et al., 2014). A concern regarding IVIS is that it tends to decrease safety by increasing the eye-off-the-road time (EoRT) (National Highway Traffic Safety Administration, 2012). It is pointed out as a problem that infotainment systems are often outside the driver's field of view. Also, physical control by task is required (Mathur et al., 2017). Therefore, additional eye movements by the driver are required to see these displays.

There is a trend towards touchscreens replacing traditional physical buttons (Suh & Ferris, 2019). However, flat touchscreens have performance issues compared to physical buttons, leading to difficulties in operation and safety concerns while driving. (Peng, Boyle, & Hallmark, 2013; Yoon, Lim, & Ji, 2015). Furthermore, a lot of studies suggest that touch buttons perform worse than physical buttons (Tao et al., 2018). As a result, research on infotainment systems is required from the standpoint of driving performance and safety. The National Highway Traffic Safety Administration (NHTSA) has set the limitation for glance duration time (less than 2 s on average), Number of glance time (less than 15% of the total), and total eyes-off-road time (TEORT; 12 s) for in-vehicle devices (National Highway Traffic Safety Administration, 2012). Several IVIS studies have also attempted to provide guidance by examining driving performance and risks in relation to touch button size (Feng et al., 2018; Kim et al., 2014) and layout (Li, Chen et al., 2017).

1.3.2 User Satisfaction Issues

Users can be satisfied by the system when the icons are unambiguous and easy to comprehend (Hua & Ng, 2010; Naujoks et al., 2019). This, in turn, increases the level of customer pleasure and, in addition, delivers an experience that is safer when driving (Gibson et al., 2016; Cha et al., 2015). The fact that customers can make efficient use of the entertainment system even while driving contributes to an increase in the level of overall user satisfaction (Smith & Fu, 2011). The aesthetic design of icons can provide consumers with an aesthetically pleasant experience, which further contributes to increased enjoyment while using the infotainment system in a vehicle (Smith & Fu, 2011; McDougall et al., 2016). The aesthetic aspects of a product, including color, hold significant influence over the purchasing decisions of users, constituting a majority of over 60% in determining their choice (Singh, 2006). The ongoing advancement of automotive technology has led to the increasing utilization of driver-IVIS interaction as an important tool for automobile companies to meet consumer demands.

Furthermore, user experience satisfaction takes a crucial role, especially with the advent of autonomous driving. There is a need for differentiated interfaces that can enhance the user experience during times when driving is not required such as in-vehicle entertainment functions (audio playback, social communication, life services, etc) (Cha et al., 2015). Nevertheless, with the increasing use of in-vehicle screens and the expanding range of functions they provide, the sources of driving distractions are becoming more extensive and complicated (Dobres et al.,2014; Lee, Hwangbo, & Ji, 2016). Furthermore, as many features are expected to be added to infotainment systems in the future, research to satisfy user experiences is crucial (Norman et al., 2016).

1.4 Objective of the Research

Therefore, the design guidelines on infotainment system is important in ensuring driver's driving performance and satisfaction (Stevens, 2002). Current research has mainly focused on several factors such as icon color, icon symbol related to driver performance (Singh, 2006). Especially, it’s necessary to access the influence of the icon features is affected by different design factors because ineffective combinations may have an impact on driving safety (Society of Automotive Engineers, 2004).

One of the most important aspects of icon design is the border's shape and color (Lin et al., 2016; Huang and Chiu, 2007). The effectiveness and precision of visual search are influenced by the color of the icon and the shape of the border, and it influences user experience (McDougall et al., 2016).The purpose of this study is how various icon features of infotainment systems can affect a driver's performance, perception, and attention. Specifically, the study investigates how the shape of borders (square vs. circle), and the color of icons (color vs. monochrome) can positively impact a driver's driving performance and driving experience.

To achieve this, this study presents two research questions:

1. Does the shape of borders on icons (SquareBorder vs. CircleBorder vs NoBorder) influence a driver's driving performance and driving experience?
2. Does the color of icons (Color vs. Monochrome) influence a driver's driving performance and driving experience?

Through this research, the study aims to derive the effects of icon features in infotainment system that improves a driver's driving performance and reduce distraction, ultimately contributing to the development of infotainment systems that enhance user satisfaction.

Chapter 2. Method

2.1 Participants

For this experiment, a total of 24 participants were engaged. Each participant has been driving for at least a year and has a current driver's license without any physical impairments and required the ability of reading English. The demographic surveys collected information about participants, including their age, gender, education level, driving experience, accident records, presence of an infotainment system in their vehicles, and experiences or familiarity with the use of Google CarPlay or Android AutoPlay usage. The mean age of the participants was 22.6 years old (SD = 2.95), with 19 male and 5 female individuals. The participants' average driving experience is 4.9 years and 18 participants replied that they have a touchscreen in their personal automobiles. 7 participants said they always use the infotainment system. 6 participants said they usually use the infotainment system. 10 participants replied they use Apple Carplay, and 4 participants replied they use Android Auto. The experimental methods, encompassing the recruitment of participants, collecting of data, and subsequent analysis, were carried out after receiving an exemption from the Institutional Review Board (IRB) at the University of Michigan. This exemption was granted following a thorough evaluation of the research protocol (HUM00233009).

2.2 Apparatus

A driving simulator was used to collect data while presenting prototypes of infotainment system including various icon features. The simulator setup includes vehicle cabin with steering wheels, pedals, controls and displays. An Open-DS driving simulator was used to present driving scene and control. The driving scenario was included into the driving simulator and consisted of driving at straight and curved highways. The speed and their corresponding Mile Per Hour (MPH) can be visually assessed through a HUD display on the screen.

A controller, a tablet PC, a software, a video-recording tool were included for the experiment. A tablet PC was utilized to fulfill the role of the vehicle's infotainment system. The IVIS prototype and touchscreen was attached to the top of the center fascia (Graichen et al., 2019). Figure 2,3 shows the experimental setup, which includes the driving simulator and software, the controller, and the touchscreen. The software of the IVIS prototype was developed as an application using software Figma and PowerPoint on an iPad Pro 11(screen size 11.9 in). A software was developed using the Java programming language to provide high-quality roadway simulation for the experiment. It was used to observe and measure the participants' driving performance as well as giving various effects and sounds such as weather changes, engine noise. To capture participants' behavior, video recording was employed. It was used to record the driver's face to measure the driver's eye profile such as eye dwelling time and the number of glances (Boyle et al, 2013). iPad was used recording with Zoom not only was used as an infotainment system.

Figure 2. The Driving Simulator and the Software of the Experiment Environment

Figure 3. The Controller and the Touchscreen of the Experiment Environment

2.3 Prototypes

The icons for the infotainment system were designed as prototypes using a prototyping software (Figma). The experiment conditions consisted of 2 factors: The shape of borders (Square vs. Circle vs NoBorder), and color (Color vs. Monochrome). Each screen has a set of 8 icons (Setting, Weather, Music, Message, Help, Payment, Podcast, and Call). The button size was selected with reference to the standard set by NHTSA (National Highway Traffic Safety Administration, 2012). The minimum sizes of buttons which are 18.7mm and 9 mm, were determined with established guidelines. To ensure consistency in the distance traveled by a participant's finger, it was necessary for the length between the buttons to be equal. According to Jin et al. (2007), the buttons were arranged at a spacing of 6 mm. The font size for the touch button was based on the font standard, specified by NHTSA (National Highway Traffic Safety

Administration, 2012). The optimal font size of 4.3 mm, as well as a minimum font size of 2.6 mm was used. The vertical distance between the eye level and the prototype was measured to be 75 cm. To assess the effects of the presence or absence of a border, two variables were designed: one with border and one without border were developed. The thickness of the edge was set at 1 mm. To evaluate the impact of the border shape, two variables were selected and designed: one for the square, one for the circle. To evaluate the impact of the color of the icons, two variables were designed: one with color tone, and one with monotone. Eight chromatic hues (Red, Yellow, Green, Cyan, Blue, Purple, Brown and Gray), and three achromatic colors (Black, Gray, and White). The icon color was selected the most saturation within a gradient, while simultaneously minimizing brightness to the extent feasible, considering the driving conditions. The background color was black. The 6 types of interface designs can be seen in Figure 4. Each set were followings: SquareBorder/Mono, CircleBorder/Mono, Noborder/Mono, SquareBorder/Color, CircleBorder/ Color, Noborder/Color.

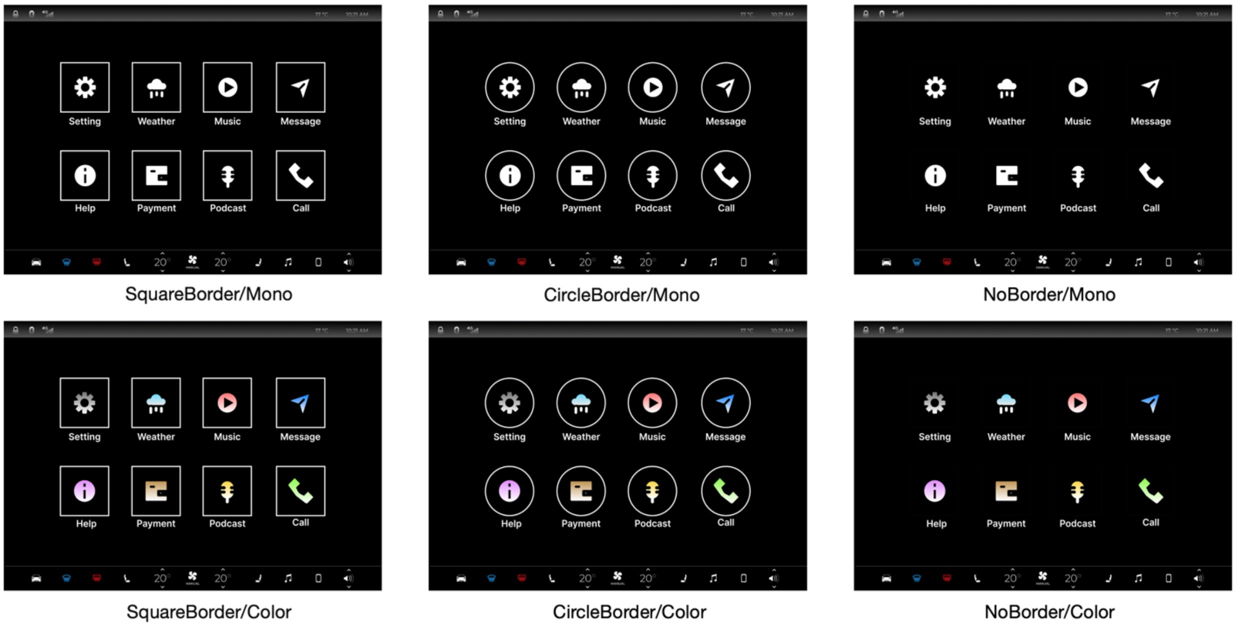


Figure 4. The 6 Types of Prototype Interface Designs

2.4 Procedures

The two factors; the shape of border (SquareBorder, CircleBorder, NoBorder, three levels), and the color (Color and Monochrome, two levels) result in a total of 6 combinations. Each screen has 8 icons (Setting, Weather, Music, Message, Help, Payment, Podcast, and Call). The dashboard exhibited the buttons that were used as the experimental tasks that depict different functions in vehicle. There were a total of 24 tasks (6 Sets of infotainment system * 4 tasks). The order of the 6 sets, the order of buttons was randomized to prevent participants' bias. Every icon positions and every icons are equally distributed and randomized.

Participants were provided with consent form and demographic questionnaires to collect basic information. Participants was given the detailed instruction of purpose and procedures of the experiment, the infotainment system, and icons. Participants engaged in a training session driving on the simulator to become familiar with the equipment and experimental procedures.

Each participant was given time with the simulation to practice driving and maintaining consistent speed. The purpose was to reduce the likelihood of driving mistakes resulting from participants' unfamiliarity with the controls' dissimilarity to their accustomed vehicles. Participants adjusted the seat based on the height and the length of the torso to put themselves in a comfortable driving position. Participants were given the restrictions 1) road regulations such as maintaining a consistent speed of 50 mph, only using the second lines, and going in a straight direction 2) required use of steering wheel and pedals. Once the participants sit down on the seat and begin a driving process, the experiment begins. A screen was displayed a blank background. At this point, drivers are gazing attentively ahead, focusing on driving the highway simulation. However, IVIS will be unexpectedly and randomly shown the screen with the icons and instruct driver to press specific icons with random audio prompts, such as "Music," "Call". The participants were trained to execute by pressing the corresponding button with speed and accuracy while the participants are driving. When IVIS was clicked by participants, and it turns into blank screen again and participants began to focus on driving again (Figure 5).

The driving route consists of straight and curved road. Considering the difficulty, the operation of pressing buttons was only conducted only while driving in a straight line. After the completion of each set, the participants were given 2 minutes break, and NASA-TLX were used to measure the participants' workload and frustration (Jakus et al., 2015; Kim et al., 2014; Villalobos-Zúñiga et al., 2016). After finishing all the 6 sets of experiment, the participants were given some questions about subjective satisfaction, to gather users' thoughts on effectiveness, aesthetics, and overall satisfaction (Figure 6).

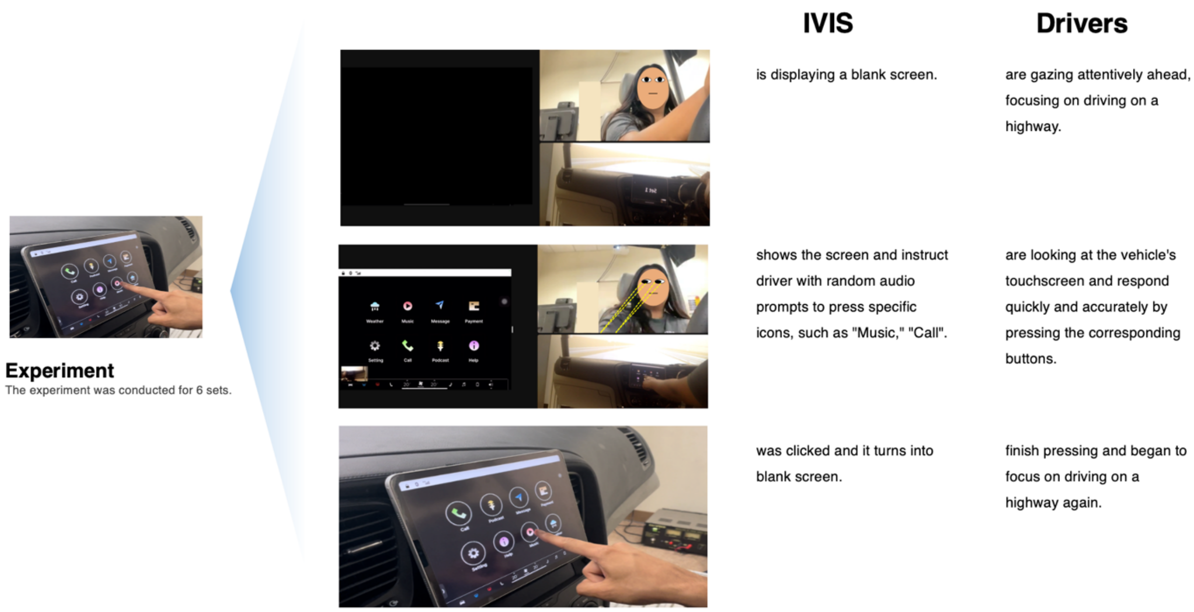


Figure 5. The Task Procedure

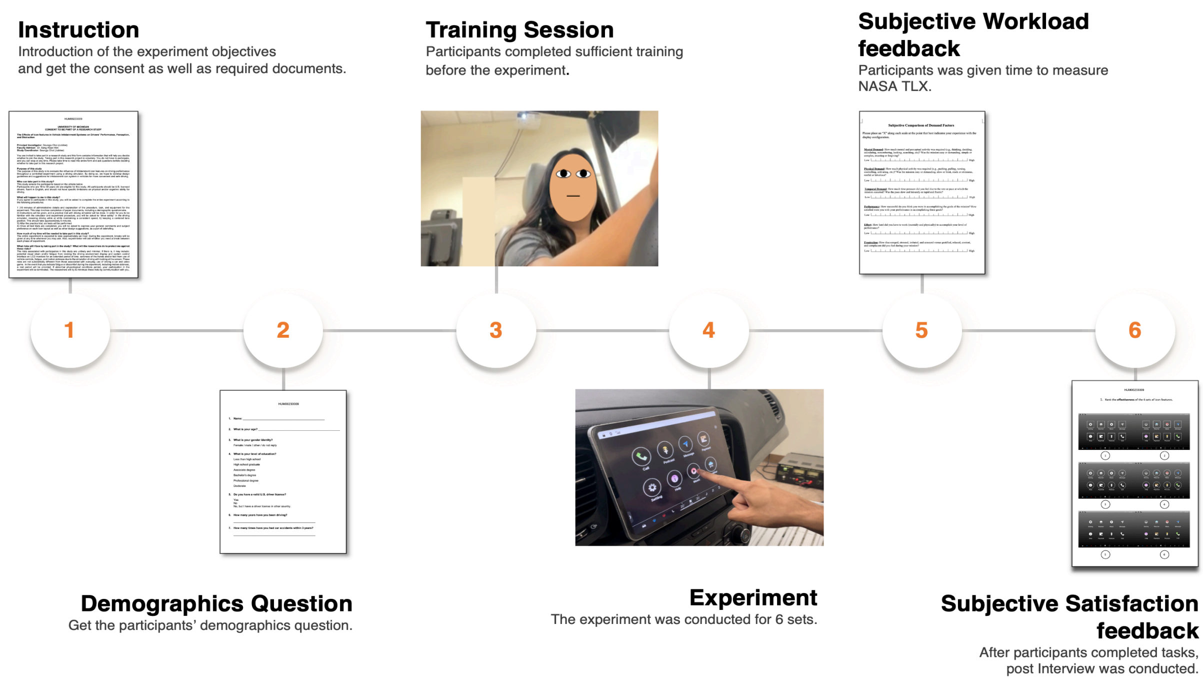


Figure 6. The Procedure of the Experiment

2.5 Variables and Measurements

The Independent Variables of this experiment were the Shape of Border (3 levels: Square, Circle, Noborder) and Color (2 levels: Color, Mono). The Dependent Variables were Task Completion Time (Angelini et al., 2016), Number of Errors, Number of Misclicks, Eye Attention Profile Data (Eye Dwelling Time, The Number of Glance) (Lee, Hwangbo, & Ji, 2016), Driving performance (Mean of Longitudinal Position, Mean of Lateral Lane-keeping Position, Mean of Speed, Mean of Steering wheel, Mean of Brake Pedal Press, Mean of Gas Pedal Press, Standard Deviation (Stdev.) of Longitudinal Stability, Stdev. of Lateral Lane-keeping Stability, Stdev. of Speed, Stdev. of Steering wheel Manipulation, Stdev. of Brake Pedal Press, Stdev. of Gas Pedal Press), Subjective Workload measured using NASA TLX (Mental demand, Physical demand, Temporal demand, Effort, Performance, Frustration, Overall Workload) (Kaber et al., 2013), Subjective Satisfaction (Effectiveness, Aesthetics, Overall Satisfaction) (Smith & Fu, 2011).
For each button operation, the time the button was pressed were analyzed by using Adobe Premier Pro to measure millisecond. Pressing the wrong button were considered error and if the participants were clicking the exact buttons but pressing outside of the edge or duplicates were considered the Number of Misclicks. The eye tracking data collected were the total dwelling time. NASA-TLX questionnaires were used for the survey items. A scale of 0 to 20 was used for evaluation for each combination of independent variables. The cognitive load was measured using NASA-TLX questions on Mental Demand, Physical Demand, Temporal Demand, Effort, Performance, Frustration, and total workload. The subjective satisfaction questionnaire consisted of four questions concerning Effectiveness, Aesthetics, and Overall Satisfaction. Table 1 shows the whole taxonomy of measures.

Table 1. Whole Taxonomy of Measures

Category	Variables
Task Completion time	• Task Completion time
Number of Errors	• Number of Errors • Number of Misclicks
Eye Attention Profile Data	• Eye Dwelling Time • The Number of Glance
Driving Performance	• Mean of Longitudinal Position • Mean of Lateral Lane-keeping Position • Mean of Speed • Mean of Steering wheel • Mean of Brake Pedal Press • Mean of Gas Pedal Press • Standard Deviation (Stdev) of Longitudinal Stability • Stdev. of Lateral Lane-keeping Stability • Stdev. of Speed • Stdev. of Steering wheel Manipulation • Stdev. of Brake Pedal Press • Stdev. of Gas Pedal Press
Subjective Workload	• Mental demand

NASA-TLX (0–20 Score)	• Physical demand • Temporal demand • Effort • Performance • Frustration • Overall Workload
Subjective Satisfaction	• Effectiveness • Aesthetics • Overall Satisfaction

Chapter 3. Results

3.1 Task Completion Time

The study examined the effect of Independent Variables (The Shape of Border, and Icon Color) on the Dependent Variables (Task Completion Time). Analysis of variance (ANOVA) results showed that the color was marginally significant ($F(1,544) = 2.95$, $p = 0.086$) in figure 7. ANOVA results showed that the task completion time for the shape of border was not significantly different ($F(2,544) = 0.52$, $p = 0.595$). Color has an impact on task completion time, but shape and border had no apparent impact on task completion time for participants. It is marginally faster with color when it comes to task completion time.

The mean of task completion time of color tone was 1305 ms, while monochrome tone was 1359 ms. Figure 8 is shown that NoBorder/Color has the fastest performance in the mean of task completion time (1303ms) and SquareBorder/Mono has the slowest (1396ms). The rank is as follows: NoBorder/Color (1303ms), CircleBorder/Color (1305ms), SquareBorder/Color (1307ms), NoBorder/Mono (1322ms), CircleBorder/Mono (1357ms), SquareBorder/Mono (1396ms).

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
No	23	23683700	1029726	7.36	0.000
Trial	5	667347	133469	0.95	0.446
shape	2	145094	72547	0.52	0.596
color	1	412271	412271	2.95	0.087
shape*color	2	116330	58165	0.42	0.660
Error	542	75818780	139887		
Lack-of-Fit	110	17102105	155474	1.14	0.176
Pure Error	432	58716675	135918		
Total	575	100843521			

Figure 7. ANOVA Result of Task Completion Time

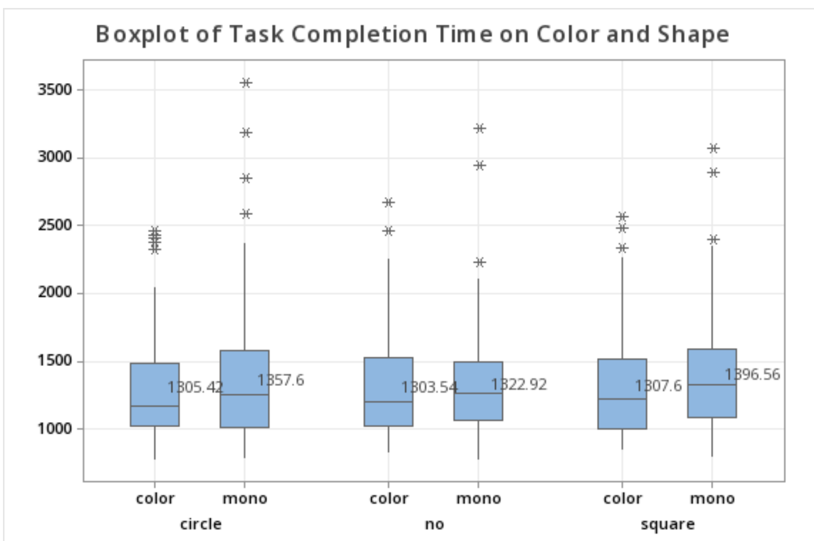


Figure 8. Boxplot of Task Completion Time

3.2 Number of Errors and Number of Misclicks

The study examined the effect of Independent Variables (The Shape of Border, and Icon Color) on Dependent Variables (Number of Errors and Number of Misclicks) through Kruskal-Wallis (non-parametric) test. Results of the Kruskal-Wallis test for the effect of shape on the number of errors (χ^2_2=0.51, p = 0.775) and number of misclicks (χ^2_2=0.58, p = 0.750) were not significant. Results of the Kruskal-Wallis test for the effect of color on the number of errors (χ^2_1=0.00, p = 1.000) and number of misclicks (χ^2_1=1.18, p = 0.277) were not significant. The "circle" shape tends to have lower number of errors compared to the overall average (z value = -0.15). The “NoBorder” has several errors that is in line with the overall average (z value = 0.00). The “SquareBorder” tends to have higher number of errors compared to the overall average (z value = 0.15). The "CircleBorder”, “SquareBorder” tends to have a slightly lower number of misclicks compared to the overall average (z value = -0.10), while “NoBorder” shape has several misclicks that is in line with the overall average (z value = 0.20). (Figure 9 and 10).

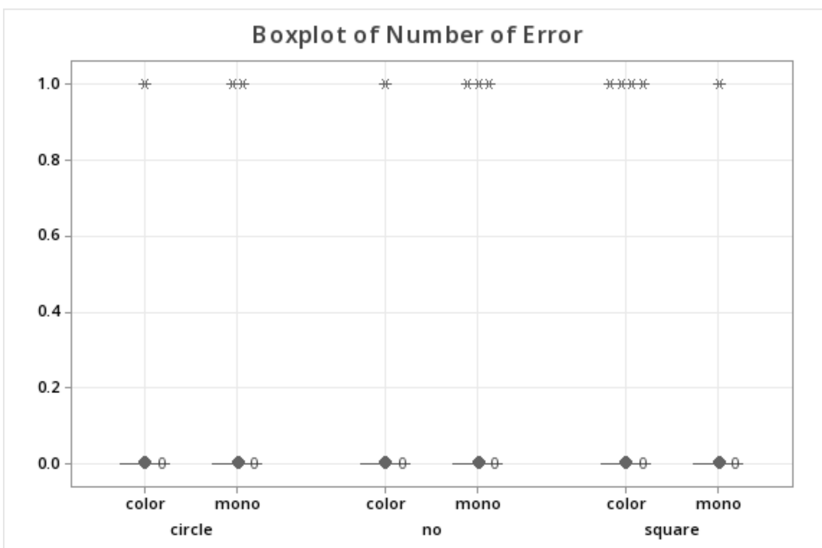


Figure 9. Boxplot of Number of Error

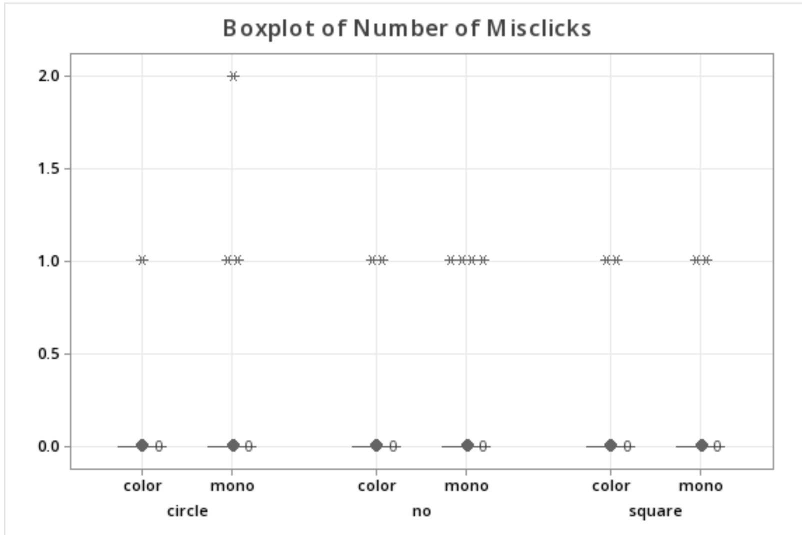


Figure 10. Boxplot of Number of Error

3.3 Eye Attention Profile Data

The study examined the effect of Independent Variables (The Shape of Border, and Icon Color) on the Dependent Variables (Eye Dwelling Time, The Number of Glance). The dwell time and frequency of eye movement were gathered by manually monitoring the participants' eye movements in recorded videos of their faces during the experiment, using a video editing tool to track pupil movements. Both dwell time and frequency of eye profile data were standardized (z-scores) to address individual differences such as eye movement speed.

For eye dwelling time, analysis of variance (ANOVA) was conducted. Analysis of variance (ANOVA) results showed that the Eye Dwelling Time was not significantly different in shape ($F_{(2,544)} = 0.76$, $p = 0.467$) and in color ($F_{(1,544)} = 2.61$, $p = 0.107$). Figure 11 is shown the ANOVA Result of Eye Dwelling Time. The mean of Eye Dwelling Time of color tone was 920 ms, while monochrome tone was 970 ms.

Figure 12 is shown the boxplot of Eye Dwelling Time. It is shown that NoBorder/Color has the shortest the mean of eye dwelling time (903ms), and CircleBorder/Mono has the longest

(988ms), and the rank is as follows: NoBorder/Color (903ms), CircleBorder/Color (914ms), NoBorder/Mono (937ms), SquareBorder/Color (986ms), SquareBorder/Mono (986ms), and CircleBorder/Mono (988ms). For frequency of eye movement, the non-parametric Kruskal test was conducted. The number of glances also was not significant in shape (χ^2_2= 0.18, p = 0.913) and in color (χ^2_1= 0.00, p = 0.984). Figure 13 is shown the Boxplot of Number of Glance.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
No	23	18310441	796106	5.77	0.000
Trial	5	618453	123691	0.90	0.483
shape	2	209872	104936	0.76	0.468
color	1	359001	359001	2.60	0.107
shape*color	2	44226	22113	0.16	0.852
Error	542	74741572	137900		
Lack-of-Fit	110	16389772	148998	1.10	0.247
Pure Error	432	58351800	135074		
Total	575	94283566			

Figure 11. ANOVA Result of Eye Dwelling Time

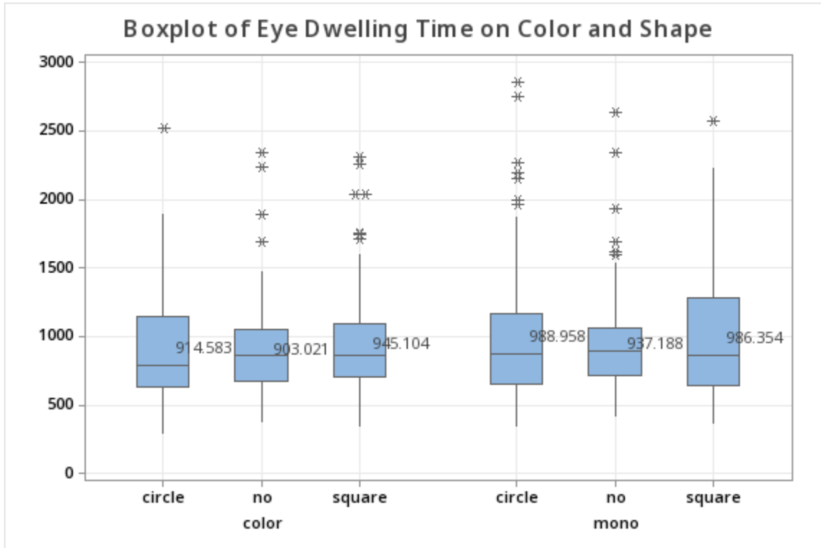


Figure 12. Boxplot of Eye Dwelling Time

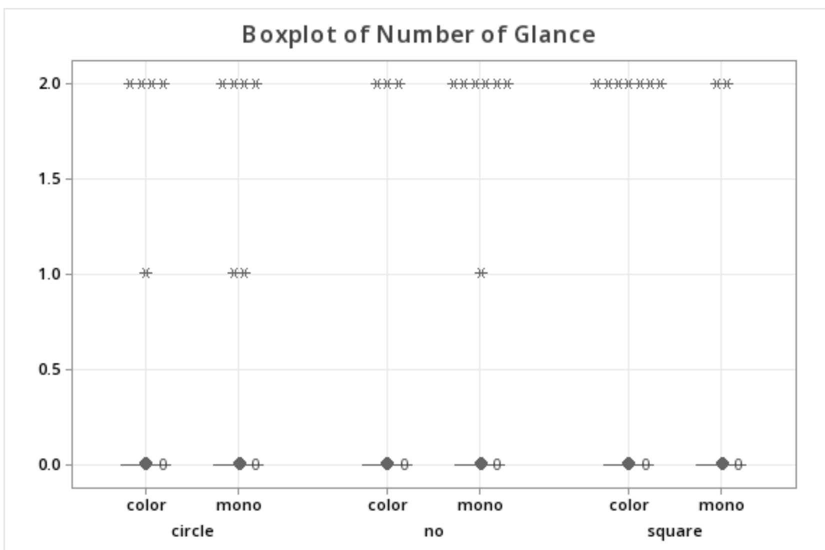


Figure 13. Boxplot of Number of Glance

3.4 Driving Performance

The study examined the effect of Independent Variables (The Shape of Border, and Icon Color) on the Dependent Variables (Driving Performance; Mean of Longitudinal Position, Mean of

Lateral Lane-keeping Position, Mean of Speed, Mean of Steering wheel, Mean of Brake Pedal Press, Mean of Gas Pedal Press, Standard Deviation (Stdev.) of Longitudinal Stability, Stdev. of Lateral Lane-keeping Stability, Stdev. of Speed, Stdev. of Steering wheel Manipulation, Stdev. of Brake Pedal Press, Stdev. of Gas Pedal Press).

ANOVA showed that Mean of Longitudinal Position, Stdev. of Longitudinal Lane-Keeping Stability, Stdev. of Lateral Lane-Keeping Stability, Stdev. of Gas Pedal Press was significant. However, ANOVA showed that Mean of Lateral Lane-keeping Position, Mean of Speed, Mean of Steering wheel consistency, Mean of Brake Pedal Press, Mean of Gas Pedal Press, Standard Deviation (Stdev.) of Speed, Stdev. of Steering wheel consistency, Stdev. of Brake Pedal Press were not significantly different.

3.4.1 The mean of Longitudinal Position

ANOVA results showed that the mean of Longitudinal Position, was significantly different in color ($F (1,110) = 4.83$, $p = 0.030$), while it was not significantly different in the shape of border in figure 14. It is the most table with color when it comes to the mean of longitudinal position. NoBorder/Color has the consistent and seamless driving (202), and SquareBorder/Mono has the least seamless driving (150), and the rank is as follows: NoBorder/Color (202), SquareBorder/Color(198), CircleBorder/Color (184), CircleBorder/Mono (179), NoBorder/Mono (157), SquareBorder/Mono (150). Figure 15 shows the boxplot the mean of Longitudinal position.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
No	23	647625	28157.6	3.49	0.000
Trial	5	36783	7356.5	0.91	0.476
shape	2	1461	730.7	0.09	0.914
color	1	39012	39012.2	4.83	0.030
shape*color	2	13597	6798.5	0.84	0.433
Error	110	887798	8070.9		
Total	143	1626277			

Figure 14. ANOVA Result of Mean of Longitudinal Position

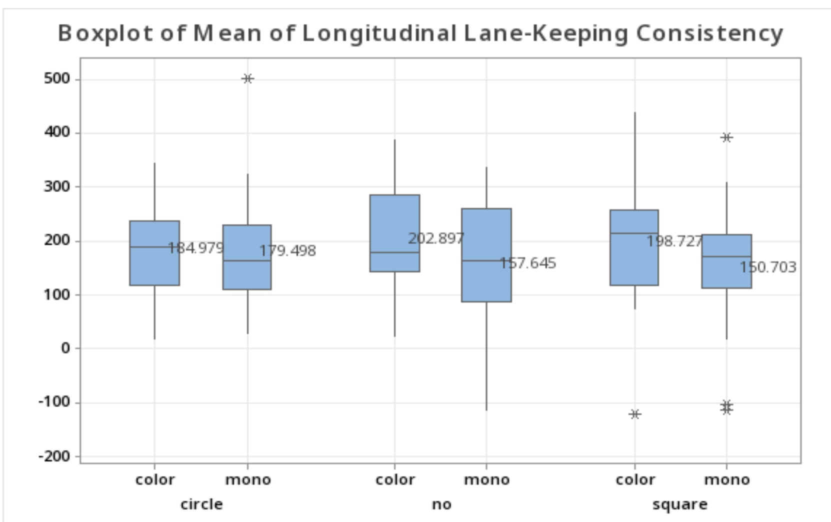


Figure 15. Boxplot of Mean of Longitudinal Position

3.4.2 The Standard deviation (Stdev.) of Longitudinal Lane-keeping Consistency

ANOVA results showed that the Standard deviation (Stdev.) of Longitudinal Lane-keeping Consistency was significantly different in color ($F(1,110) = 7.64$, $p = 0.007$) (Figure 16), while it was not significantly different in the shape of border. It is the most table with color when it comes to longitudinal lane keeping consistency. SquareBorder/Color has the best longitudinal lane keeping consistency (599), NoBorder/Mono has the most unstable longitudinal lane keeping consistency (632). The rank is as follows: SquareBorder/Color (599), NoBorder/Color (601), CircleBorder/Color (607), CircleBorder/Mono (614), SquareBorder/Mono (625), NoBorder/Mono (632). Figure 17 shows the Boxplot of Stdev. of Longitudinal Lane-Keeping Stability.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
No	23	144503	6282.7	2.95	0.000
Trial	5	18864	3772.8	1.77	0.125
shape	2	1008	504.2	0.24	0.790
color	1	16296	16295.6	7.64	0.007
shape*color	2	3851	1925.7	0.90	0.408
Error	110	234581	2132.6		
Total	143	419104			

Figure 16. ANOVA result of Stdev. of Longitudinal Lane-Keeping Stability

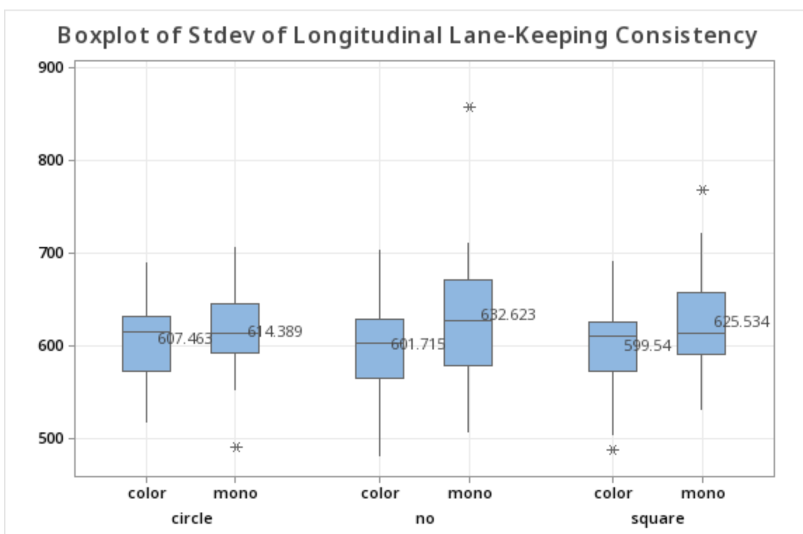


Figure 17. Boxplot of Stdev. of Longitudinal Lane-Keeping Stability

3.4.3 The Standard deviation (Stdev.) of Lateral Lane-Keeping Stability

ANOVA results showed that the Stdev. of Lateral Lane-Keeping Stability was significantly different in shape ($F\ (1,110) = 4.88$, $p = 0.009$) while it was not significantly different in the shape of border (Figure 18). Figure 19 shows the Boxplot of Stdev. of Lateral Lane-Keeping Stability. It implies that NoBorder, SquareBorder shows the stable lateral lane keeping, while CircleBorder shows the least. NoBorder/Mono has the most stable lateral lane keeping (576), and CircleBorder/Mono has the least stable lateral lane keeping (632) and the following, SquareBorder/Color has the best longitudinal lane keeping consistency (599), NoBorder/Mono has the most unstable longitudinal lane keeping consistency (632). The rank is as follows: NoBorder/Mono (576), SquareBorder/Mono (573), SquareBorder/Color (573), NoBorder/Color (562), CircleBorder/Color (539), CircleBorder/Mono (536).

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
No	23	473773	20598.8	5.67	0.000
Trial	5	40029	8005.7	2.21	0.059
shape	2	35449	17724.6	4.88	0.009
color	1	517	517.5	0.14	0.706
shape*color	2	1970	984.8	0.27	0.763
Error	110	399279	3629.8		
Total	143	951017			

Figure 18. ANOVA result of Stdev. of Lateral Lane-Keeping Stability

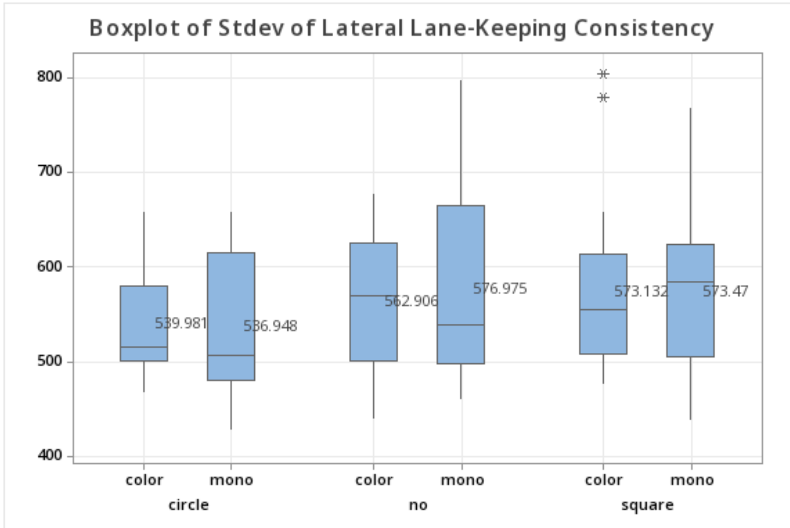


Figure 19. Boxplot of Stdev. of Lateral Lane-Keeping Stability

3.4.4 The Standard deviation (Stdev.) of Gas Pedal Press

ANOVA results showed that the Stdev. of Gas Pedal Press was marginally significant in color ($F_{(1,110)} = 3.91$, $p = 0.051$) while it was not significantly different in the shape of border. Mono leads to the consistent gas pedal usage, while Color leads to the high gas pedal usage. CircleBorder/Mono has the lowest gas pedal press (0.179) and SquareBorder/Color has the highest (0.193). The rank is as follows: CircleBorder/Mono (0.179), NoBorder/Mono (0.182), SquareBorder/Mono (0.184), NoBorder/Color (0.185), CircleBorder/Color (0.188), SquareBorder/Color (0.193) Figure 20 shows the ANOVA result of Stdev. of Gas Pedal Press, Figure 21 is shown the boxplot of Stdev. of Gas Pedal Press.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
No	23	0.144956	0.006302	14.30	0.000
Trial	5	0.004475	0.000895	2.03	0.080
shape	2	0.000694	0.000347	0.79	0.457
color	1	0.001722	0.001722	3.91	0.051
shape*color	2	0.000228	0.000114	0.26	0.773
Error	110	0.048472	0.000441		
Total	143	0.200546			

Figure 20. ANOVA result of Stdev. of Gas Pedal Press

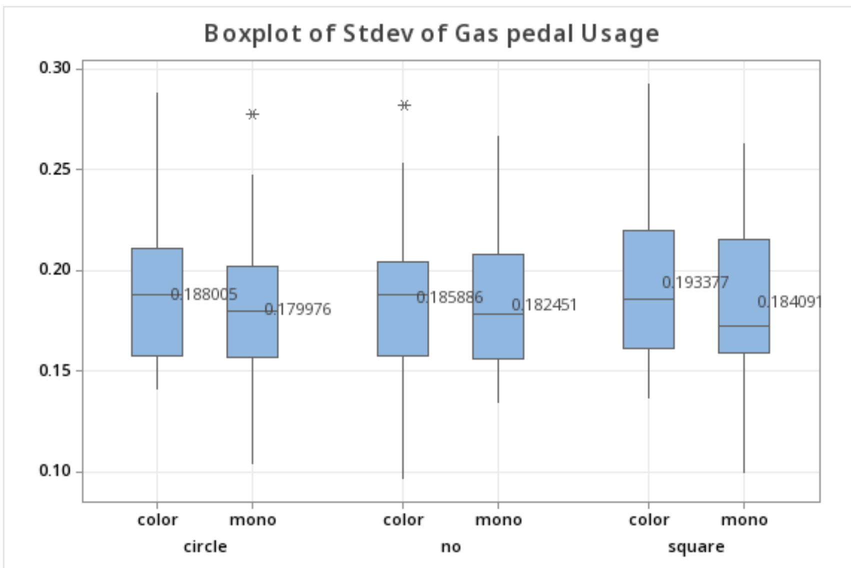


Figure 21. Boxplot of Stdev. of Gas Pedal Press

3.5 Subjective Workload

The study examined the effect of Independent Variables (The Shape of Border, and Icon Color) on the Dependent Variables (NASA TLX; Overall Workload, Mental Demand, Physical Demand, Temporal Demand, Effort, Performance, Frustration). ANOVA results showed that the ratings on Mental demand ($F_{1,110} = 30.31$, $p < 0.001$), Temporal demand ($F_{1,110} = 7.67$, $p = 0.007$), Effort

($F_{1,110}$ = 19.71, $p < 0.001$), Performance ($F_{1,110}$ = 10.33, $p = 0.002$), and Frustration ($F_{1,110}$ = 8.00, $p = 0.006$), Overall Workload ($F_{1,110}$ = 16.43, $p < 0.001$) were significantly different in color (Figure 20,21,22,23,24,25,26,27,28,29,30, and 31), while it was not significantly different in the shape of border. It implies participants feel less mentally, less temporally overload, less frustrated, less effort-made and feel confidence doing a performance in color.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
No	23	2.36639	0.10289	3.64	0.000
Trial	5	0.25826	0.05165	1.83	0.113
shape	2	0.04024	0.02012	0.71	0.493
color	1	0.85563	0.85563	30.31	0.000
shape*color	2	0.12885	0.06443	2.28	0.107
Error	110	3.10535	0.02823		
Total	143	6.75472			

Figure 22. ANOVA result of Mental Demand

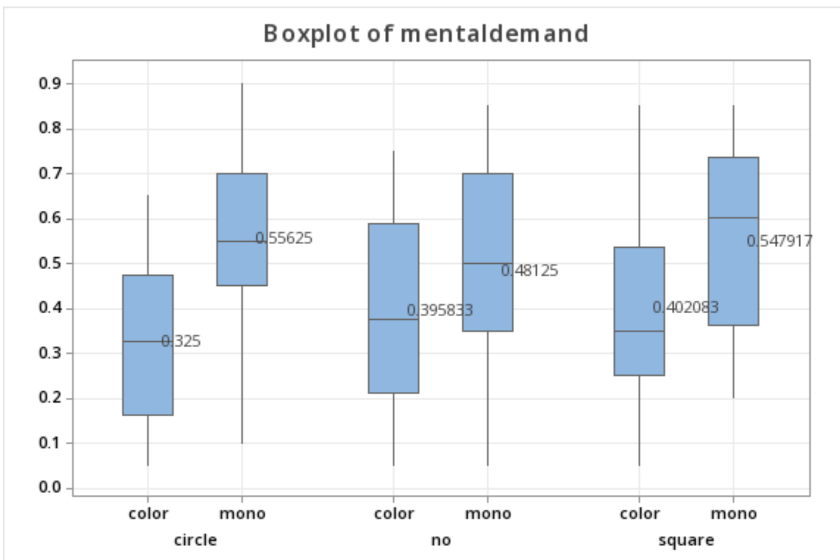


Figure 23. The Boxplot of Mental Demand

The rank is as follows for mental demand: CircleBorder/Color (0.40), NoBorder/Color (0.41), SquareBorder/Color (0.43), NoBorder/Mono (0.47), SquareBorder/Mono (0.50), CircleBorder/Mono (0.49).

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
No	23	2.60910	0.113439	3.99	0.000
Trial	5	0.11201	0.022403	0.79	0.560
shape	2	0.00795	0.003976	0.14	0.870
color	1	0.21778	0.217778	7.67	0.007
shape*color	2	0.00962	0.004809	0.17	0.845
Error	110	3.12514	0.028410		
Total	143	6.08160			

Figure 24. ANOVA result of Temporal Demand

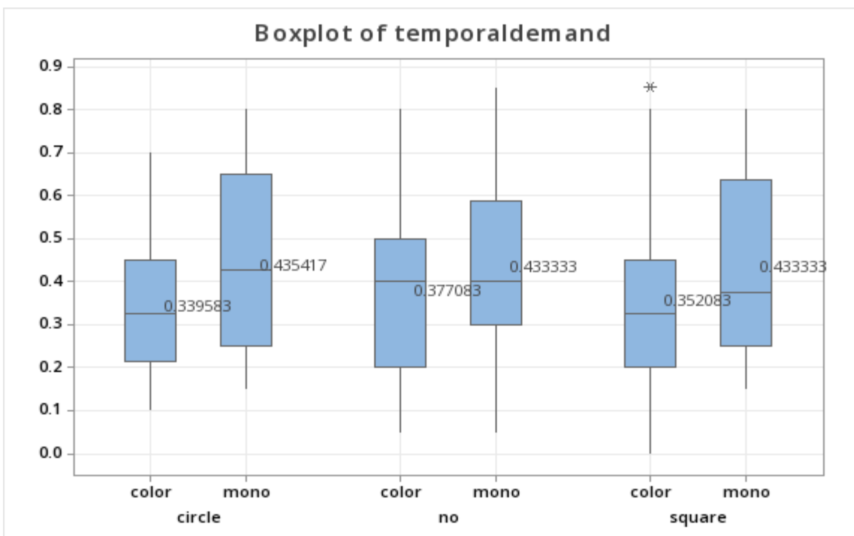


Figure 25. The Boxplot of Temporal Demand

The rank is as follows for mental demand: CircleBorder/Color (0.40), SquareBorder/Color (0.43), NoBorder/Color (0.41), NoBorder/Mono (0.47), SquareBorder/Mono (0.50), CircleBorder/Mono (0.49).

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
No	23	3.29889	0.143430	5.64	0.000
Trial	5	0.16806	0.033611	1.32	0.261
shape	2	0.04649	0.023247	0.91	0.404
color	1	0.50174	0.501736	19.71	0.000
shape*color	2	0.00899	0.004497	0.18	0.838
Error	110	2.79972	0.025452		
Total	143	6.82389			

Figure 26. ANOVA Result of Effort

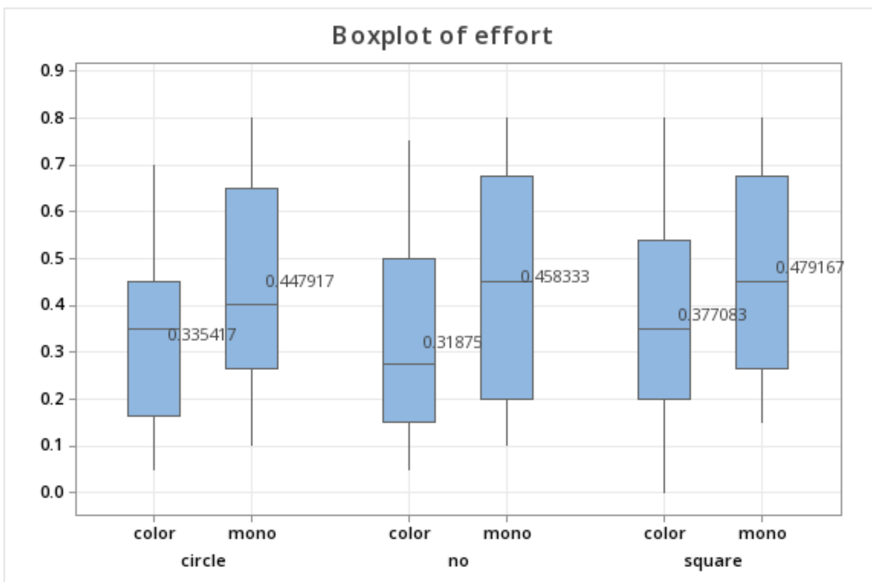


Figure 27. The Boxplot of Effort

The rank is as follows for effort: NoBorder/Color (0.41), CircleBorder/Color (0.40), SquareBorder/Color (0.43), CircleBorder/Mono (0.49), NoBorder/Mono (0.47), SquareBorder/Mono (0.50).

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
No	23	1.51873	0.06603	3.56	0.000
Trial	5	0.05092	0.01018	0.55	0.738
shape	2	0.04847	0.02424	1.31	0.274
color	1	0.19141	0.19141	10.33	0.002
shape*color	2	0.04542	0.02271	1.23	0.297
Error	110	2.03753	0.01852		
Total	143	3.89248			

Figure 28. ANOVA Result of Performance

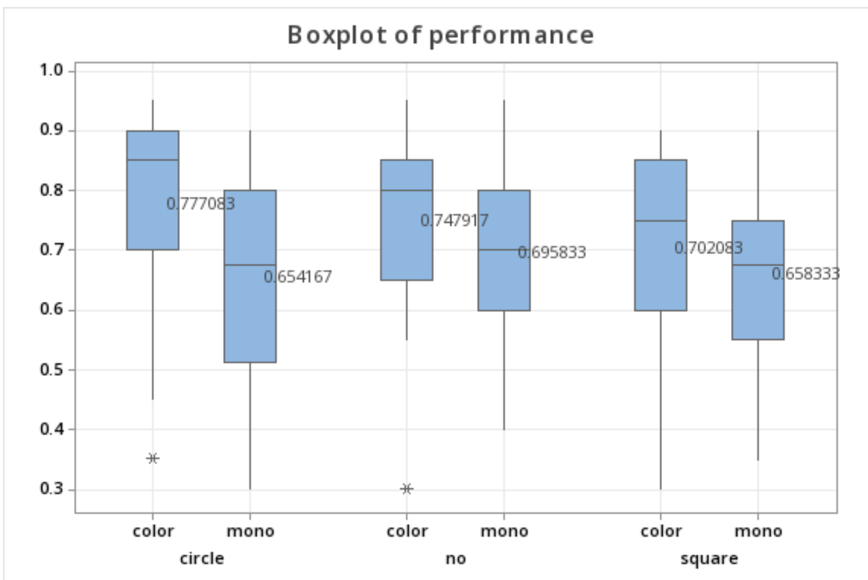


Figure 29. The Boxplot of Performance

The rank is as follows for performance: CircleBorder/Color (0.40), NoBorder/Color (0.41) SquareBorder/Color (0.43), NoBorder/Mono (0.47), SquareBorder/Mono (0.50), CircleBorder/Mono (0.49).

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
No	23	3.88068	0.168725	6.31	0.000
Trial	5	0.02911	0.005823	0.22	0.954
shape	2	0.04156	0.020781	0.78	0.462
color	1	0.21391	0.213906	8.00	0.006
shape*color	2	0.04885	0.024427	0.91	0.404
Error	110	2.94198	0.026745		
Total	143	7.15609			

Figure 30. ANOVA Result of Frustration

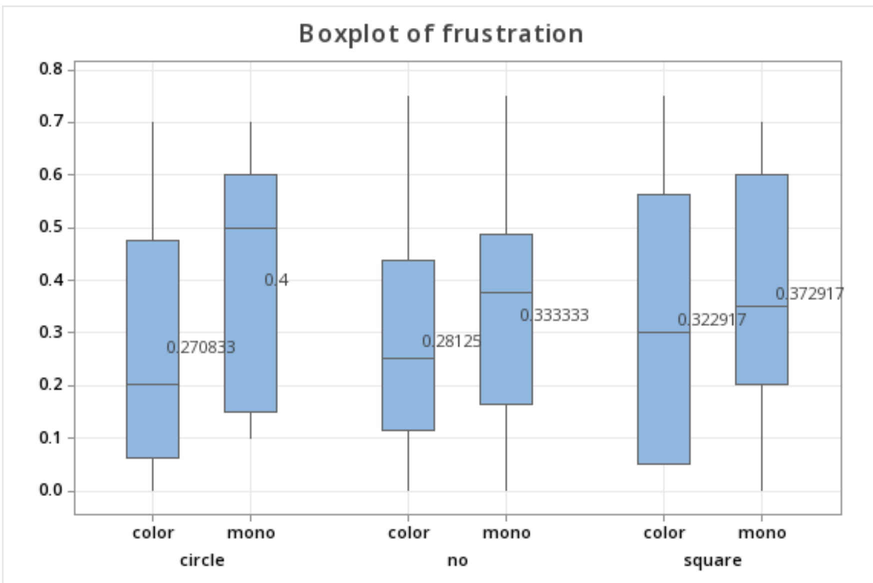


Figure 31. The Boxplot of Frustration

The rank is as follows for frustration: CircleBorder/Color (0.40), NoBorder/Color (0.41) SquareBorder/Color (0.43), NoBorder/Mono (0.47), SquareBorder/Mono (0.50), CircleBorder/Mono (0.49).

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
No	23	1.51105	0.065698	6.02	0.000
Trial	5	0.13759	0.027518	2.52	0.034
shape	2	0.02389	0.011944	1.09	0.339
color	1	0.17945	0.179446	16.43	0.000
shape*color	2	0.00760	0.003798	0.35	0.707
Error	110	1.20129	0.010921		
Total	143	3.06086			

Figure 32. ANOVA result of Overall Workload

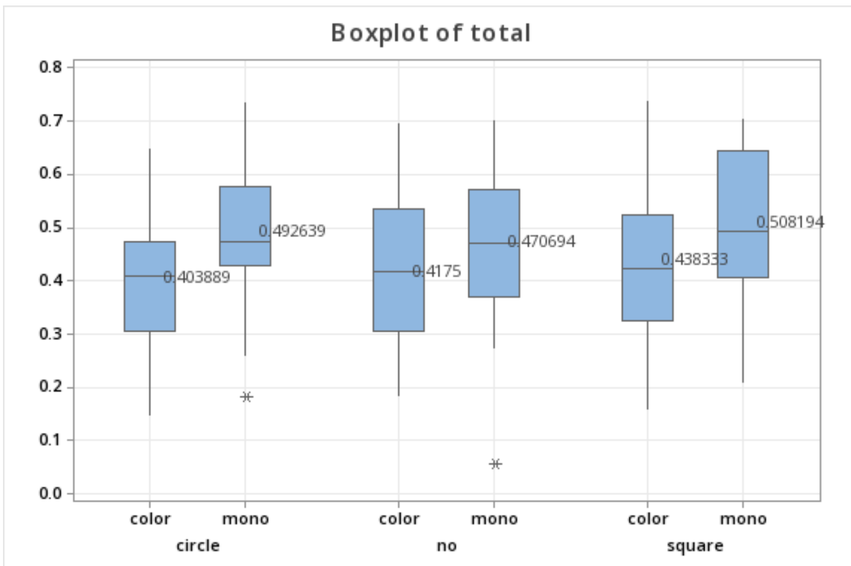


Figure 33. The Boxplot of Overall Workload

The rank is as follows for overall workload: CircleBorder/Color (0.40), NoBorder/Color (0.41) SquareBorder/Color (0.43), NoBorder/Mono (0.47), CircleBorder/Mono (0.49), SquareBorder/Mono (0.50).

3.6 Subjective Satisfaction

The study examined the effect of Independent Variables (the 6 sets: SquareBorder/Mono, Circle Border/Mono, Noborder/Mono, SquareBorder/Color, CircleBorder/ Color, and Noborder/Color) on the Dependent Variables (Effectiveness, Aesthetics, and Overall Satisfaction). The interview was conducted after the experiment. Results of the Kruskal-Wallis test for the 6 set and the Effectiveness (χ^2_5=46.53, $p < 0.001$) Aesthetics (χ^2_5=51.84, $p < 0.001$), and Overall Satisfaction (χ^2_5=48.80, $p < 0.001$) were significant. For effectiveness, participants think it is effective when the IVIS is giving the guidelines by having a color. Participants think it is satisfying to have border, especially square. For aesthetics, Participants thinks it is aesthetically pleasing when it has color. For overall satisfaction, Participants thinks it is satisfying when it has border and color.

The ranking for Effectiveness is as follows: SquareBorder/Color, CircleBorder/Color, Noborder/Color, SquareBorder/Mono, CircleBorder/Mono, Noborder/Mono in Figure 32. Participants thought it is effective when the infotainment system is giving the guidelines by having a border. The ranking for Aesthetics is as follows: Noborder/Color, CircleBorder/Color, SquareBorder/Color, Noborder/Mono, CircleBorder/Mono, SquareBorder/Mono in Figure 33. Participants thought it is aesthetically pleasing when it has no border and less informative. The ranking for Overall Satisfaction is as follows: SquareBorder/Color, CircleBorder/ Color, Noborder/Color, SquareBorder/Color, SquareBorder/Mono, CircleBorder/Mono, Noborder/Mono. Figure 34, 35 and 36 shows the rank of Effectiveness, Aesthetics, and Overall Satisfaction.

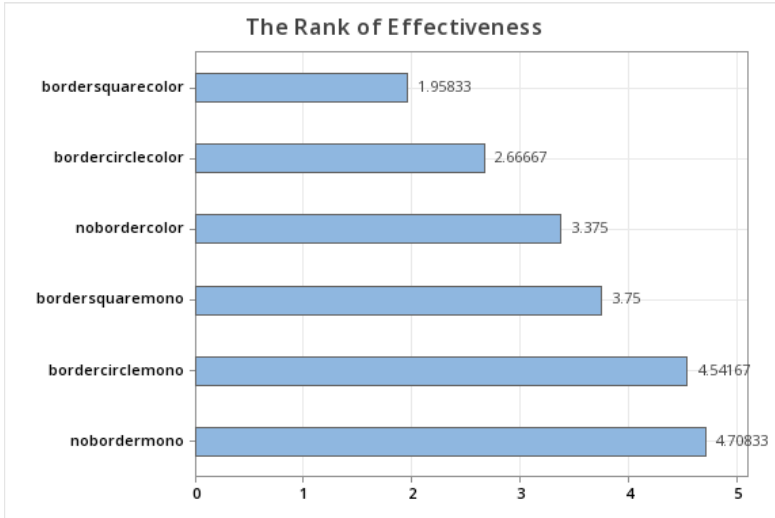


Figure 34. The Rank of Effectiveness

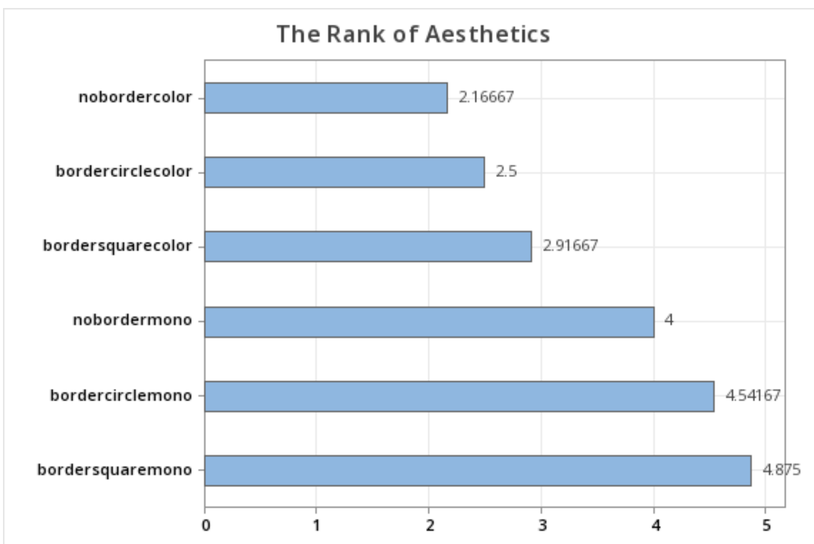


Figure 35. The Rank of Aesthetics

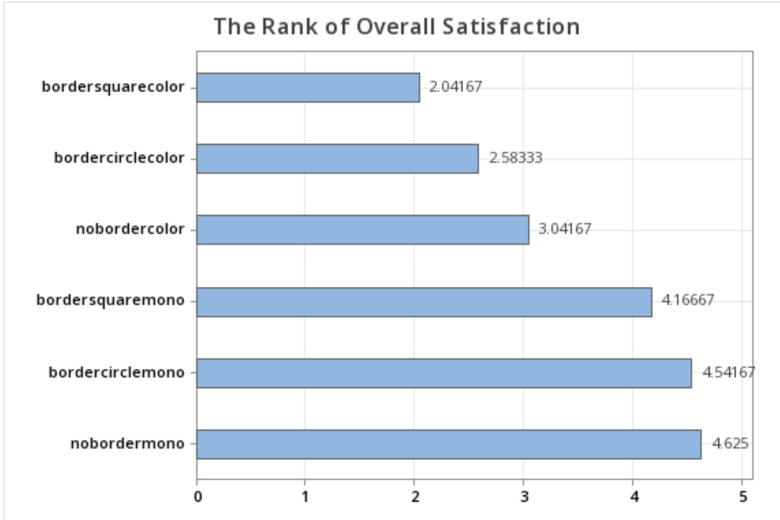


Figure 36. The Rank of Overall Satisfaction

3.7 Post-Experiment Questionnaire and Interview

After the experiment, post-experimental interviews were conducted with all 24 participants. The opinions seem to come from various individuals discussing their perceptions and experiences with these design choices. Table 2 shows the comments from the Post-Experiment Interview.

Table 2. Comments from the Post-Experiment Interview

Comments		
NoBorder vs SquareBorder vs CircleBorder	No Border	“When it has no border, I feel less distracted, border was another information to me” "I prefer no border because they take less space on display, I found it simple and beautiful” “If there's no line, I might misclick the wrong area”
	Border	“Border is preferable. It is very clear and letting me know where to put my finger” “It’s reducing the risk of misclicks” “Border is one of the information and that makes the design cluttered”
	Square	“Square visually looks bigger area to click enough” “Square aesthetically looks too strict and normal, so it is not that fancy"
	Circle	“I think circle is beautiful because every icon seems quite circular and harmonious” “Circle seems smaller than square, when it is circle border, everything looks all circle and circle and circles. That makes me confusing”
Color vs Mono	Color	“I think there is a color advantage: it is very easy to memorize like blue is weather, red is music”

		“color helps some icons really stands out, so it’s not confusing”
	Mono	“Mono looks beautiful to me because I love simple” “I feel relaxed, it is uncluttered icon and I feel less distracted” “If it is mono, it will be confusing to distinguish” “White border with mono makes all the same and it’s not safety”
Preference for Clear Boundaries and Lively Designs		“There's an advantage to using color in design. It's like having a visual memory aid. For example, it’s easy to remember the icon”
Preference Clean and Simple Designs		“Simplicity in design is important to me and it helps reduce confusion”
Consideration of User Habits and Mental Models		"I am always used to color, for me red is ‘Youtube’ and green is ‘call,’ so I can relate to the icon color as red for music and green for call”

3.8 Discussion

1. The findings indicated that color significantly affected task completion time, driving performance, subjective workload, satisfaction, and usability compared to a mono scheme.
2. While the shape of border did not significantly impact performance, participants

exhibited diverse preferences based on visual attractiveness and usability advantages on border.

3. Border vs. No Border: Some prefer designs with borders because they make the icons stand out and provide a clear visual separation. Others like the clean and uncluttered look of icons with no borders, finding them visually pleasing.
4. Square vs. Circle: Square shapes are seen as having a sharper and more defined feature, while circles are appreciated for their aesthetic appeal, especially when icons are circular in nature.
5. Color vs Monochromatic: Color is generally favored for its ability to help differentiate icons. However, it's mentioned that color can be confusing if similar colors are used, and clarity is essential. Monochromatic designs, which typically use a single-color scheme, are appreciated for their simplicity and lack of distraction.
6. Preference for clear boundaries and lively designs: Most people express a preference for standing out and memorable design, which may align with the border and color preferences.
7. Preference Clean and Simple Designs: Few individuals express a preference for clean, simple, and uncluttered designs, which may align with the no-border and monochromatic preferences.
8. Consideration of User Habits and Mental Models: Some users mention that their preferences are influenced by their existing habits and mental models, such as associations between specific colors and functions.

In summary, these comments reflect diverse preferences when it comes to design elements like borders, shapes, colors, and simplicity. These preferences can vary based on user habits, usability considerations, and individual aesthetics. Design choices should often aim to strike a balance between aesthetics and usability, keeping the end user's needs in mind. Table 3 shows the summary of recommendations for the icon features based on the dependent variables.

Table 3. Summary of Recommendations for the Icon Features

Dependent Variables		**Shape of Border**	**Color**	**Shape of Border*Color**
Task Completion time	Task Completion time	-	Marginally Faster with color	-
Number of Errors	Number of Errors	-	-	-
	Number of Misclicks	-	-	-
Eye Profile Data	Eye Dwelling Time	-	-	-
	The Number of Glance	-	-	-
Driving Performance	Mean of Longitudinal Position	-	Consistent with color	-
	Mean of Lateral Lane-Keeping Position	-	-	-
	Mean of Speed	-	-	-
	Mean of Steering wheel Consistency	-	-	-
	Mean of Brake Pedal Press	-	-	-
	Mean of Gas Pedal Press	-	-	-
	Stdev. of Longitudinal Lane-Keeping Stability	-	Consistent with color	-
	Stdev. of Lateral Lane-Keeping Stability	Stable with Shape (NoBorder, Square)	-	-
	Stdev. of Speed	-	-	-
	Stdev. of Steering wheel Consistency	-	-	-
	Stdev. of Brake Pedal Press	-	-	-
	Stdev. of Gas Pedal Press	-	Low Gas Pedal Usage With mono	-

Subjective Workload NASA-TLX (0~20 score)	Overall Workload	-	Lower Workload, High Confidence with color	-
	Mental Demand	-	Lower with color	-
	Physical Demand	-	-	-
	Temporal Demand	-	Lower with color	-
	Effort	-	Lower with color	-
	Performance	-	High Confidence with color	-
	Frustration	-	Lower with color	-
Subjective Satisfaction	Effectiveness	High Effectiveness with Shape (Square)	High Effectiveness with color	-
	Aesthetics	High Aesthetics with Shape (No Border)	High Aesthetics with color	-
	Overall Satisfaction	High Satisfaction with Shape (Square)	High Satisfaction with color	-

Chapter 4. Conclusion

4.1 Summary of Study

In summary, this research has examined the design principles of Human-Machine Interface, especially infotainment systems, with a specific focus on their impact on driving performance and driving satisfaction. Specifically, the study investigated the influence of design factors such as the shape of border (square or circle), and the color of icons (color or monochrome). The main objective of the study was to investigate the impact of various design elements on the usability of In-Vehicle Information Systems (IVIS). A study was conducted to test objective task performance utilizing a driving simulator and integrated with prototypes, as well as to assess subjective workload and preference.

The findings indicated that color significantly affected task completion time, driving performance, subjective workload, satisfaction, and usability compared to a mono scheme. This suggests that the usability is influenced by the color that is visually distinct and easily remembered. The square and circle shapes mostly do not have a significant impact on performance. However, they have received positive feedback in terms of subjective preference for various reasons. The presence of a border on the button gives distinct and easily recognizable visual indicators to the user. Additionally, the border assists in guiding the user's finger placement, hence enhancing task performance.The participants showed a diverse range of preferences for square and circular shapes, as they recognized the visual attractiveness of circular icons while also admitting the usability advantages of square shapes.

Overall, the research generated insights for enhancing icon design to optimize information display and input effectiveness in IVIS. The study's outcomes have generated suggestions on the design of touch buttons, and color combinations to enhance the effectiveness of information display and input. This study may be built upon by these results in the future.

4.2 Caveats and Future Study

The first caveat of this study was a limited demographic, primarily restricted to the 18-30 age group, potentially overlooking differences related to age. A more extensive sample with a broader spectrum of ages and varying levels of driving experience might yield more generalizable results. Additionally, the experiment was conducted on a highway, which differs from real road environment. Real road conditions are much more complex, with factors such as interactions with other vehicles, traffic conditions, road signs, and traffic lights affecting driving. Therefore, caution is required when extrapolating the experiment results to real road situations. Furthermore, the study only considered two shapes for the border shape and did not explore specific effective uses of color considered in the interface design. Only two shapes were used in the experiment. There were no significant variations found in the shapes of the buttons. Further research on various shapes and symbols is needed. In this study, color combinations for the background, while label and fonts were selected based on suggestions in the literature and the results of research on actual cars. While the number of possible combinations could be various, only some color combinations were included in this study to avoid oversizing the experiment. Further research is needed to study more color combinations. Other functions that are including icons such as label, fonts are needed to study. In the future, it is necessary to conduct detailed studies in which various edge colors and thicknesses are considered. Many vehicles have touch screens, while the majority are limited to the infotainment system. On the other hand, the number of physical buttons on steering wheels is increasing because of the addition of functions. The results of this IVIS study, which was focused on the operation of touch buttons, can be used basic information for the design of the touch button working area.

Appendices

Appendix A. Consent Form

HUM00233009

UNIVERSITY OF MICHIGAN
CONSENT TO BE PART OF A RESEARCH STUDY

The Effects of Icon features in Vehicle Infotainment Systems on Drivers' Performance, Perception, and Distraction

Principal Investigator: Seungju Choi (Jubilee)
Faculty Advisor: Dr. Sang-Hwan Kim
Study Coordinator: Seungju Choi (Jubilee)

You are invited to take part in a research study and this form contains information that will help you decide whether to join the study. Taking part in this research project is voluntary. You do not have to participate, and you can stop at any time. Please take time to read this entire form and ask questions before deciding whether to take part in this research project.

Purpose of this study
The purpose of this study is to evaluate the influence of Infotainment icon features on driving performance throughout a controlled experiment using a driving simulator. By doing so, we hope to develop design guidelines and suggestions for infotainment icon system in vehicles for more convenient and safe driving.

Who can take part in this study?
This study selects the participants based on the criteria below.
Participants who are 18 to 50 years old are eligible for this study. All participants should be U.S. licensed drivers, fluent in English, and should not have specific limitations on physical and/or cognitive ability for driving.

What will happen to me in this study?
If you agree to participate in this study, you will be asked to complete the entire experiment according to the following procedures:

1)10 minutes of administrative details and explanation of the procedure, task, and equipment for the experiment. This step involves completion of paper documents, including a demographic questionnaire.
2) Instructions will be given, and a practice trial with driving simulator will be done. In order for you to be familiar with the simulator and experiment procedure, you will be asked to "drive safely" in the driving simulator, meaning driving while a) while maintaining a consistent speed, b) keeping a centered lane position. This should take approximately 5 minutes.
3) After the practice trial, six tests will be performed.
4) Once all test trials are completed, you will be asked to express your general comments and subject preference on each Icon layout as well as other design suggestions, as a part of debriefing.

How much of my time will be needed to take part in this study?
The entire experiment is expected to take approximately an hour. During the experiment, breaks will be given at any time whenever you may ask. Also, experimenter will ask whether you need a break between each phase of experiment.

What risks will I face by taking part in the study? What will the researchers do to protect me against these risks?
The risks associated with participation in this study are unlikely and minimal. If there is, it may include: potential visual strain and/or fatigue from viewing the driving environment display and system control interface on LCD monitors for an extended period of time, soreness of the hands and/or feet from use of vehicle controls, fatigue, and motion sickness due to the simulation driving with looking at the screen. These risks are not substantially different from those associated with everyday use of driving a car and video game. In the event that you indicate fatigue or discomfort during the experiment, including motion sickness, a rest period will be provided. If abnormal physiological conditions persist, your participation in the experiment will be terminated. The researchers will try to minimize these risks by communication with you.

You are required to answer about their status after each test trial. The schedule of the experiment changes depending on your condition. If you are in poor condition, you can stop the test. You will also be given as many breaks as you want. You are requested to complete a questionnaire after the test trial. You do not have to answer any questions you do not want to answer. Because this study collects information about you, one of the risks of this research is a loss of confidentiality. See other section of this document ***("What will happen to the information collected in this study? ")*** for more information on how the study team will protect your confidentiality and privacy.

If I want to stop participating in the study, what should I do?
You are free to leave the study at any time. If you leave the study before it is finished, there will be no penalty to you. If you decide to leave the study before it is finished, please tell one of the persons listed in the section of "***Who can I contact about this study?***". If you choose to tell the researchers why you are leaving the study, your reasons may be kept as part of the study record. The researchers will keep the information collected about you for the research during the study unless you ask us to delete it from our records. If the researchers have already used your information in a research analysis it will not be possible to remove your information.

How will the researchers protect my information?
Any of your personal information will not be collected except your age, gender and basic driving experience in the demographic qestionnaire. Only participant number will be used for the study. Your personal information such as name and email address that you have provided us duirng recruiting process will be destroyed. In addtion, all dataset incluidng your performance data and video files will be kept confidentially, such as stored in locked office, cabinet, and secured laptop.

Who will have access to my research records?
Only research staff described at top of this document, including PI and study coordinators can access your research records. However, based on need, legal personnel such as University, government officials, study sponsors or funders, auditors, and/or the Institutional Review Board (IRB) may access the records.

What will happen to the information collected in this study?
We will keep the information we collect about you during the research for this research only. We will not keep your name or other information that can identify you directly. The dataset that you are going to provide will be analyzed using de-identified information such as participant number. However, after completion of the study, all the information including your personal information will be completely destroyed.

Will my information be used for future research or shared with others?
Once the data analysis completed the results of this study could be published in an article or presentation. Any reports of this study will not present individual response information. Data will be analyzed and reported based average responses and standard deviations for the experimental conditions. Also, the dataset that you provide will not be shared any future research nor others.

Who can I contact about this study?
Please contact the researchers listed below to:

- Obtain more information about the study
- Ask a question about the study procedures
- Report an illness, injury, or other problem (you may also need to tell your regular doctors)
- Leave the study before it is finished
- Express a concern about the study

Principal Investigator: Seungju Choi(Jubilee)
Email: jubileee@umich.edu

Faculty Advisor: Sang-Hwan Kim
Email: dysart@umich.edu

Consent/Assent to Participate in the Research Study
By signing this document, you are agreeing to be in this study. Make sure you understand what the study is about before you sign. We will give you a copy of this document for your records and we will keep a copy with the study records. If you have any questions about the study after you sign this document, you can contact the study team using the information provided above.

I understand what the study is about and my questions so far have been answered. I agree to take part in this study.

Print Legal Name: ____

Signature: ____

Date of Signature (mm/dd/yy): ____

Investigators are reminded that they should give a copy to the participant and retain a full copy of the consent including a copy of the signature page as part of your research records. Participants must complete all of the required information (printed name, signature and date).

Consent to use video recordings and audio recordings for purposes of this research.
This study involves video and audio recordings. If you do not agree to be video and audio recorded, you can still take part in the study.

_____ *Yes, I agree to be video recorded and audio recorded.*

_____ *No, I do not agree to be video recorded and audio recorded.*

Print Legal Name: ____

Signature: ____

Date of Signature (mm/dd/yy): ____

Consent to use of video recordings, audio recordings or photographs for publications, presentations or for educational purposes.
I give permission for audio recordings/video recordings/photographs made of me as part the research to be used in publications, presentations or for educational purposes.

_____ *Yes*

_____ *No*

Print Legal Name: ____

Signature: ____

Date of Signature (mm/dd/yy): ____

Appendix B. Demographic Question Survey Form

HUM00233009

Demographic questions

Thank you for participating the experiment. This research is conducted by graduate students at University of Michigan - Dearborn working on research about the effects of icon features in Vehicle Infotainment Systems on drivers' performance, perception, and distraction.

Research Information

Department of Industrial and Manufacturing System Engineering,
University of Michigan - Dearborn

Researchers:
Seungju Choi (jubileee@umich.edu)

Faculty Advisor:
Dr. Sang-Hwan Kim (dysart@umich.edu)

HUM00233009

1. **Name:** ____

2. **What is your age?** ____

3. **What is your gender identity?**

   Female / male / other / do not reply

4. **What is your level of education?**

   Less than high school

   High school graduate

   Associate degree

   Bachelor's degree

   Professional degree

   Doctorate

5. **Do you have a valid U.S. driver license?**

   Yes
   No
   No, but I have a driver license in other country.

6. **How many years have you been driving?**

   ____

7. **How many times have you had car accidents within 3 years?**

   ____

8. Do you have a touchscreen (infotainment system) in your car?

Yes

No – > This is the end of the survey.

8-1. If yes, How often do you use your infotainment system while driving?

Always

Usually

Sometimes

Seldomly

Never

8-2. If yes, Do you use Apple carplay or Android Auto?

No

Yes, Apple Carplay

yes, Android Auto

Appendix C. NASA-TLX

Subjective Comparison of Demand Factors:

For each of the pairs listed below, circle the scale title that represents the more important contributor to workload in the display.

Mental Demand	or	Physical Demand
Mental Demand	or	Temporal Demand
Mental Demand	or	Performance
Mental Demand	or	Effort
Mental Demand	or	Frustration
Physical Demand	or	Temporal Demand
Physical Demand	or	Performance
Physical Demand	or	Effort
Physical Demand	or	Frustration
Temporal Demand	or	Performance
Temporal Demand	or	Frustration
Temporal Demand	or	Effort
Performance	or	Frustration
Performance	or	Effort
Frustration	or	Effort

Definition of Task Demand Factor

Mental demand

How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

Physical demand

How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Temporal demand

How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

Performance

How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

Frustration level

How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Effort

How hard did you have to work (mentally and physically) to accomplish your level of performance?

Subjective Comparison of Demand Factors

Please place an "X" along each scale at the point that best indicates your experience with the display configuration.

Mental Demand: How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc)? Was the mission easy or demanding, simple or complex, exacting or forgiving?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

Physical Demand: How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the mission easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

Temporal Demand: How much time pressure did you feel due to the rate or pace at which the mission occurred? Was the pace slow and leisurely or rapid and frantic?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

Performance: How successful do you think you were in accomplishing the goals of the mission? How satisfied were you with your performance in accomplishing these goals?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

Effort: How hard did you have to work (mentally and physically) to accomplish your level of performance?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

Frustration: How discouraged, stressed, irritated, and annoyed versus gratified, relaxed, content, and complacent did you feel during your mission?

Low |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| High

Appendix D. Post Experiment Survey

HUM00233009

Post Experiment Survey & Open-Ended Questions

Thank you for participating the experiment. This research is conducted by graduate students at University of Michigan - Dearborn working on research about the effects of icon features in Vehicle Infotainment Systems on drivers' performance, perception, and distraction. The purpose of this survey is to focus on your personal preference about the 6 sets of icon features.

Research Information

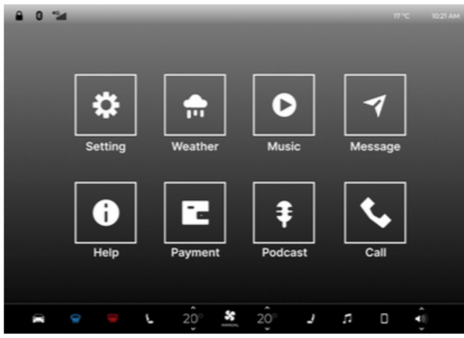
Department of Industrial and Manufacturing System Engineering,
University of Michigan - Dearborn

Researchers:
Seungju Choi (jubileee@umich.edu)

Faculty Advisor:
Dr. Sang-Hwan Kim (dysart@umich.edu)

HUM00233009

1. Rank the **effectiveness** of the 6 sets of icon features.



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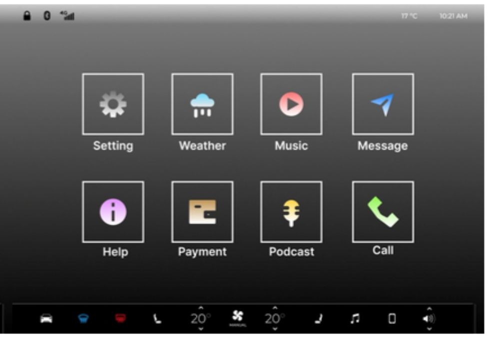

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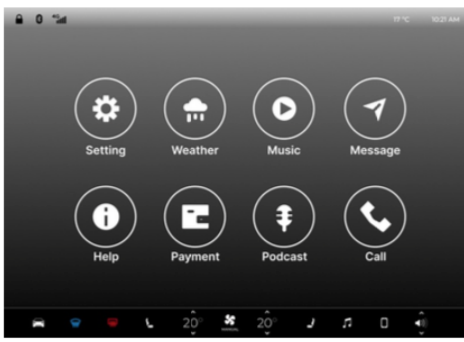

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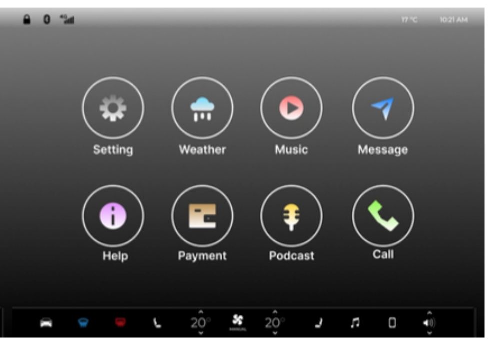

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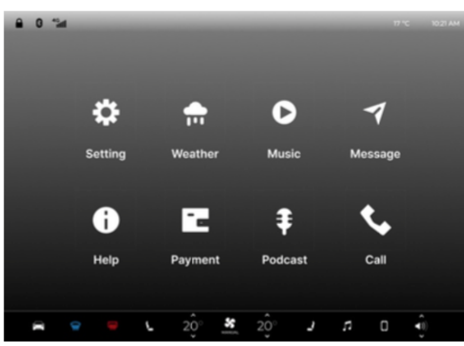

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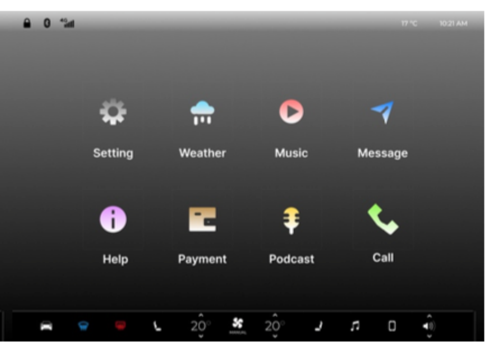
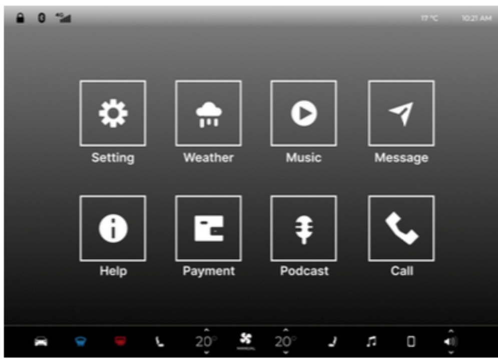
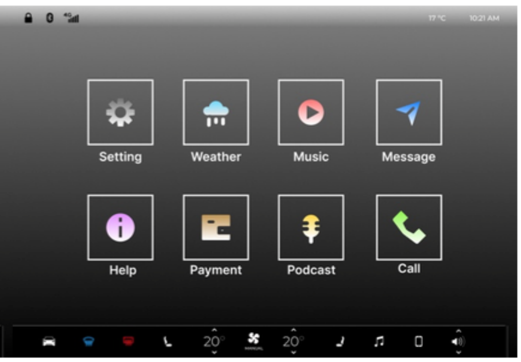


6

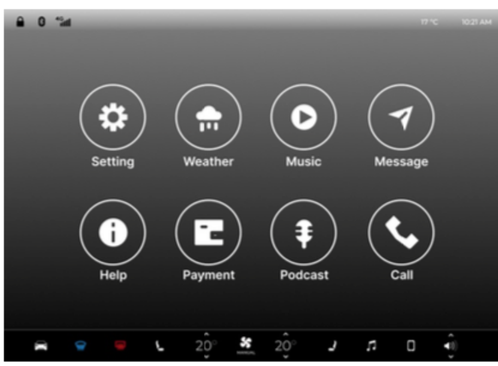
2. Rank the **aesthetics** of the 6 sets of icon features.



1



2



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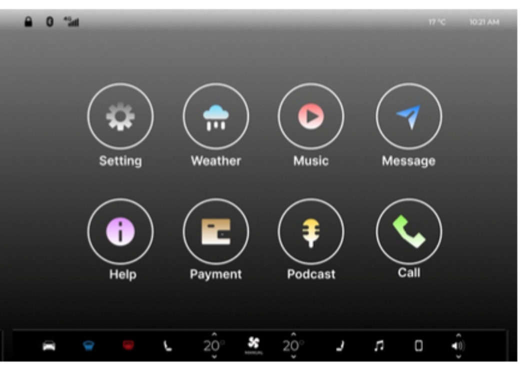

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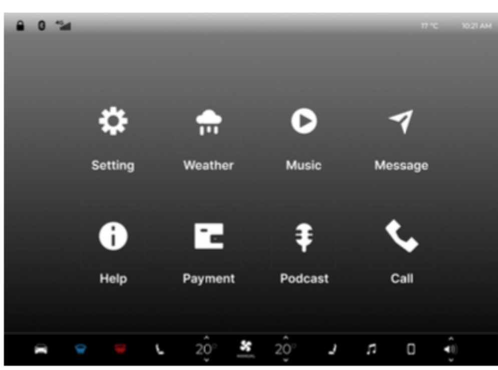

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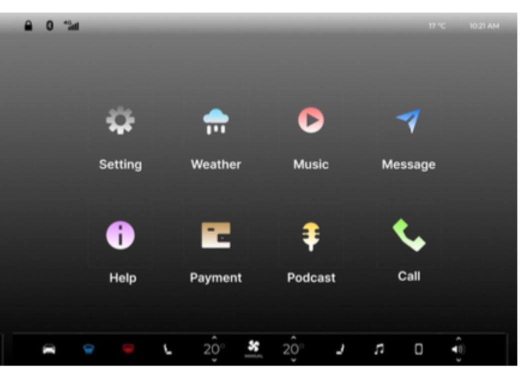
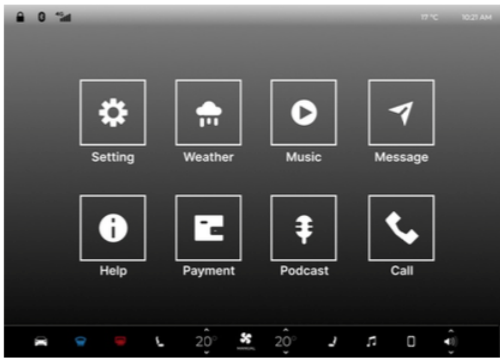


6

3. Rank the **overall satisfaction** of the 6 sets of icon features.



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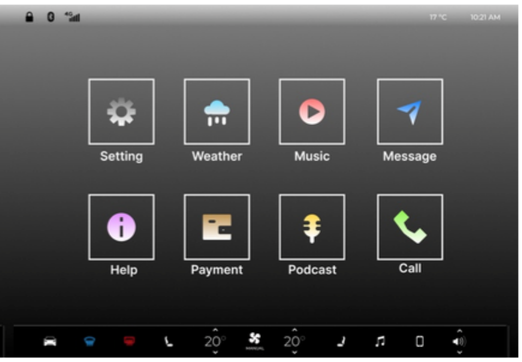
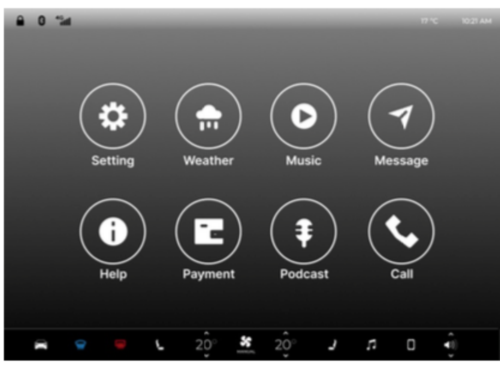
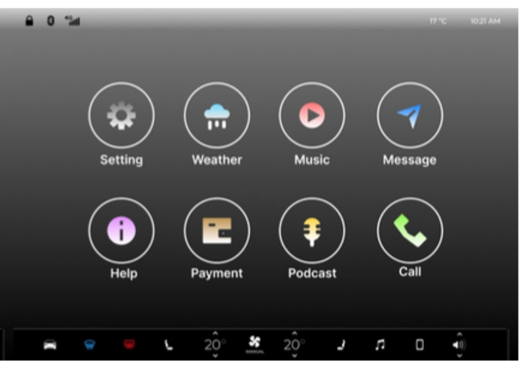


2



3



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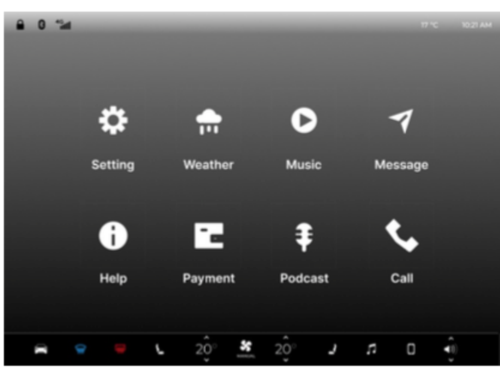

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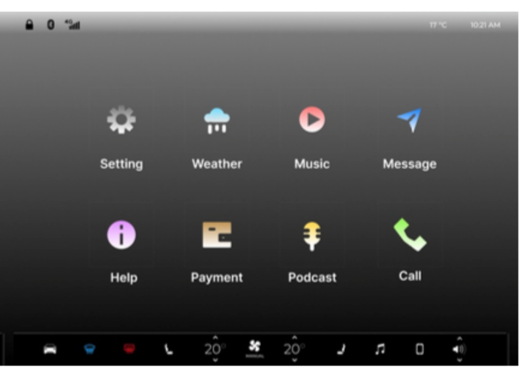

6

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