Investigating effects of font faces and line spacing in vehicle Infotainment system on driver performance including driving distractions.

by

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ABSTRACT

The objective of this study was to investigate the legibility of font faces and line spacings used in actual commercial in-vehicle displays by three empirical studies. A total of four fonts were selected, including three fonts from the automotive market and one font for a baseline. The three fonts called the font V, F, and T have different characteristics in their typeface style, each representing the humanist style, the geometric style, and the square grotesque style. The first experiment examined the impact of 4 types of font face on the tracking performance, distinguishing correct word among the visually similar words. The results demonstrated the font T was associated with the best tracking performance, while the font V induced poor tracking performance. Also, the results showed the secondary task arouses the cognitive workload that negatively affects performing the primary task.

The second experiment asked participants to understand the messages' context and fill out the same texts' blanks. The results revealed no significant difference in the tracking performance with the font face styles and the line spacings. However, the distraction of the secondary tasks was validated with this experiment. These results demonstrated that the types of fonts or line spacings do not influence comprehending the context and tracking performance. On the other hand, the subjective preference survey demonstrated that participants preferred the font F and V, but the font C. Also, they rated the largest line spacing the best, which was 180% of the font size.

Only the eye dwell time on the secondary task area was examined across the font faces and the line spacings for the last experiment. The results presented no significant differences

in the eye dwell time with the font faces and the line spacings. The prior research explained these results about eye-glance behavior in driving situations, proposing that eye-glance behavior is a human's intrinsic behavior. That is, eye dwell time is not determined by the design factors, but by the humans' action of instinct.

Consequently, the consideration of font faces may be utilized for the in-vehicle interface design, which required drivers to distinguish certain words among others

CHAPTER 1

INTRODUCTION

1.1. Importance of user interface in in-vehicle display

Distracted driving is generally defined as when a driver's attention is deflected from the driving task itself to a secondary task (Ranney, 2008). Driver distraction is a significant cause of vehicle accidents. There are many sources of driving distraction (Strayer et al., 2011). Some traditional factors such as talking to passengers, drinking, listening to the radio, eating, lighting a cigarette, applying makeup, and reading were considered the main reasons for driving distraction (Stutts et al., 2003). However, as more and more vehicles tend to have in-vehicle screens and the use and role of screens in vehicles becomes more diverse and vital, driving distraction sources becomes broader and more complex (Dobres et al.,2014). Strayer et al. proposed the three sources of driving distraction: manual impairment, cognitive impairment, and visual impairment (Strayer et al., 2011). Manual impairment occurs as drivers take their hands off the steering wheel to operate functions from the infotainment system. Impairment to cognition can cause when drivers withdraw attention from driving to operate secondary tasks. Lastly, visual impairment occurs as drivers take off their eyes from the road to implement secondary tasks' visual information processing.

According to Bach et al., the 90 percent feedback that drivers inquire about while they are engaging in driving is visual information (Bach et al., 2009). As the in-vehicle display's role, providing necessary visual information to drivers, becomes more critical, designing an infotainment system has faced challenges such as decreasing visual distraction while driving and optimizing the environment of the display, including contrast and brightness

(Sonnenberg,2010). Since drivers have to recognize visual information accurately in a short time while driving, the interface of the screen has to be designed precisely, particularly in terms of legibility. As drivers obtain information on the display with glance looking, it is explicit to ensure that interfaces are optimized to interact with drivers quickly and accurately (Dobres et al., 2016). Therefore, minimizing visual demands and reducing off-road glance time is critical in designing in-vehicle infotainment systems (Dobres et al., 2016)

1.2 Extrinsic factors of Legibility

Legibility means the extent of how the characters are easily read in terms of typography features (Kim & Park, 2012). Legibility is highly influenced by the font, which has two factors: Extrinsic and intrinsic (Reimer et al., 2012). Extrinsic factors are psychophysical considerations and do not include graphical shapes of characters (Bigelow & Matteson, 2011), (Reimer et al., 2014). It includes the size, contrast, polarity, illumination, and color of the font (Bigelow & Matteson, 2011). On the other hand, intrinsic factors refer to altering the shapes of characters, including case, width, weight, and serifs (Bigelow & Matteson, 2011), (Reimer et al., 2014). Several previous studies that researched extrinsic factors revealed that the size of the text has a significant effect on legibility and reading speed (Legge & Bigelow, 2011). In this regard, the height of fonts is suggested to be 3.1mm in minimum in static situations. As the vehicle's movement and shivering reduce the legibility, the minimum height of a character is recommended as 4.9mm (UMTRI, 1994). According to Green, in-vehicle infotainment systems, the value that comes from the height of font(H) being divided by distance(D) should be more significant than 0.007 ($H/D > 0.007$) (Green, 1999).

Line spacing implies the space between the baselines of two text lines (Rello et al., 2016). By designing interfaces in the computer, the line spacings are provided by default relative to the font size. A spacing of 1.0 equals 120% of the font size (Sawyer et al., 2020).

According to Bix, the optimal line spacing is dependent on the design of typeface and layout, except for the general suggestion to sublate extreme line spacing (Bix, 2002).

1.3 Intrinsic factors of Legibility

Compared to extrinsic factors, intrinsic factors have not been extensively studied (Bigelow & Matteson, 2011). Selecting a typeface for design is not a simple task and requires many considerations (Sawyer et al., 2020). There are amounts of research that explore the graphical factors of fonts, such as serif or sans-serif, and different font styles. Serif refers to a feature that is an extended line from the end of the strokes. So, serif fonts indicate the group of fonts that have serif on their strokes, while sans-serif, where ‘sans’ means 'get rid of', means the group of fonts that do not have serifs. Dobres et al. compared the relative legibility of four san-serif Chinese typefaces and one serif Chinese typeface. They found out that the serif typefaces with complex strokes were less legible on screen. Moreover, the most legible typeface was more efficient by 33.1% than the least legible typeface (Dobres et al., 2016).

Reimer et al. experimented with two typefaces (which were "square grotesque" and "humanist"). In Figure 1, the upper characters represent the square grotesque typefaces, while the lower show the humanist typeface style. Reimer et al. assumed that the humanist typeface style might be more legible as it has more distinguishable features on the characters. For instance, the humanist font face characters have more traits that make them evident within the sentence, as having more open space in the characters and different spaces between the characters. They revealed that the "square grotesque" typeface increased visual demand for men when compared to the "humanist" typeface since the humanist typeface induced shorter glance time and lower error rates (Reimer et al., 2012). This finding was supported by other research by Dobres et al., indicating humanist-style typeface was significantly more legible than a square grotesque-style typeface (Dobres et al., 2016).

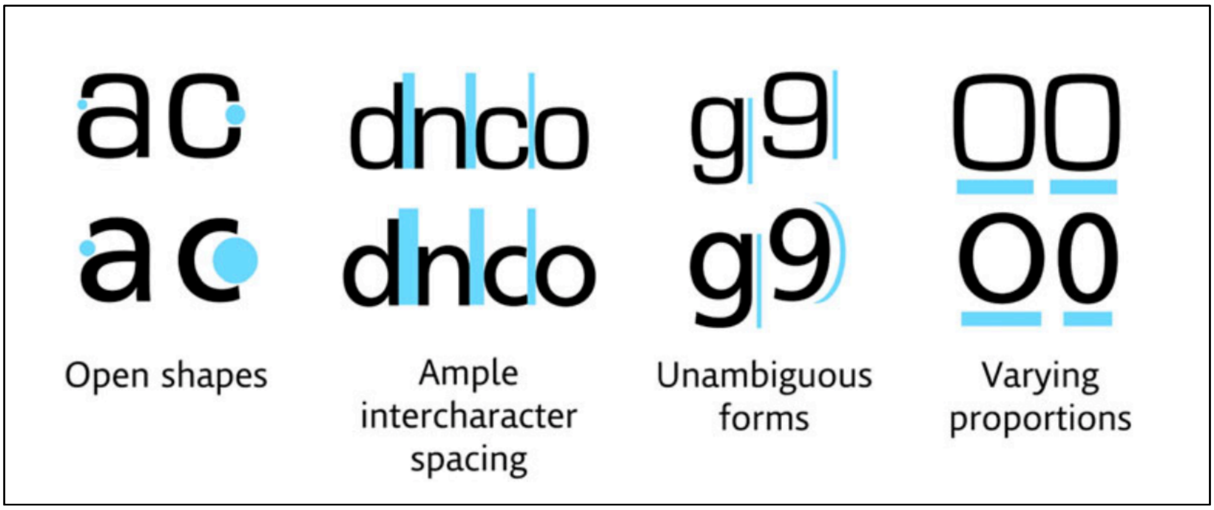

Figure 1. The comparison of the humanist and the square grotesque typeface by Reimer et al. (Reimer et al., 2012).

1.4 Objective of the Research

The present study aims to explore whether typeface design characteristics—that are currently in use in the automotive industry for in-vehicle displays and the extent of line spacing—can impact legibility in an in-vehicle display context in a manner that can be objectively measured. In this regard, the typefaces with apparent differences in graphical features and are currently occupied for in-vehicle displays were considered. For comparison, three typeface designs from the automotive industry, and one typeface design for a baseline, were selected. Two of the typefaces, the font V and the font F, each has strong characteristics of each humanist style and grotesque style. The font T has characteristics of both humanist and grotesque genres, which can be inferred as geometric sans-serif. The last typeface, the font C, is not involved in the humanist nor grotesque genre. Reimer et al. assumed that humanist genre typefaces are more legible because they have highly distinguishable features, such as open space inside the letterforms, ample space between the letterforms, and varied horizontal proportions (Reimer et al., 2012).

On the other hand, grotesque genre typefaces have opposite characteristics to humanists that cause ambiguity to be distinguished at a glance (Reimer et al., 2012). As illustrated in Figure 1, the font V typeface has more characteristics of the humanist genre, while the font F is closer to that of the grotesque genre. As Reimer et al. indicated, the font V characters have a more varied horizontal proportion, open space inside the character, and ample space between the character that makes it more distinguishable. .

This research presents the findings of two experiments the study of Reimer et al. (Reimer et al., 2012) designed to assess which typeface design impacts legibility for drivers. The first experiment aimed to assess four different typefaces' legibility in selecting a navigation setting location. The second condition assessed the impact of the typeface designs and line spacing on glance behavior.

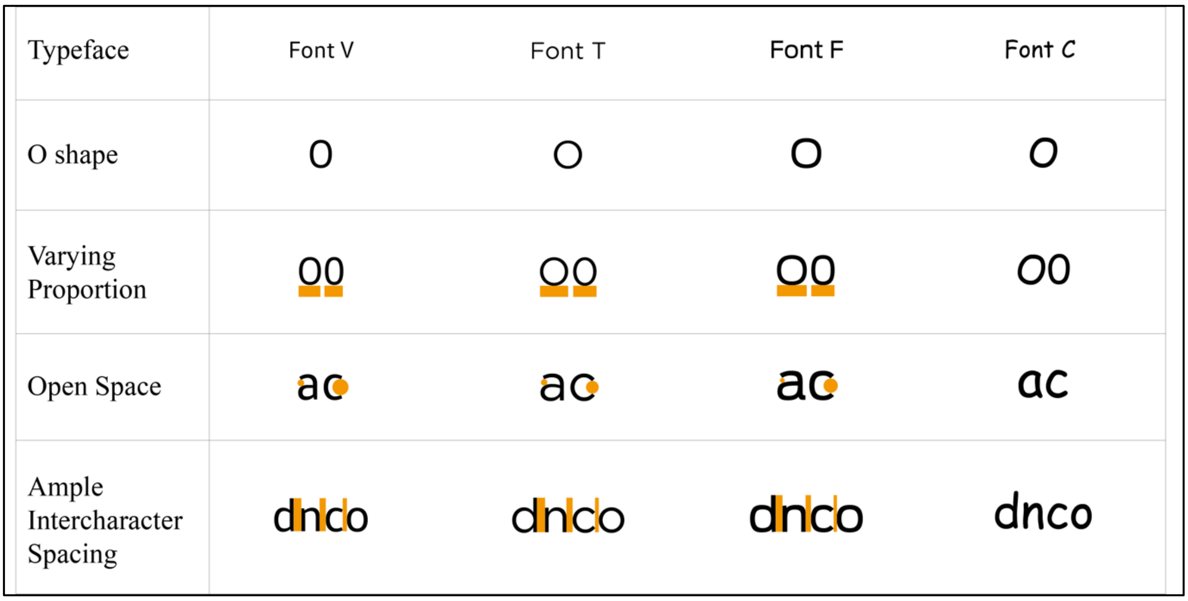

Figure 2. The characteristics of each font faces based on the study of Reimer et al. (Reimer et al., 2012).

CHAPTER 2

EXPERIMENT I

The first experiment was designed to test our beliefs. First, engaging in the secondary task may influence the participants' tracking performance. The experiment process can be decided into three phases: the first phase, the second phase, and the third phase. The first phase represents how the participant engages in the primary task without information about the secondary task. Immediately after the first phase, an example word for the secondary task is given. The second phase still requires the participant to perform the primary task only, but unlike the first phase, the participant knows about the secondary task's words. Lastly, in the third phase, the participant is asked to attend the primary task and the secondary task simultaneously. Since each phase provides different types of information and multitasking, it was expected that the difference in each stage might influence the participants' tracking performance. Second, font face styles may impact participants' tracking performance, including the average distance between the participants' cursor and the target, tasks completing time (speed), and accuracy. Besides, as prior studies presented, the font face styles with similar features to humanist font style may positively affect participants' performance. In contrast, the font faces closer to square grotesque font style may lead to lower performance of the participants. Since current methods require participants to complete the secondary task with eye glancing while they are engaging in the primary task, which is tracking the target with their cursor, it was expected that different font face styles contribute to the difference in glance time.

2.1 Method

2.1.1 Participants

A total of 16 participants were recruited for this experiment. The volunteers were required to have sufficient experience using video conference tools and experience of using infotainment systems while driving. Participants in the experiment ranged in age from 20-35, with a mean of 28 years. Among 16 participants, ten people were male, and six were female.

All participants gave their consent to participate in the online form, as outlined by the Committee on the Use of Humans as Experiment Subjects of the University of Michigan. Before the training trial, all participants were asked to answer the survey questions to establish the general features of the sample population (see Appendix A). They were asked about the general driving experience, the number of car accidents they have experienced within three years, and the frequency of using the infotainment system while driving (e.g., Google Auto, Apple CarPlay, navigation). The participants reported an average of 6.53 years for driving experience (sd=4), an average of 0.93 times for experiencing car accidents within three years. On a scale ranging from (1=Never) to (5=Always), participants answered an average rating of 4.53 (sd=0.83) for the frequency of using the infotainment system when they are driving. It indicates that no to a minimal number of participants never use the infotainment system while driving.

2.1.2 Prototypes

A Java-based application was developed for the experiment and used to measure the participants' performance and accuracy. When the application is operated, the data includes the coordinate of the cursor, time, and the phases records in the experimenter's computer as a .txt format file. All the graphics used in the prototype were designed with Adobe Illustrator. The prototype consists of two screens: the prototype for participants and the experiment controller.

Apparatus The experiment was conducted in an online video conference tool. The experiment was run on a 2.5GHz MacBook Pro running Mac OS X 10.15.5. Stimuli were created by Adobe Illustrator and programmed using JavaScript. Stimuli were displayed on a MacBook monitor and shared the screen using an online video conference tool controlled by the researcher's keyboard. Participants completed given tasks using their mouse with remote control function embedded in the conference tool and gave an oral response to provided questions.

The prototype for the Participants. The prototype for the participants is shown in Figure 3. This prototype has two main task areas: one is for the primary task, and the other is for the secondary task. The primary task's task area is located at the prototype's eye level, representing a windshield area in vehicles. The orange circle in Figure 3, the target, was programmed to move randomly so that the participants can continuously engage in the primary task. Also, the black-lined circle is a cursor of the participants. The color of the cursor represents the participants' performance since it turns red when the cursor deviates a certain distance from the target.

The other task area in the lower right corner of the prototype is for the secondary tasks, representing an in-vehicle infotainment display. This section was designed to fit into the participant's peripheral vision to make participants move their focal point for completing the secondary tasks. As Figure 5 shows, the secondary task screens are appeared (Appendix 4). As one set of the experiment consisted of 8 trials, the prototypes for the screen were developed for a total of 8 questions, employing four types of font faces.

All typefaces' character heights averaged 3.1mm, measuring based on a 15-inch laptop monitor. This size is the minimum recommended size of the font on screen. Text was displayed on the pure white (RGB : 255, 255, 255) background with pure black color (RGB : 0, 0, 0).

Figure 3. The screen for the participants

The Experiment Controller. Figure 4 illustrates the experiment controller. This controller is developed for the experimenters to control the prototype for the participants. This controller is displayed on the extended monitor to only be seen by the experimenters. Since the participants occupy the mouse, the controller was designed to be operated by keyboards: "S" key and "Q" key. The primary task starts by pressing "S" key, and data starts recording from this point. The screens for the secondary tasks are also switched by pressing the "Q" key.

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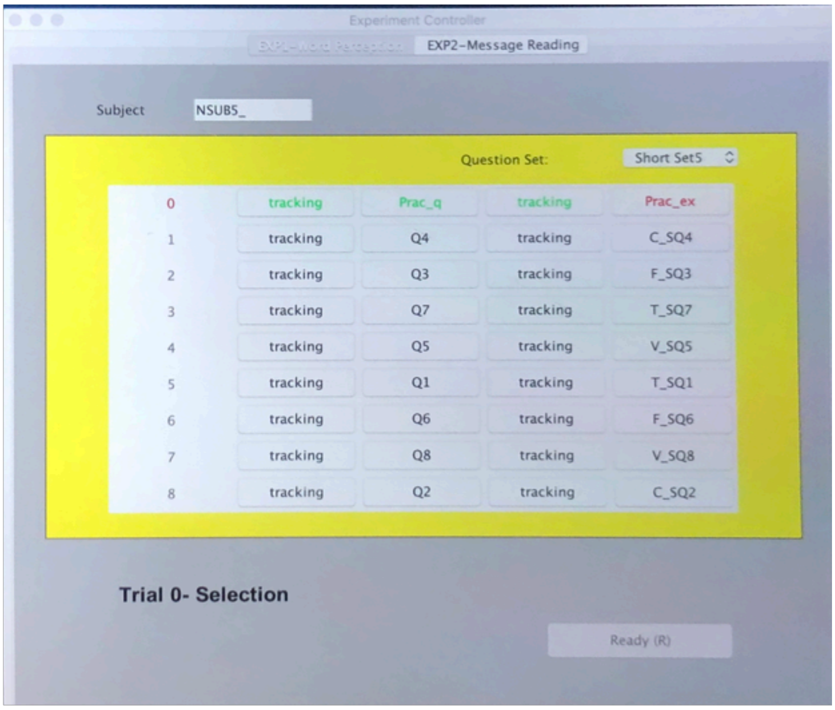

Figure 4. The experiment controller for the Experiment I.

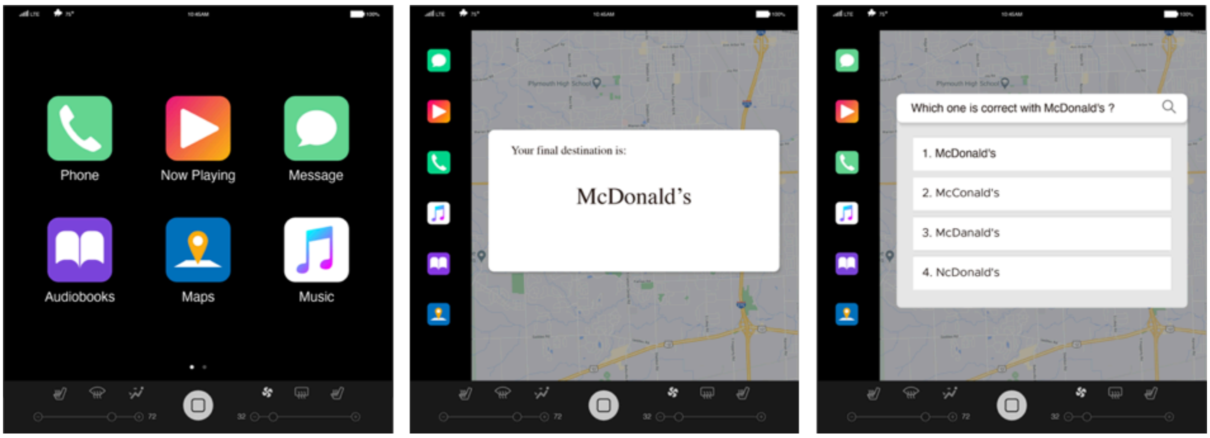

Figure 5. The secondary tasks' prototypes for the Experiment I.

2.1.3 Tasks

The participants' task was to perform the secondary task while engaging in the primary task simultaneously. All participants were given eight trial sets and one practice set before starting the experiment. After they completed all trials, they were requested to rank font face styles (see Appendix B).

The primary task. The primary task that is to chase the target circle, an orange circle in the Figure, with the cursor was designed by employing the task of Ballas et al. to make participants engage in the task as they were driving a car in an actual situation (Ballas et al., 1992). The target moves randomly along the x, y-axis by the sum of 9 random sine functions, and the participant follows the target by manipulating the cursor using the mouse. In this regard, the distance between the target and the participant's cursor indicates the driving performance.

The secondary task. The secondary task is employing a situation, selecting a destination in navigation. The procedure of the task is illustrated in Figure 7. As the one set of the trial started, participants were first asked to perform the primary task only. After a while, participants were given a word that refers to a destination, and they were instructed to engage in the primary task again. In the random point, the screen showed the options that consist of 3 options and 1 example word, and they asked to choose the provided location among the options. The options were employed visually similar words (e.g., Starbucks vs. Sturbucks, Starbacks, Starbocks), requiring participants to identify characters' differentiation accurately for correct target selection (Reimer et al., 2014). To not allow any biases, an irrelevant font face (e.g., Times New Roman) was employed for the example words.

Throughout the experiment, participants performed two sets per font face (2 sets x 4 font faces = eight trials) (see Appendix D). In order to make a fair comparison between the prototypes, all combinations that can be made with question type, font face types, and order were randomly shuffled

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2.1.4 Experimental Design and Procedures

The experiment employed a within-subject design. Participants completed eight trials in two prototypes for one font face style (2 set x 4 font faces = eight trials). The experiment included 128 trials across participants (16 participants x 8 trials).

Besides, the current study employed a novel experimental methodology, using a commercial video conference tool to collect participants' performance data. Figure 6 illustrates the overall method of operating experiments with a commercial video tool and the expected form of results. The experiment started with inviting participants to a video conference meeting room. After participants joined the meeting room, informed consent (see Appendix C) was reviewed and signed by the participants. Following the introduction, participants were asked general questions, including driving experience, residential area, the number of car accidents they have experienced within three years, and the frequency of using infotainment system as they are driving (see Appendix A). Afterward, participants were instructed to request the remote controlling function to the experimenter. The participants practiced with the prototype, including following the target with their cursor and performing the secondary task. These practices and the experimental session were implemented as many times as the participants wanted. When the participants felt familiar with the tasks, the regular experimental trial began, as Figure 7 describes. All participants completed eight trials for a set, and they were asked if they want to rest in the middle of the experiment. Each experiment set consisted of 8 trials, lasting approximately 15 minutes. After the participants completed all the trials, they were required to rank each four font faces based on their subjective preference.

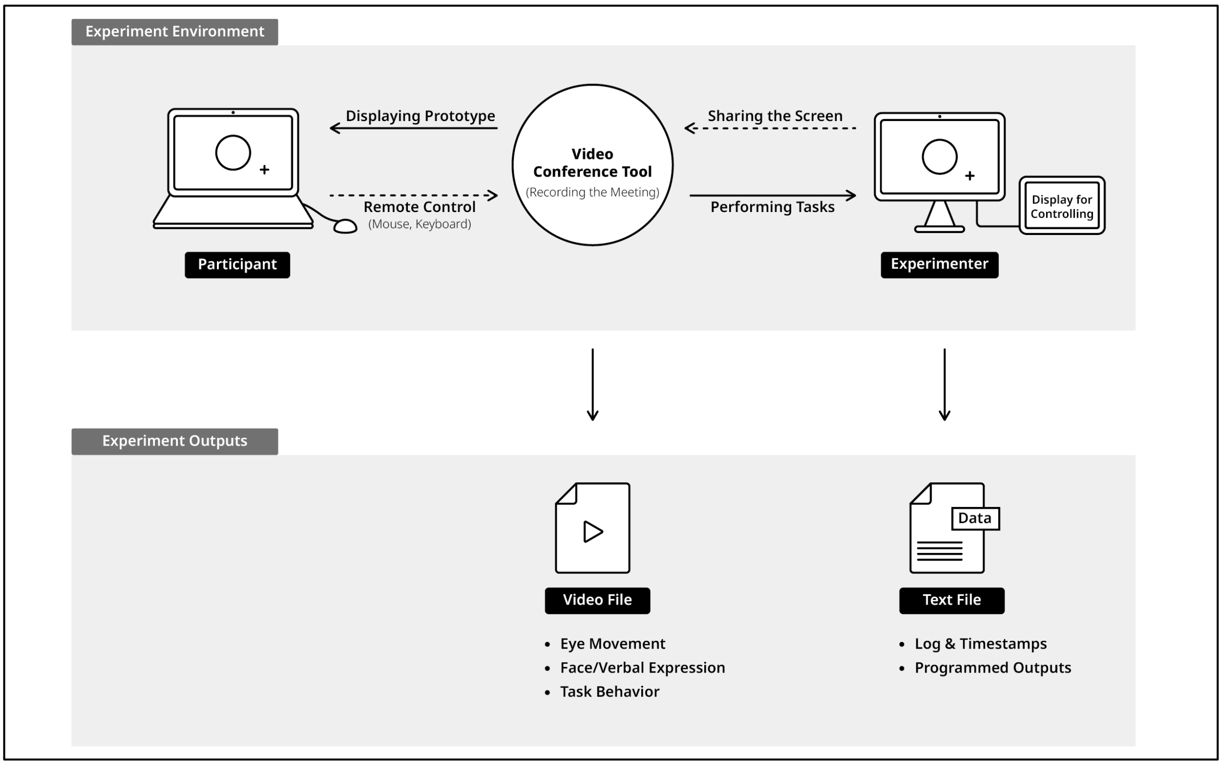

Figure 6. The overview of the experimental design and the expected results.

Figure 7. The procedure of the experiment I.

2.1.5 Variables and Measurements

The IVs (independent variable) of this experiment were the four types of font faces and three different phases of the experiment process. Four types of font faces refer to the font V, the font T, the font F, and the font C, which is used as a baseline. There are three phases in this experiment in terms of whether the participants know about the example word and whether they perform the secondary task or not. Also, the questions consist of 8 different versions. The DVs (dependent variable) included completing the tasks, the performance, incorrect answers, and subjective ranking based on the preference. The time-to-task data was measured from when the secondary screen was raised to the time people responded. So, the participants were instructed to answer the secondary tasks as soon as possible. The performance refers to the distance between the target and the participants' cursor. The performance data was recorded automatically with the prototype application, measuring the real-time distance between the coordination of the cursor and the target. The incorrect answers were defined as a failure of selecting the provided word among the options. In order to measure the subjective preference of font faces, all participants were asked to complete the post-experiment survey (see Appendix B). With the survey, subjective preference raking data was collected.

2.2 Results of the experiment I

2.2.1 Time-to-Secondary Task Completion

Overall Comparison. Using Analysis of variance (ANOVA), results revealed that the average task completion time between 4 font faces was not significantly relevant ($F_{3,124}=0.938$, $p=0.424$). The results suggest that the difference in font typefaces does not shorten the participants' reaction time for performing the secondary tasks. Figure 8 presents the actual task completion time for each prototype made with four different font faces.

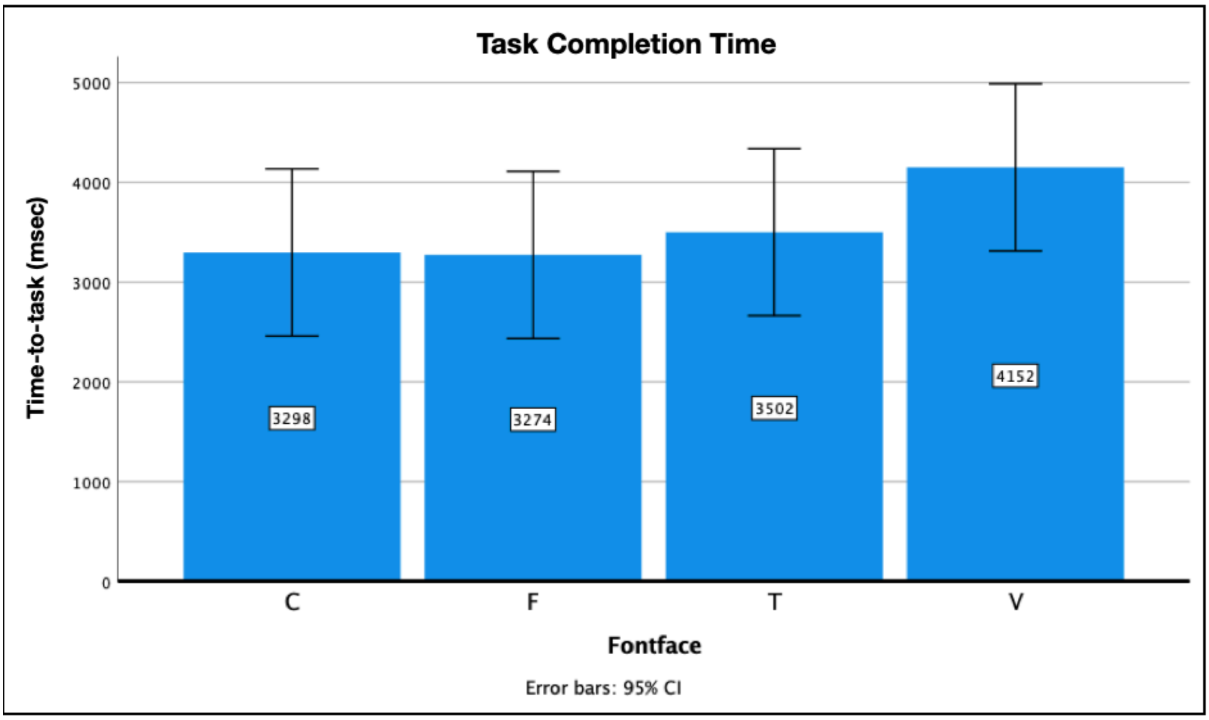

Figure 8. Task completion time (in msec) by four different font faces.

2.2.2 Tracking Performance Results

Overall Comparison. In order to examine what factors yielded better performance in keeping close and consistent distance from the target, the performance data, the distance from the participant's mouse cursor and the target, analyzed by analysis of variance (ANOVA). All the results revealed the statistical power exceeded .90. The results present a significant relevance between the performance and the font faces ($F_{3,288}$=4.918, p=0.002) and a significant effect of the phases in the experiment on the participants' performance ($F_{2,288}$=6.979, p=0.001). Also, the results present the significant effect of questions used in the experiment on the participants' performance ($F_{7,288}$=2.182, p=0.036). Therefore, the results reveal that the font faces induce cognitive distraction that interferes with the participants' focus on the primary tasks. In contrast, the font faces do not influence task completion time.

Moreover, the results propose that knowing the example word for the tasks affects participants' performance. The results also present the types of questions that affect the participants' performance. Figure 9 shows the average distance from the participants' cursor to the target.

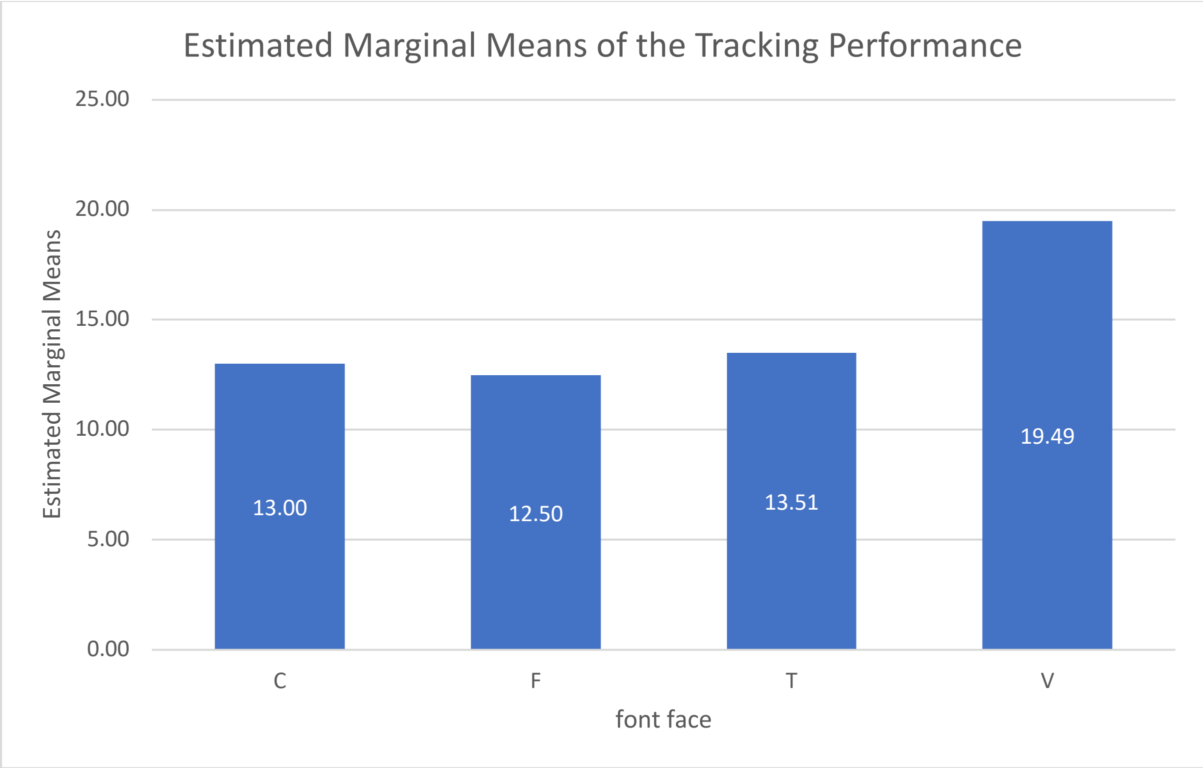

Figure 9. The average of the tracking performance by four font faces

Comparisons between the font face styles. In order to identify which type of font faces induced better performance, ANOVA was performed to the tracking performance data using four font face styles. ANOVA results revealed a significant interaction effect between the types of four fonts and the participants' tracking performance ($F_{3,288}$=4.918, p=0.002). The analysis of variance (ANOVA) also yielded marginally significant variation among font faces ($F_{3,288}$=4.918, p=0.067). A post hoc Duncan test proposed that font T alone and font T belonging group differed from font V and its belonging group. The result presented that the font T associated with the better tracking performance, while the font V associated with the poor tracking performance. This result also contradicted one of our assumptions that font with features of humanist font face style may be more legible than the fonts with features of square grotesque font face style.

Comparisons between the phases. ANOVA was performed on participants' performance data with the phase factors. ANOVA results presented a significant relevance between the phases and the participants' performance ($F_{2,288}=6.979$, $p=0.001$). As mentioned above, phases are consisted of three sections: the first section that participants do not know what example word will be provided; the second section refers that participants know what word they have to find in the secondary task; the last section is that participants are performing the primary task as well as the secondary task. A Duncan test revealed that the phase of knowing the example word for the secondary task and its belonging group differed from the phase of answering the question and its group. Moreover, the results proposed participants performed worse when they are engaging in the secondary task and the primary task than when they are asked to perform only the primary task.

2.2.3 Subjective Preference Results

Overall Comparison. Results from the post-experiment subjective survey were averaged across all 16 participants. The participants were asked to rank the four font faces on a scale of 1 to 4 (where the first rank = the best and the fourth rank = the worst). Friedman's nonparametric ANOVA test result revealed no significant differences in participants' preference among the four font faces ($p=0.170$). All ranking data were converted into reverse order (4 = the best and 1= the worst) before analyzing. The participants preferred the font F the most, while they ranked font V the worst.

2.3 Discussion of the experiment I

2.3.1 Discussion of Tracking Performance and the Phases

By examining the results of tracking performance on the phases, the assumption previously mentioned was validated. The phases consist of three: the first phase represents the step in which the participant participates in the primary task without information about the secondary task; the second phase still requires the participant to perform the primary task only, but unlike the first phase, the participant knows about the example word of the secondary task; the third phase asked the participants to perform the primary task and the secondary task at the same time. However, the phases can be classified into two phases: with or without the secondary task. The first and the second phase required participants to engage in only the primary task, while the third phase asked the participants to perform both primary and secondary tasks.

The results revealed a significant difference in tracking performance across the phases. Overall results proposed that participants' tracking performance was better when they were performing only the primary task, which is the tracking task. In other words, performing a secondary task distracted the participants to track the target concisely. Since the participants needed to divide their eye dwell between the primary task and the secondary task, there was the moment they could not keep their eyes on the primary task. Moreover, since the secondary tasks required the participants' cognitive workload, the cognitive impairment distracted them from performing the tracking task. To analyze the difference among the phases in more detail, the participants showed the best tracking performance in the second phase, the phase that participants know what word they should find for the secondary task. In contrast, they performed worst in the third phase, requiring participants to complete the secondary and primary tasks. This result implicates that providing the example word arouses the participants' cognitive ability, resulting in better performance on the primary task. On the other hand, requiring participants to engage in both tasks overloaded the cognitive workload, resulting in poor performance.

2.3.2 Discussion of Tracking Performance and the Phases Discussion of Tracking Performance and Font Faces

The second assumption proposed previously was partially validated by the experiment. Preceded studies proposed that humanist typeface led to a lower error rate and eye dwell time, while square grotesque type fonts were not (Dobres et al., 2016). Based on this prior research, it was expected that the font face, which has similar traits to the humanist style, will lead to better tracking performance. The analyzed results revealed a significant relevance between the tracking performance and the font faces. However, the results from the current experiment presented the opposite implication that the font V which is relatively close to the humanist font style, induced worse participants' tracking performance.

On the other hand, the font T with features of geometric font style led to the best performance among the remaining font styles. This unexpected result implicates some inferences. First, there was a difference in the experiment settings between the current experiment and the prior experiment. As mentioned above, the proceeded research measured the font's impact on the performance for completing the secondary tasks. In contrast, the current experiment measured the primary task's performance across the font faces. Therefore, in the current experiment results, the font V is highly legible and practical for character recognition. However, it can be interpreted as having too much impact on the cognitive workload and interfering with the tracking performance. Second, extrinsic fonts' limitation can be considered because each font face was designed with its own extrinsic features such as letter-spacing or width. These extrinsic factors can affect the perception of font faces even if the font face has the same setting as other font faces. Also, there was no statistically significant meaning on the subjective preference survey, but the participants preferred font F the most.

Based on these experimental results, if a font is considered to be used in the infotainment system, a font with humanist style features can make the text easier to read on display; however, it can negatively affect the driving performance. Therefore, in terms of the safety issue of driving, the font T, which has geometric style fonts, can be applied to appropriate applications.

CHAPTER 3

EXPERIMENT II

The second experiment was to investigate another feature that plays an essential role in legibility for in-vehicle display. Also, this experiment employed another situation that the drivers may encounter in terms of using an infotainment system while driving: reading text messages and comprehend the context of the message. While the prototype methods used in the first experiment were designed to evaluate only the impact of font faces on the tracking performance, this experiment adopted another feature that influences legibility: line spacings and the four types of fonts. Similar to the expectations on the first experiment, it was expected that the phases of the experiment might have an impact on participants' performance, while the types of questions are not. Also, the four types of font may impact the legibility of the participants, resulting in a difference in performance for the primary tasks. Moreover, the three extents of line spacings may influence the participants' performance. Through this experiment, it was anticipated to investigate which font faces and extents of line spacing result in less distraction and high comprehension of the passages.

3.1 Method

3.1.1 Prototypes

The Java-based driving simulator application, used in the experiment I, was also used in this experiment. The experiment II was implemented right after the experiment I finished. Therefore, the experiment's apparatus and settings were the same as the experiment I. However, the secondary task prototypes were different from the prototypes used in the first experiment.

Similar to the experiment I, the current experiment has two types of prototypes for the prototype for the participant and the prototype for the experimenter.

The prototype for the Participants. The prototype for the participants has the same formation as the experiment I: one task area for the primary task and the other area for the secondary task. The task area for the primary task has the same function and role as the experiment I, programmed to move a target randomly so that the participants can continuously engage in the primary task with their cursor. However, the other task area for the secondary task displays different screens from the experiment I. Since the current experiment employed the situation when a driver receives a message with the infotainment display, screens including message paragraphs are shown for the secondary task. As figure 10 illustrates, the screens mainly consist of three versions: the main screen (default), a text message screen, and a text message screen with three blanks. There are 12 types of text message that contains different context, and each type of message was designed in four types of font faces (e.g., font V, font T, font F, and font C) as well as three extents of line spacings (e.g., 100% of the font height, 150% of the font height and 180% of the font height). Therefore, 144 kinds of screens were designed for the experiment (12 messages x 4 font faces x 3 line spacings= 144 screens) (see Appendix E).

Based on the guideline for the infotainment system, all the heights of typefaces are larger than the suggested guideline. Also, the texts were displayed on the pure white (RGB: 255, 255, 255) background with pure black color (RGB: 0, 0, 0).

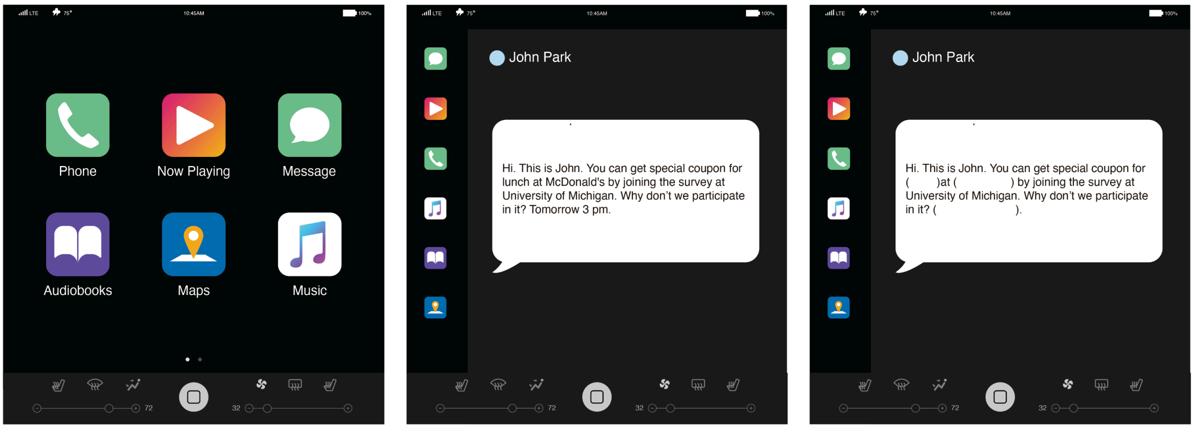

Figure 10. The prototypes for the secondary task in the Experiment II.

The Experiment Controller. Figure 11 displays the experiment controller for the experiment as identical to the controller from the experiment I. This controller is shown only for the experimenters. Also, it was designed similar to the controller from the experiment I, presenting experimenters the progress of the experiment with the color. Also, this application is operated with keyboards which are the "S" key and "Q" key. The primary task starts by pressing "S" key, and the "Q" key makes the screens for the secondary task appear or disappear. Unlike previous experiments, the experimenters have to press the "S" key to start each trial.

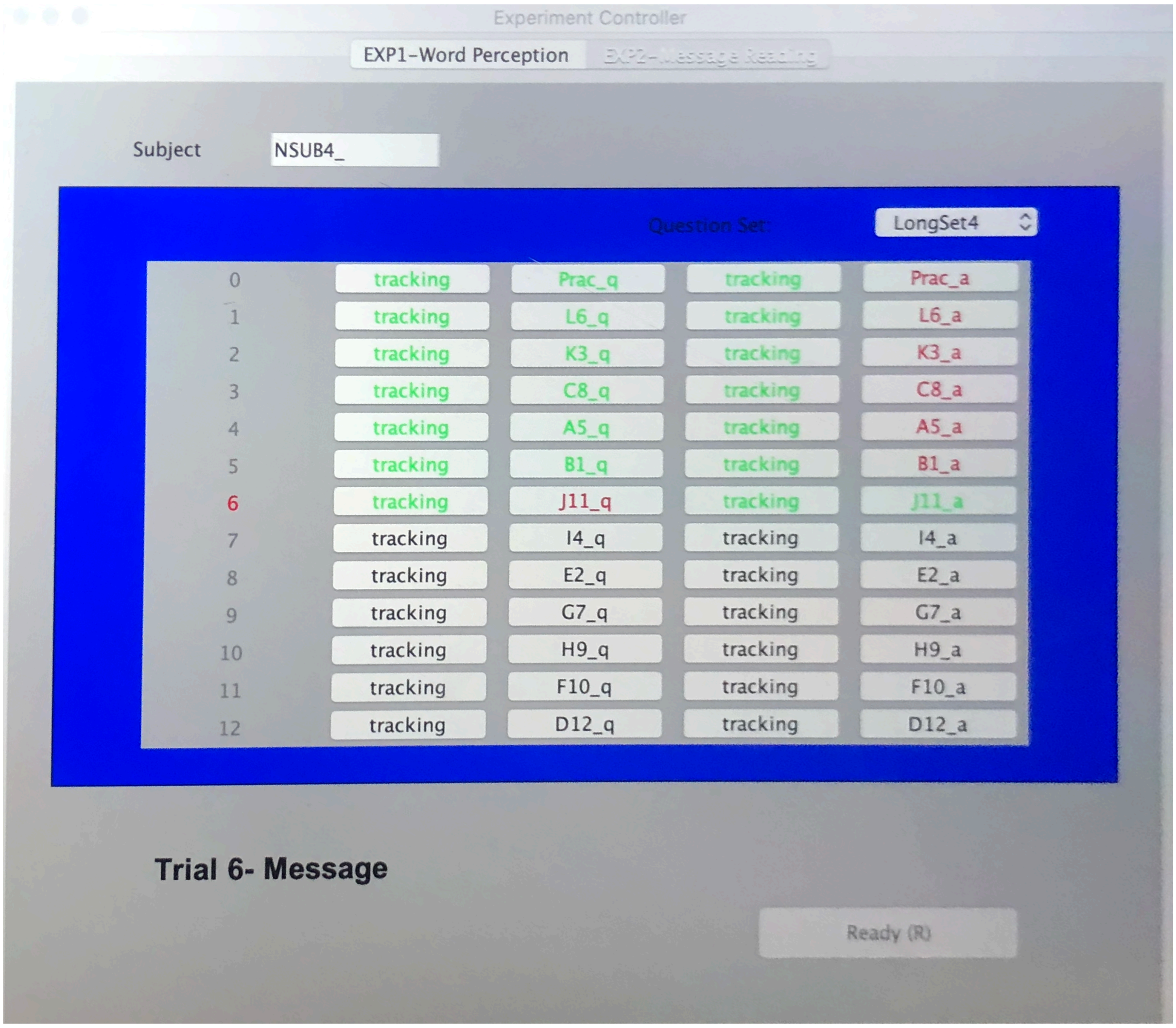

Figure 11. The experiment controller for the Experiment II.

3.1.2 Tasks

The Similar to the task conducted in the first experiment, participants were asked to perform the primary task for the beginning of the experiment and complete the secondary task in a designated phase. All participants were provided 12 trials for a one practice set and given experimental practice before performing the regular trials. After all the trials, they were asked to complete the preference survey rating on a scale ranging from (1=the worse) to (7=the best) regarding the font faces and the line spacings (see Appendix F).

The primary task. As in experiment 1, the primary task is to indicate the driving situation and keep the participant engaged constantly. By employing the task of Ballas et al., participants were asked to track the target, the orange circle, with their cursor (Ballas et al., 1992).

The secondary task. The secondary task represents the situation of receiving a message via an infotainment system while driving. As in the actual driving situation, participants need to read the message with a glance looking and comprehend the message's context at the same time. In this regard, after participants are engaging in the primary task for a while, then the text message screen is shown. They have to read the message and perform the primary task simultaneously. The participants can have as much time as they need to read and understand the message. After they finish reading the message, they are asked to fill out the blanks on the same message they were previously provided. These blanks are the single word and are the main words in a given message.

Throughout the experiment, participants completed a total of 12 trials, consist of the combination of 4 font faces and the 3 line spacings (4 font faces x 3 line spacings = 12 trials). In order to result in fair comparison data, all combinations that can be made with question type, font faces, line spacings, and order were randomly mixed.

3.1.3 Participants, Variables and Procedures.

The 16 participants in the first experiment continued their second experiment participation. Performance measurements including time-to-secondary task completion, tracking performance, the number of incorrect answers, and subjective satisfaction ratings were measured as DVs (Dependent Variables). In contrast, this experiment's IVs (independent variable) were the four types of font faces, three extents of line spacings, and 2 phases of the experiment process. The experimental setting, as well as the procedure of the experiment, were identical to the first experiment. The Figure 12 displays the procedure of the experiment II.

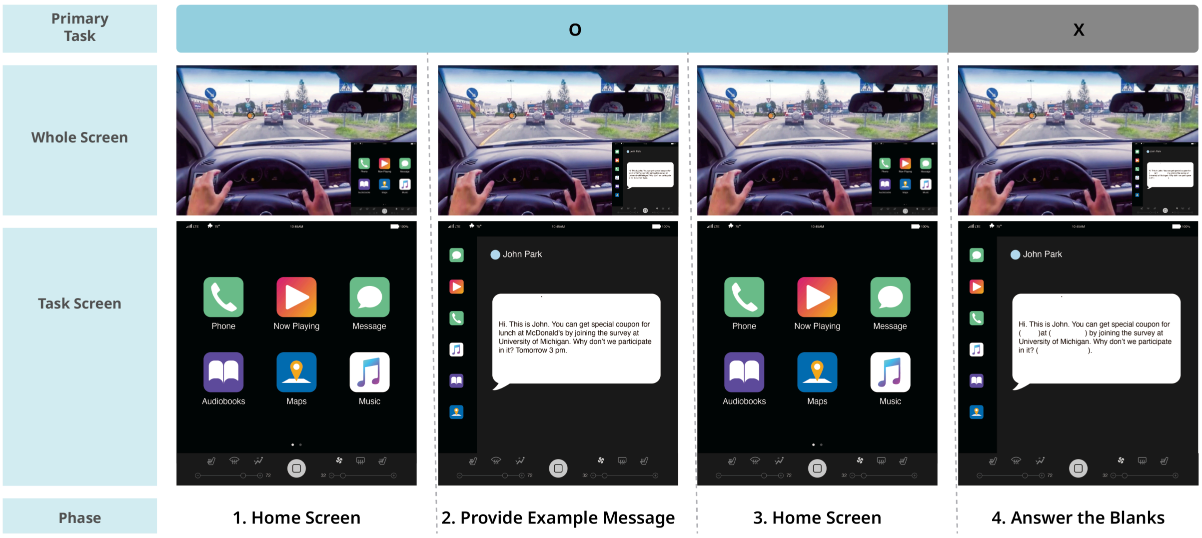

Figure 12. The procedure of the experiment II.

3.2 Results of Experiment II

3.2.1 Time -to-Secondary Task Completion

Overall Comparison. ANOVA result revealed that the average secondary completion time was not significantly different between the secondary task completion time and the four types of font faces ($F_{3,132}$=0.252, p=0.860). These results proved that font faces did not induce the difference in the secondary task completion time for the participants. Figure 13 presents the estimated secondary task completion time by each of four font faces.

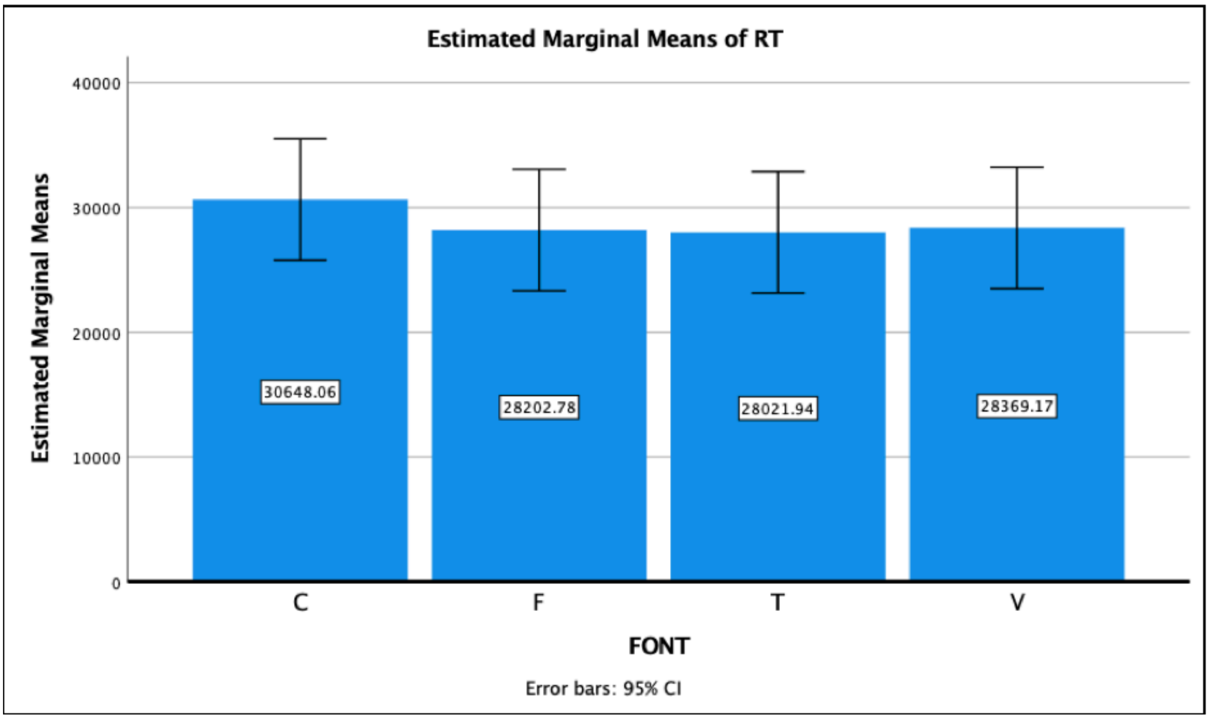

Figure 13. Task completion time (in msec) by four different font faces

3.2.2 Tracking Performance Results

Overall Comparison. In order to examine what variables have relevance to the tracking performance, the data were analyzed by analysis of variance (ANOVA). The tracking performance data, the mean value of the distance between the target and the participants' cursor, was analyzed with independent variables, including four font faces, three extents of line spacing, and the phases. The result of ANOVA revealed no significant relevance in font faces ($F_{3,538}$=1.26, p=0.287) and the line spacings ($F_{2,538}$=1.40, p=0.247), but the phases ($F_{2,538}$=3.709, p=0.025). Also, all the results showed over 0.90 detected power.

Comparisons between the phases. The results from ANOVA revealed a significant difference between the phases ($F_{2,538}$=3.709, p=0.025). Duncan test using α=0.05 as cut-off value discovered that there were potentially two groups, one group consisted of the phases that the participants performed the only primary task, which are the 1st and 2nd phases, and the other group consisted of the 3rd phase that the participants engaged the secondary task as well as the primary task. The results also showed that performing a double task reduced tracking performance compared to completing only the primary task. Figure 14 shows the tracking performance for the phases, and the alphabet above the bars indicates the potential group discovered by the Duncan test.

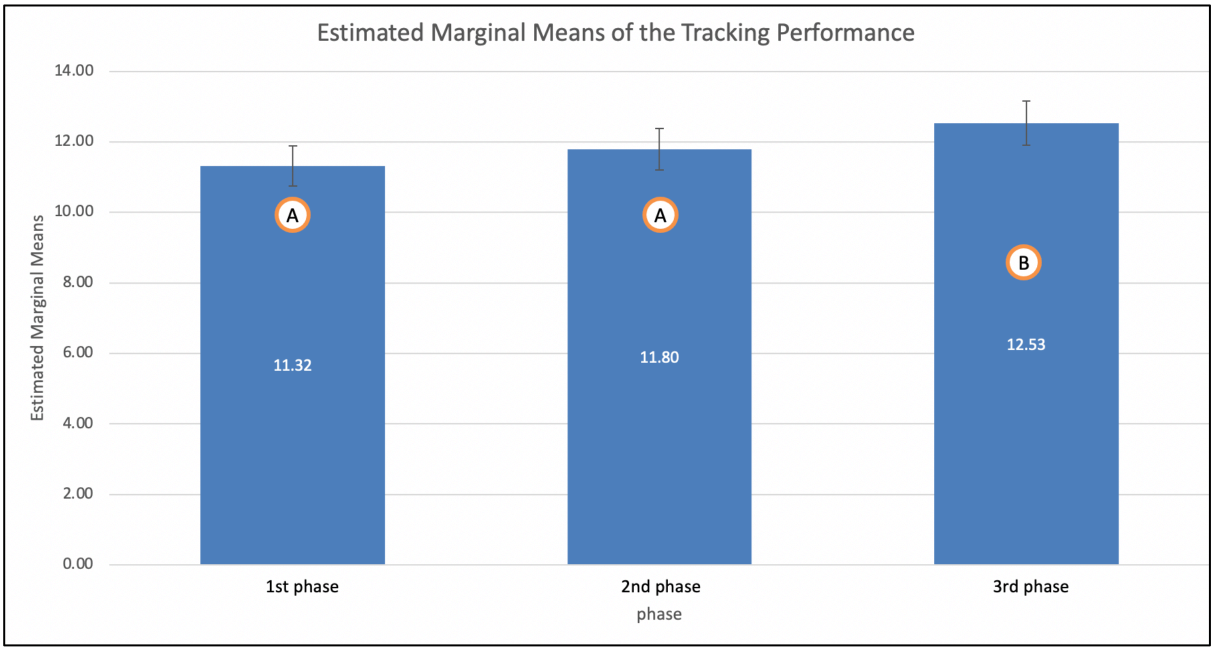

Figure 14. The estimated marginal means of the tracking performance by the phases

Comparisons between the font face styles. ANOVA results didn't propose the significant relevance between the tracking data and the font faces. However, Fisher LSD test revealed that

Comparisons between the line spacings. ANOVA was performed on participants' performance data with the line spacing factors. The results from ANOVA presented that there is no significant relevance between the line spacings and the participants' tracking performance ($F_{2,538}$=1.40, p=0.247). However, t test revealed a marginal difference between the three types of line spacing. The results proposed that there is a marginal difference between 150% and 180% of the font size, moreover, 150% of the font size induced better tracking performance compared to 180% of the font size t(126)=-1.673791, p=0.095)

3.2.3 Subjective Preference Results

Overall Comparison. Results from the post-experiment subjective survey were asked across all 16 participants. The participants were requested to rate the 12 prototypes, that consist of four types of font and three extents of line spacings on a scale ranging from 1 to 7 (1 = the worst and 7 = the best). ANOVA results presented significant differences in participants' preference among the four font faces ($F_{3,180}$=7.620, p=0.000) as well as the line spacings ($F_{2,180}$=70.540, p=0.000).

Comparison between the font face styles. The post-hoc Ducan multiple comparisons test using α=0.5 as cut-off value presented that there were potentially three groups consisted of 4 font faces. Figure 15 shows the subjective preference ratings for the font face styles. As Figure 16 describes, the participants preferred Font F the most, while the font C was the least preferred.

Comparison between the line spacings. The results analyzed by the post-hoc Duncan test revealed that each three extents of line spacing belong to different groups. Figure 16 shows the ratings on the line spacings, as presenting the participants preferred the largest line spacing while they rated the smallest line spacings the least.

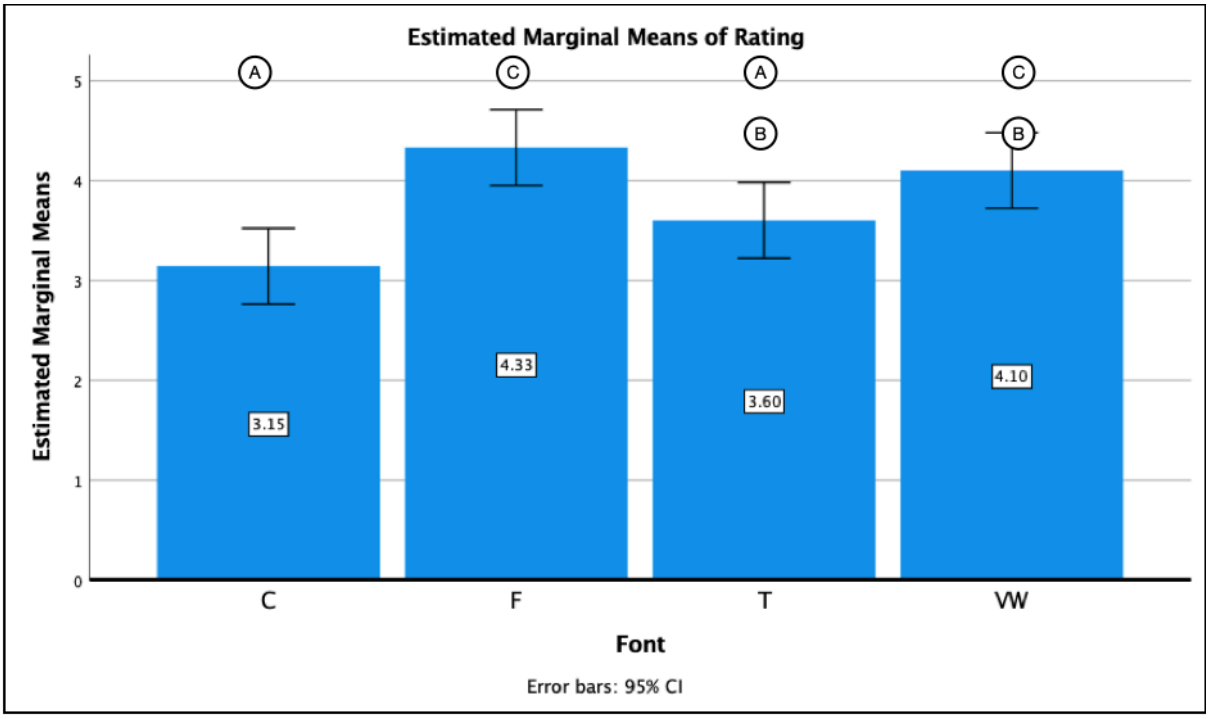

Figure 15. The average of ratings on the font faces for the Experiment II.

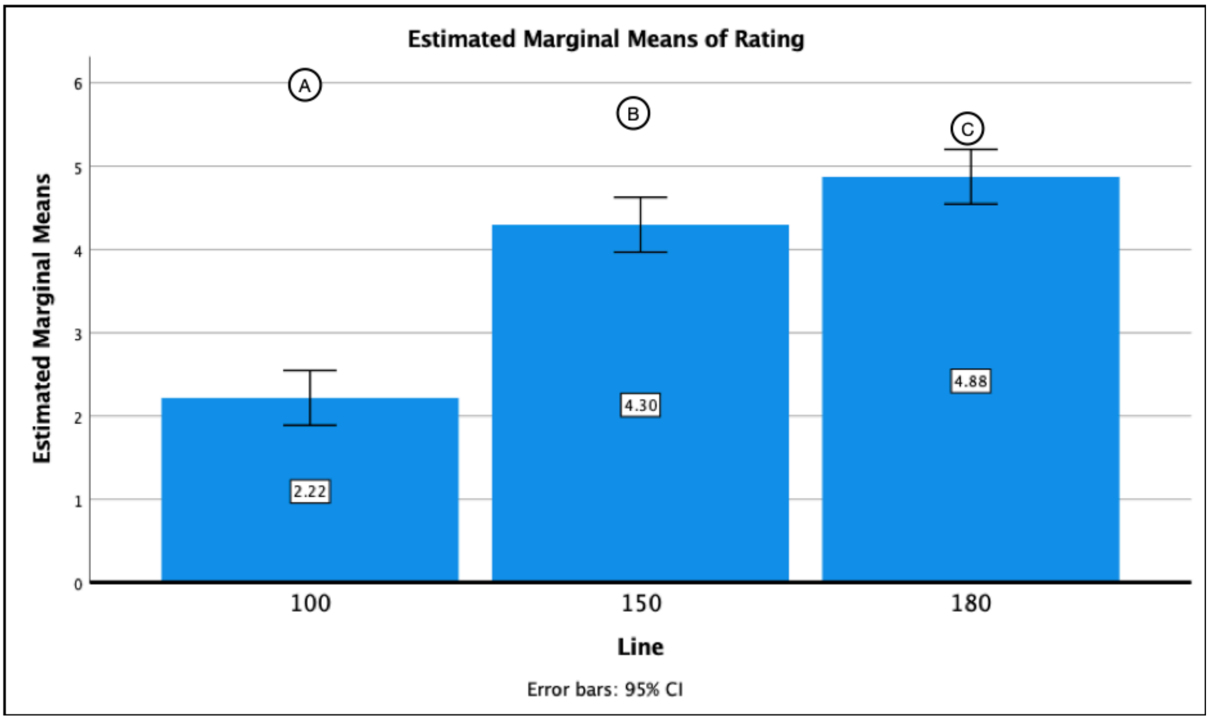

Figure 16. The average of ratings on the line spacing for the Experiment II.

3.3 Discussion of the Experiment II

Contrary to the first and second expectations, the results did not discover a significant impact of the four font faces and the three extents of line spacings on the tracking performance. Even though the tracking performance results did not reveal the significance of relevance between the tracking performance and the font faces and the line spacings, the Duncan test presented the marginal difference between the three types of line spacings. The largest line spacing, the 180% of the font size, induced slightly better performance than the smaller line spacings. However, the third expectation was validated with the experiment. As expected, the results showed a significant difference depending on the phase of the tracking performance. Participants showed better tracking performance when performing only the primary task than when they were asked to complete the secondary work simultaneously. Several reasons can be inferred to explain these results. First, the secondary task was designed to comprehend the text messages' context rather than focus on perceiving the characters. For instance, the secondary task for the experiment I required participants to select the given word among the visually similar options.

On the other hand, in the experiment II, participants were asked to comprehend the provided text messages and answer the blanks. That is, the results can be interpreted that the types of font for reading texts do not influence the driving performance. Also, it is suggested that the type of font does not significantly affect the situation where the entire text needs to be understood, rather than distinguishing the shape of words as in experiment I. Secondly, similar to the implication of the experiment I, the results inferred that implementing secondary tasks might produce a cognitive workload compared to performing only the primary task. Third, participants preferred the font F the most and the most extensive line spacing. In this regard, it is favored to consider the subjective familiarity toward the font faces. Since the vehicles employing the font F and the font V are relatively more common than the vehicles using the font T and font C, the personal experience and familiarity may have influenced the preference towards the font faces. Also, Participants preferred the largest line spacing, which is 180% of the font size, and this result can be understood in the same context as the result of tracking performance.

CHAPTER 4

EXPERIMENT III

The third experiment was to investigate the eye dwell time while participants performed tasks. The tasks included both primary tasks and the secondary tasks used in both the experiment I and the experiment II. Unlike the experiments I and II, the current experiment used both secondary tasks used in each experiment. Besides, instead of measuring the participants' performance, such as tracking performance or the number of incorrect answers for the tasks, the current experiment only focused on the eye dwell time on the secondary tasks area. Similar to the previous experiments' expectations, types of font faces and phases were expected to influence participants' eye dwell time on the secondary task area. Through this experiment, it was anticipated to find the relevance between the eye dwell time, the font faces, and the line spacings.

4.1 Method

4.1.1 Participants

A total of 12 participants participated in this experiment. The recruiting qualification of the participants was similar to the previous experiments. They were preferred to have sufficient experience of using video conference tools and using the infotainment system. The participants ranged in age of 20-30 with a mean of 26.41 years (sd=2.23). Among 12 participants, eight people were male, and four were female.

All participants filled the consent form to participate in the experiment, as outlined by the Committee on the Use of Humans as Experiment Subjects of the University of Michigan. As similar to the previous experiments, they were asked to answer the demographic questions before the experiment (see Appendix A). The participants reported an average of 6.41 years of driving experience (sd=3.48), an average of 0.91 times to have car accidents within three years (sd=1.08). Also, on a scale ranging from (1=Never) to (5=Always), the participants answered an average rating of 4.41 (sd=0.90) for the frequency of using an infotainment system when they are driving.

4.1.2 Prototypes

The Java-based prototype application used in Experiment and Experiment II was used in this experiment. While the experiment I and II used separate prototypes for each experiment, both prototypes from each experiment were used for this experiment. In the current experiment, the two prototypes used in the previous experiments were implemented in succession. The same as the previous experiments, the prototypes consist of two types: the prototype for the participant and the prototype controller. The function and the setting of the prototypes were identical to those of the experiment I and the experiment II.

4.1.3 Tasks

The participants were asked to perform the primary task at the beginning of the experiment and complete the secondary task in a designated phase. The secondary task was the same as in Experiments I and II. However, in the previous experiment, only one secondary task was required for each experiment. In the current experiment, both of the secondary tasks used in the previous two experiments were required to be performed. Therefore, the experiment was run twice. In the first experiment, a task was given to select a given word as in the experiment I was provided to the participants. The second experiment was given a task, understanding a given text message and filling in the blanks, as in experiment II.

4.1.4 Variables and Procedures

Performance measurements for this experiment include eye dwell time on the secondary task area while the participants were engaged in the secondary task, while the IVs (independent variable) of this experiment were the four types of font faces, three extents of line spacings. The experimental setting, as well as the procedure of the experiment, were identical to the first experiment and second experiment. However, the current experiment employed the secondary tasks from both the experiment I and the experiment II. Participants completed all trials of experiment I and then continuously completed all trials of experiment II.

4.2 Results of the Experiment III

4.2.1 Eye dwell time result for experiment I

The result of ANOVA revealed no significant difference in eye dwell time between the four types of font face styles ($F_{3,64}$=0.281, p=0.839). Figure 17 presents the average eye dwell time for completing secondary tasks that employed each font face.

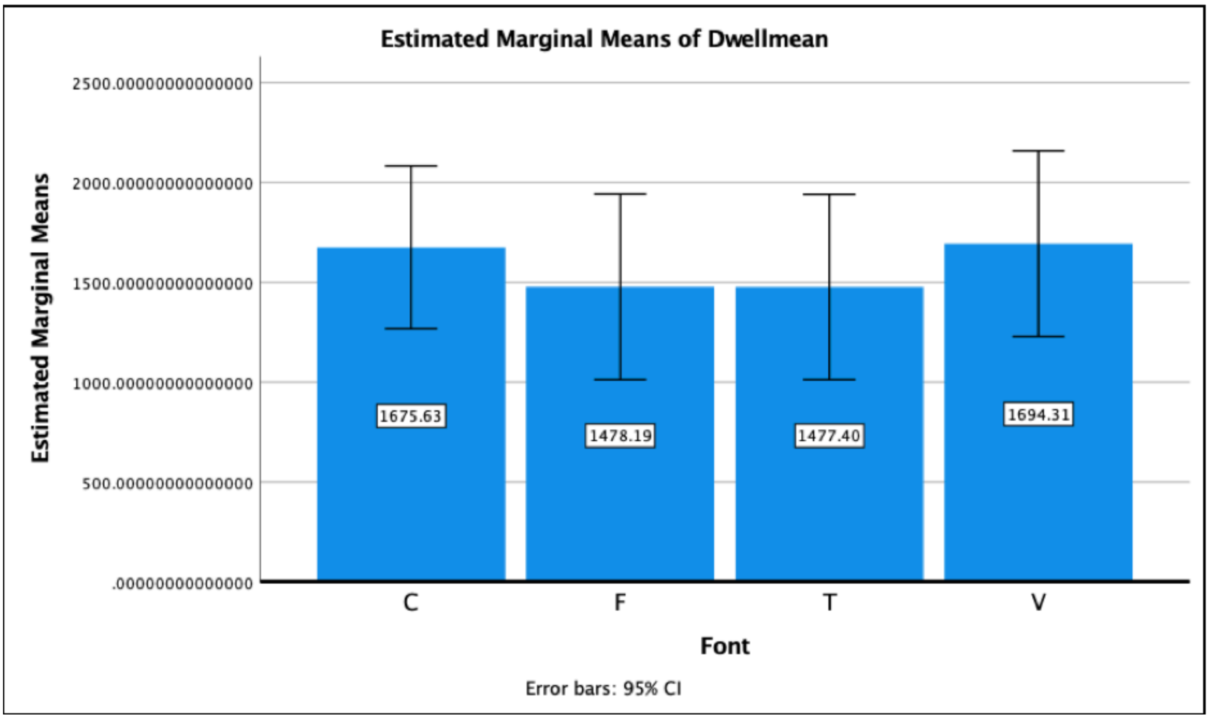

Figure 17. The eye dwell time in the experiment I's secondary task by font faces.

4.2.2 Eye dwell time result for experiment II

ANOVA result presented nothing significant difference in eye dwell time between the four types of font face styles ($F_{3,132}$=0.293, p=0.830) as well as the line spacings ($F_{2,132}$=0.057, p=0.945). Figure 18 shows the average eye dwell time for completing secondary tasks, while Figure 19 represents the average eye dwell time over line spacings.

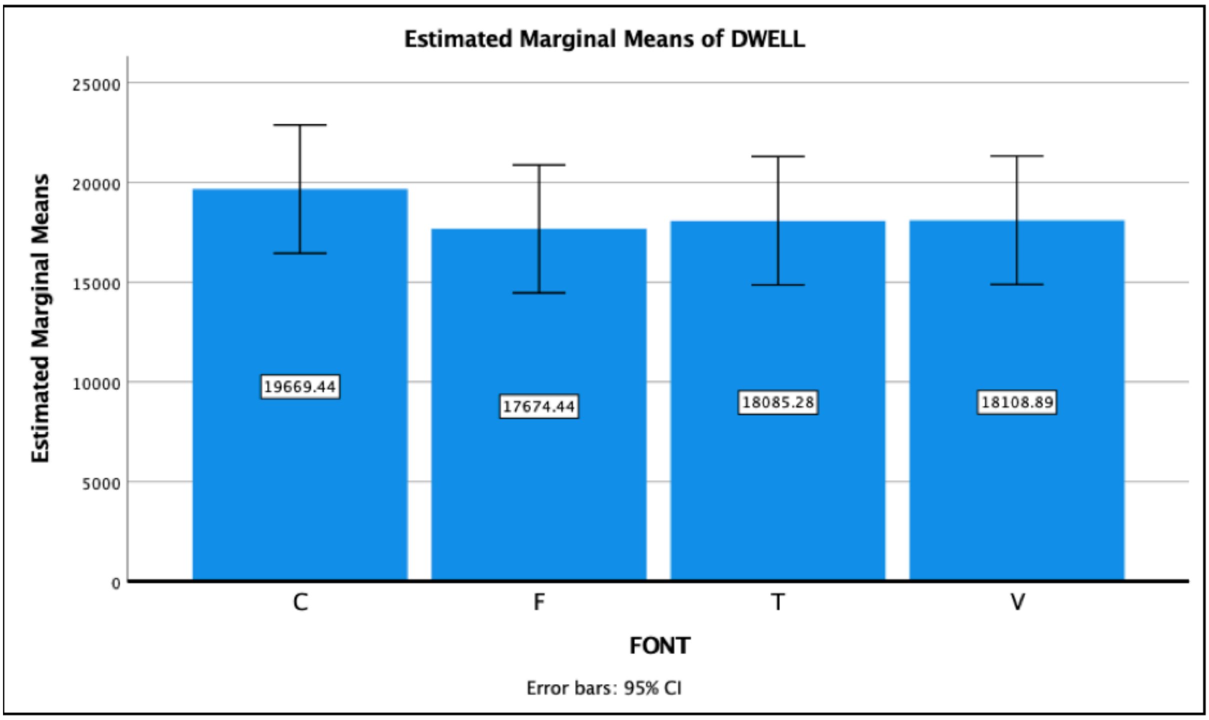

Figure 18. The eye dwell time in the experiment II's secondary task by font faces.

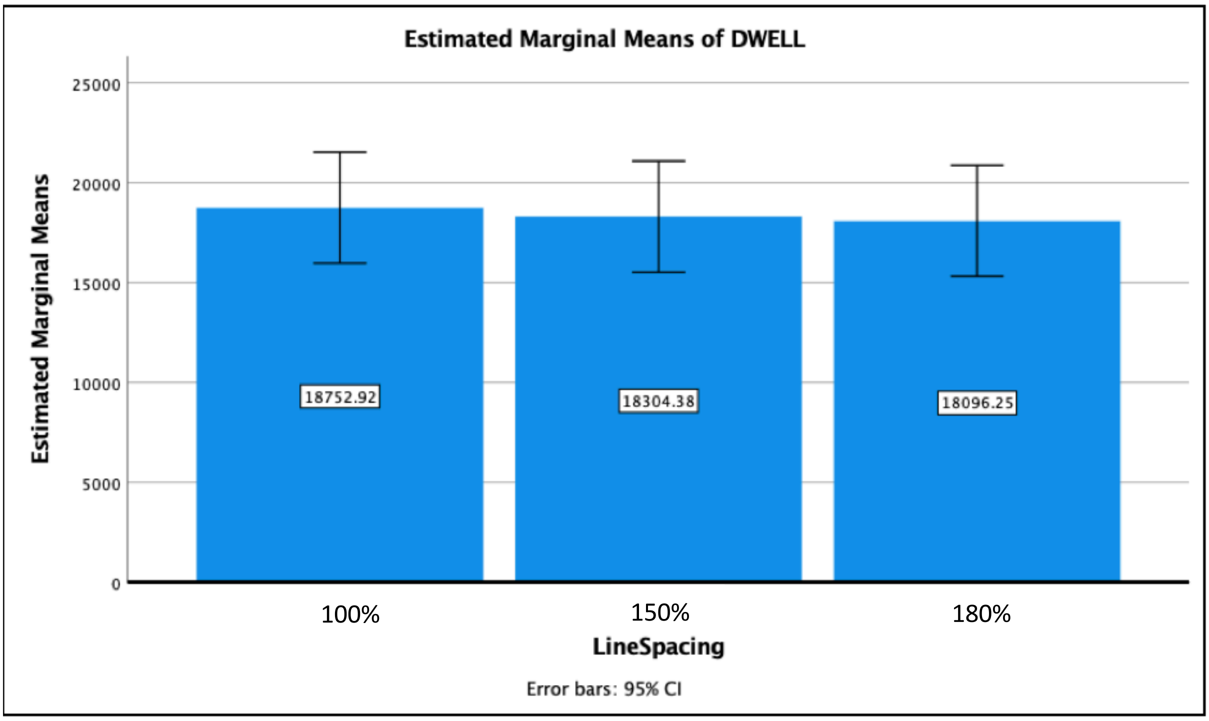

Figure 19. The eye dwell time in the experiment II's secondary task by line spacings.

4.3 Discussion of Experiment III

Unexpectedly, the assumptions mentioned previously were not validated by this experiment. The four font faces and the three extents of line spacings did not show a significant difference in eye dwell time on the secondary task prototypes. The current experiment's secondary tasks included distinguishing a given word from the other visually similar words and comprehending text messages consisting of four font faces and the three line spacings. This unexpected result implicates an inference. As National Highway Traffic Safety Administration (NHTSA) discovered, there is a pattern and consistency of drivers' eye glance behavior (Tijerina et al., 2004). In this regard, the invariance of ocular residence time for different prototypes that consisted of different font faces and different line spacings can be explained in the same context as previous studies discovered. The eye-glance behavior may not be related to the design of the interfaces itself but the intrinsic human behavior.

CHAPTER 5

OVERALL DISCUSSION AND CONCLUSION

5.1 Overall Discussion

In this study, the tracking performance data with two four types of font faces (font F, font T, font V, and font C) and three extents of line spacings (120%, 150%, and 180%) tasks was examined by two experiments. The eye dwell time on the secondary task area with four font faces and the three line spacings were analyzed by one experiment. The study results suggested design guidelines for the characteristics of fonts and the extents of line spacings, with the slightest distraction depending on the types of tasks that drivers perform. The first experiment employed the situation of selecting a location for the navigation system, distinguishing correct words among the visually similar words. The results demonstrated that there was a significant difference in the tracking performance across the font faces as well as the phases. The font T showed the best tracking performance, while the font V induced the worst tracking performance. The phases also had a significant relevance with the tracking performance. The results proposed that the phase when the participants were asked to perform the secondary task with the primary task induced more unsatisfactory tracking performance than the phases that required only the primary task to be completed. This result explained the secondary task arouses the cognitive workload that negatively affects performing the primary task.

The second experiment adopted the situation of receiving text messages when they are driving. In this experiment, the secondary task asked to comprehend the messages' context and fill out the blanks in the same texts. The results presented no significant difference in the tracking performance with the font face styles and the line spacings. However, the distraction of the secondary tasks was validated with this experiment. These results demonstrated that fonts or line spacings do not influence comprehending the context and the tracking performance. In addition, the results also inferred that the examined fonts used in the current market performed above average. On the other hand, the subjective preference survey revealed a significant difference in ratings. Participants preferred the font F and V, while the font C was the least preferred. Also, they rated the largest line spacing the best, which was 180% of the font size. In this regard, the fonts' familiarity of participants can be considered since the fonts F and V were relatively common fonts for their vehicles compared to the fonts T and C.

The last experiment recruited participants independently from the previous experiments. In this experiment, participants were asked to continuously perform the tasks used in experiment I and experiment II. For this experiment, only the eye dwell time on the secondary task area was examined across the font face and the line spacings. The results presented no significant differences in the eye dwell time on the secondary task area with the types of font face and the line spacings. The previous research can explain these results about eye-glance behavior in driving situations, presenting that eye glance behavior is the intrinsic behavior of humans. That is, eye dwell time is not determined by the design factors of interfaces but by the humans' action of instinct.

5.2 Caveats and Future Study

The first caveat of this study was the limitation of the virtual experiment environment. In this experiment, a video conference tool was used to experiment, so the sense of reality was limited compared to the laboratory experiment using a driving simulator. Also, as the experiment was conducted with the participants' equipment, the specifications such as monitor size, connection, or graphic were not identical. Also, if the internet connection was unstable, the tracking performance's quality was not clear. The second limitation of this study was that the loss of the data. In conducting experiments, most data were lost, including the tracking performance data and videos for analyzing eye dwell behaviors. With this accident, it was impossible to analyze the integrated results that include the tracking performance, accuracy of the secondary tasks, and the eye dwell time.

The limitations of this research propose several suggestions for future research opportunities: 1) It would be interesting to examine the integrated relevance between the various factors, including the tracking performance, eye dwell time, font faces, line spacings, and the accuracy of the secondary task. 2) If the experiment is conducted with a driving simulator, it would also be interesting to analyze the collected data in an environment closer to the actual driving situation. 3) It is preferable to investigate other design elements of in-vehicle infotainment displays that can increase driver satisfaction and improve driving performance.

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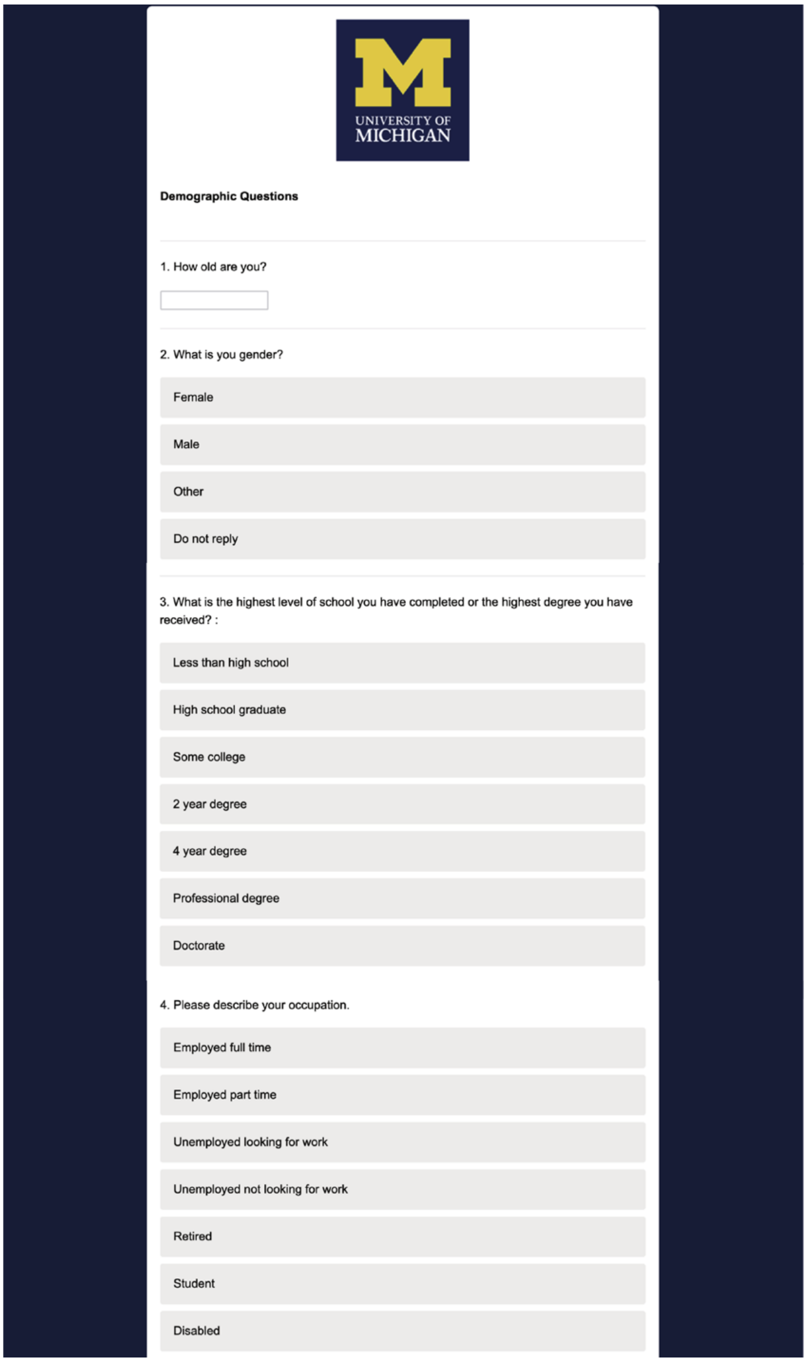
APPENDICES

APPENDIX A: General Demographic Question Survey Form



UNIVERSITY OF MICHIGAN

Demographic Questions

1. How old are you?

2. What is you gender?

- Female
- Male
- Other
- Do not reply

3. What is the highest level of school you have completed or the highest degree you have received? :

- Less than high school
- High school graduate
- Some college
- 2 year degree
- 4 year degree
- Professional degree
- Doctorate

4. Please describe your occupation.

- Employed full time
- Employed part time
- Unemployed looking for work
- Unemployed not looking for work
- Retired
- Student
- Disabled

5. Please select the option that better describe where do you live?

- Urban Area
- Suburban Area
- Rural Area
- Other

6. Do you have a valid U.S driver license?

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

7. How many years have you been driving?

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

9. How often do you use your infotainment system while driving?(e.g. navigation system, radio, Google Auto, Apple Carplay, etc.

- Always
- Usually
- Sometime
- Seldomly
- Never

→

APPENDIX B: Preference Survey Form for the Experiment I

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Post-Experiment Survey

Thank you for participating our experiments. This research is conducted by graduate students at University of Michigan - Dearborn who are working on research which has tried to figure out effective font and line spacing for in-vehicle display.

This survey is post-experiment survey. The purpose of this survey is to focus on your personal experience about four kinds of fonts and three different line spacings.

This experiment is conducted with formal approval from the University of Michigan. (IRB approved)

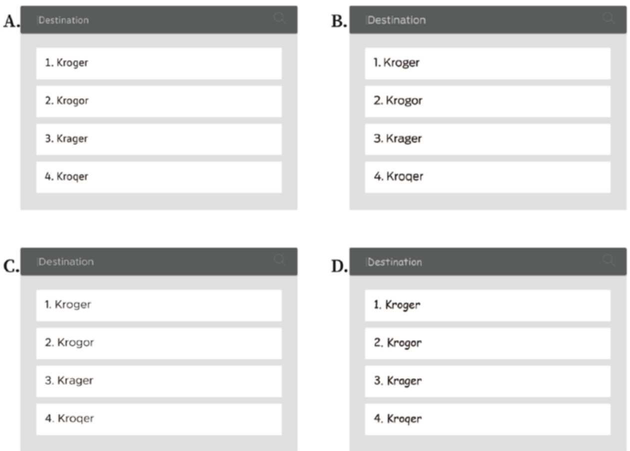
Research Information
Department of Industrial and Manufacturing System Engineering,
University of Michigan - Dearborn

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

Researchers:
HyunJoo Park (jooo@umich.edu)
HyunJae Park (jeee@umich.edu)

Rank the four font styles. (1st-the best / 4th-the worst)

Destination : Kroger



A
B
C
D

→

APPENDIX C: Inform Consent Form

Introduction
Hi. We are graduate students at University of Michigan - Dearborn who are working on research which has tried to figure out effective font and line spacing for in-vehicle display.

The purpose of this study is to find and categorize as many factors as possible to analyze trust formation models and factors in autonomous vehicle domains.

This experiment is conducted with formal approval from the University of Michigan. (IRB approved)

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

Faculty Advisor:
Dr. Sang-Hwan Kim

Researchers:
HyunJoo Park,
HyunJae Park,

Consent information

You are invited to participate in a research study about investigating infotainment system font and characteristics for legibility and satisfaction on Drivers

If you agree to be part of the research study, you will be asked to complete experiment via online software that will last around 60 minutes. However, you are not eligible to participate in this study if you are under 18 years old.

Benefits of the research: By comparing several factors with questionnaires, the relations among factors can be identified by participants responses. This can serve as infotainment system font and legibility for drivers.

Risks and discomforts: There are no significantly expected risk at all.

Compensation: none

Participating in this study is completely voluntary. Even if you decide to participate now, you may change your mind and stop at any time. You may choose not to answer any survey question and continue the experiment for any reason.

As part of the research, we may mislead you or we may not tell you everything about the purpose of the research or research procedures.

We will keep the information we collect from you during the research for this research only. The results of this study could be published in an article or presentation. The results of this study could be published in an article or presentation.

Information collected in this project may be shared with other researchers.

If you have questions about this research study, please contact Hyunjoo Park(jooo@umich.edu) or Dr. Sang-Hwan Kim(dysart@umich.edu).

Are you older than 18 years old?

Yes

No

Consent to participate in the research study

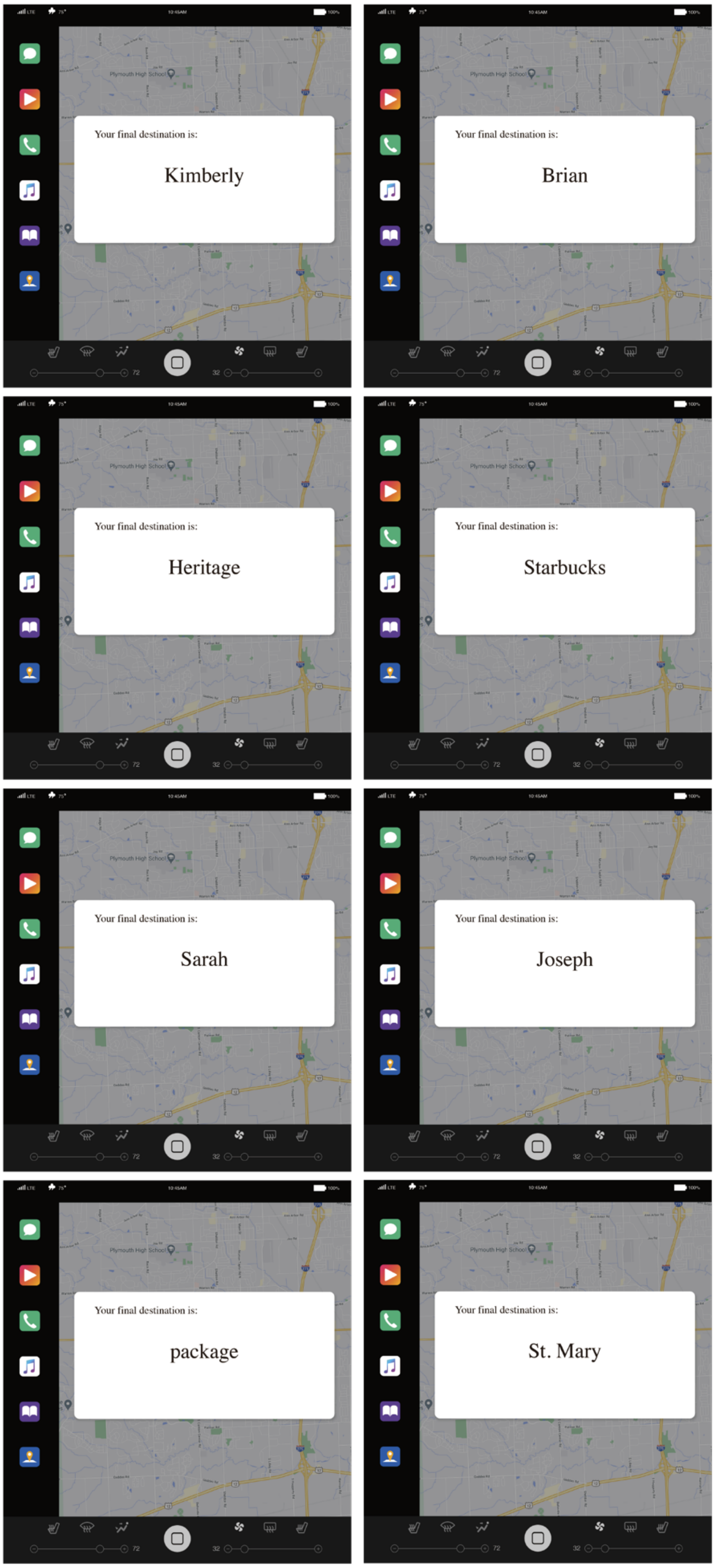
I understand what the study is about. I agree to take part in this study.

Yes

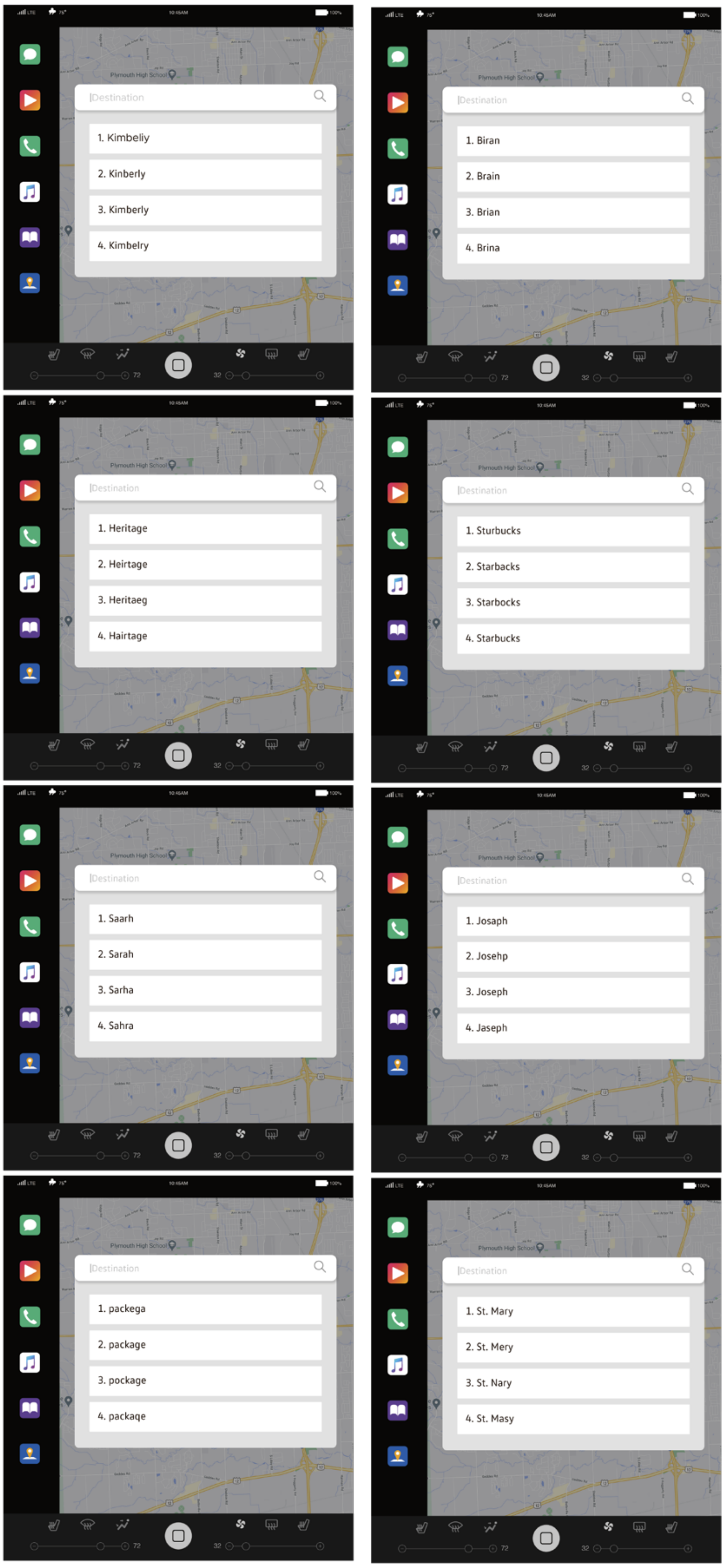
No

→

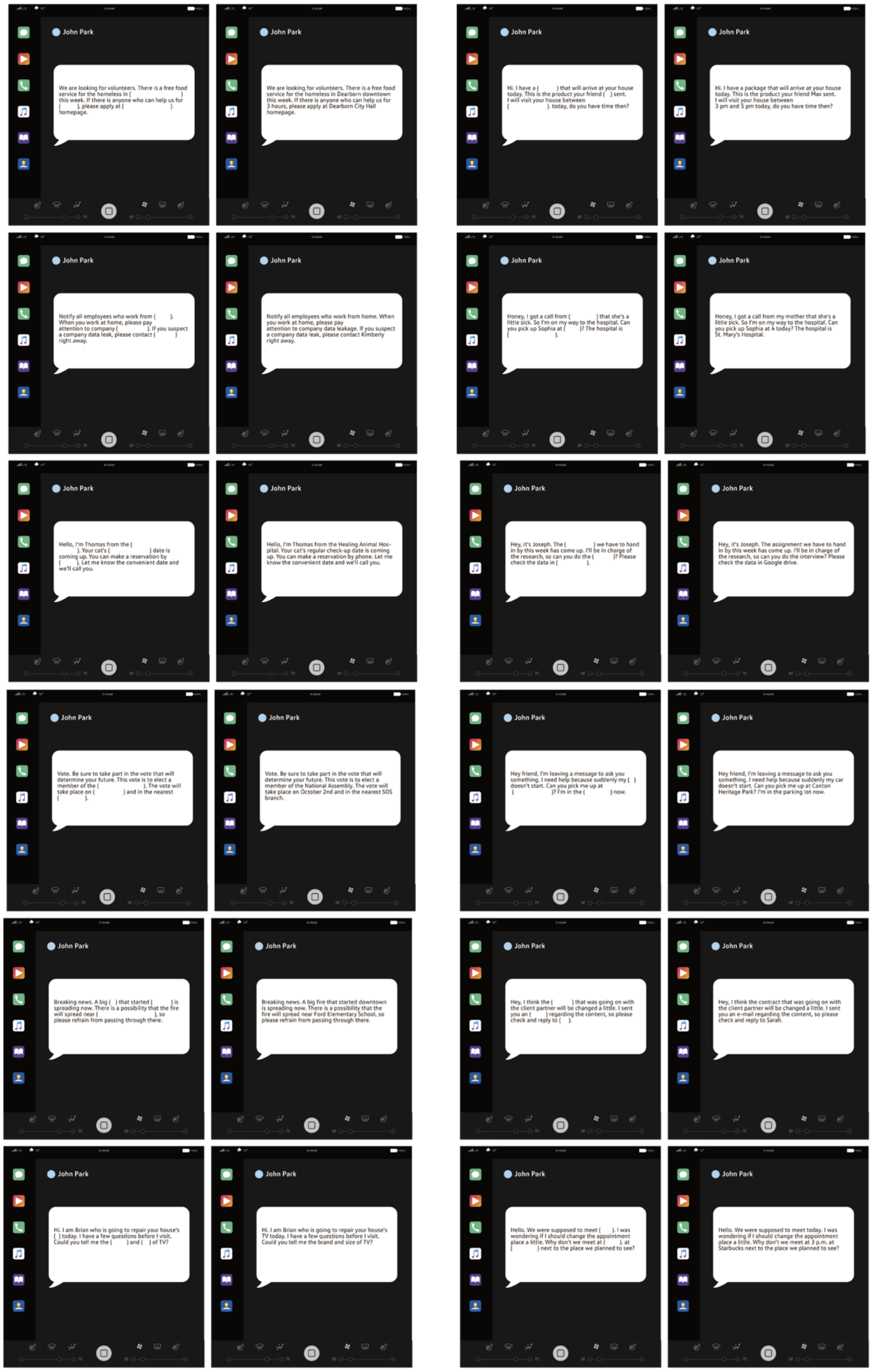
APPENDIX D-1: Prototype for the Experiment I-Prototypes for the example words



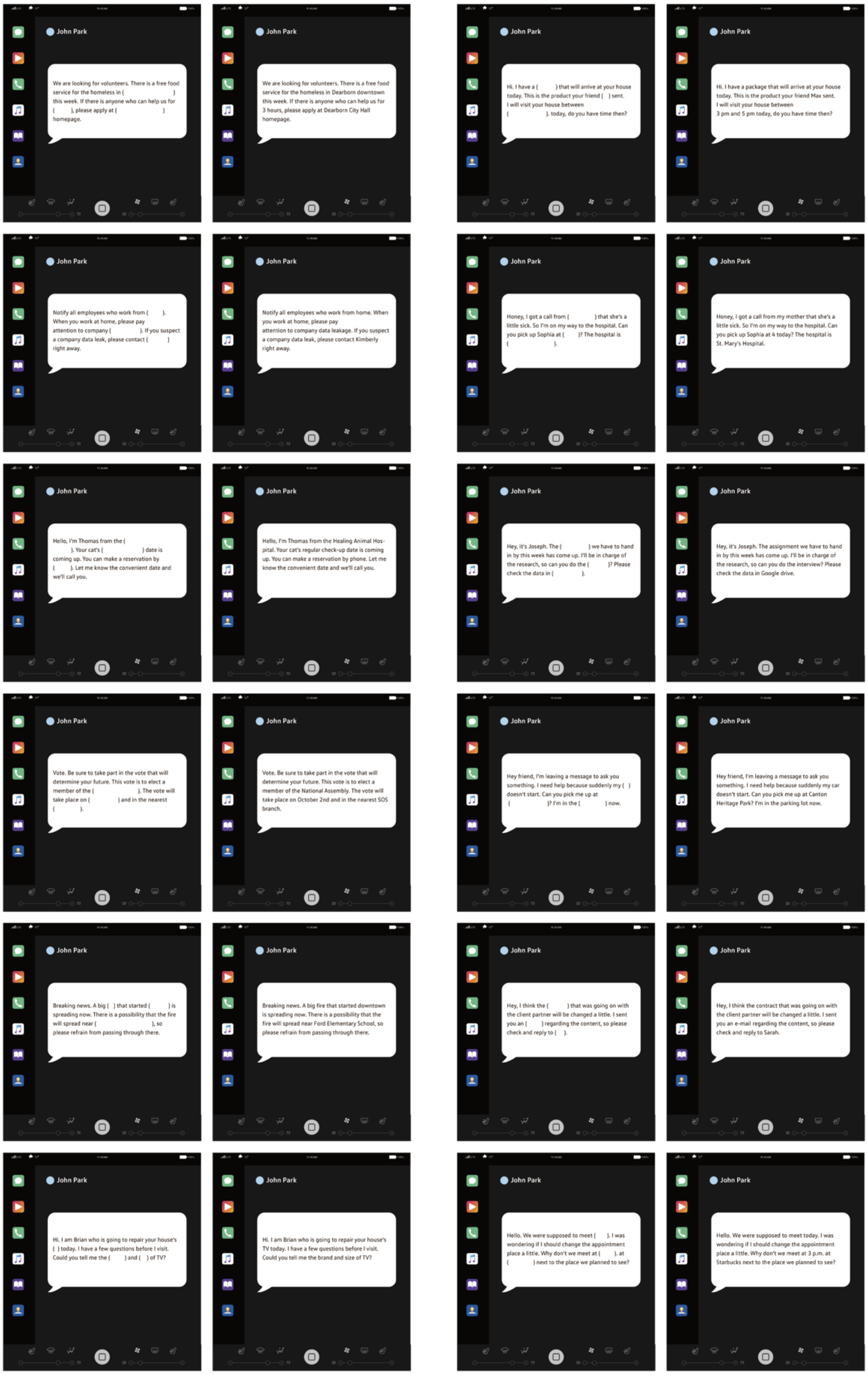
APPENDIX D-2: Prototype for the Experiment I-Prototypes for the font V



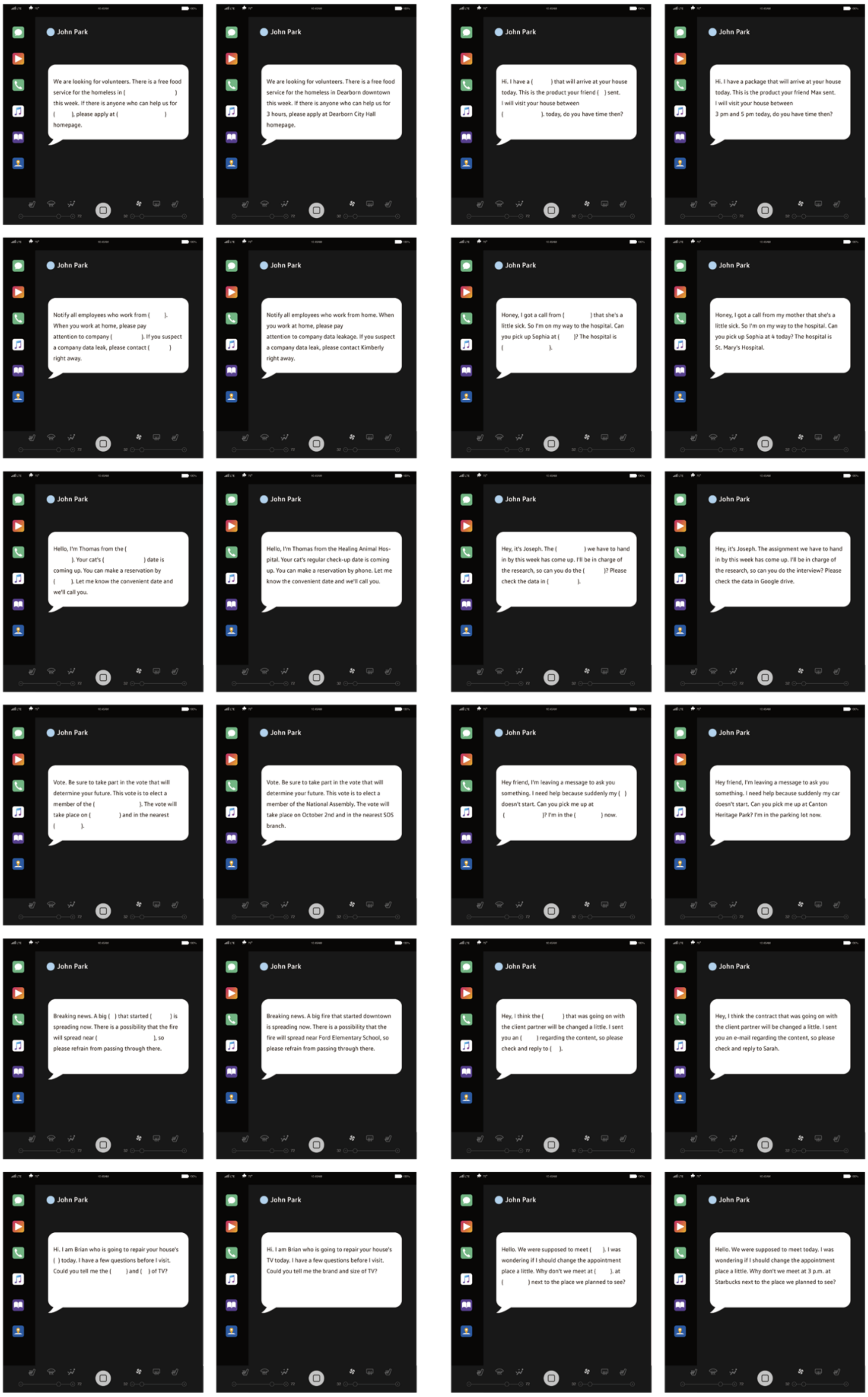
APPENDIX E-1: Prototype for the Experiment II-Prototypes for the font V and 100% line spacing



APPENDIX E-2: Prototype for the Experiment II-Prototypes for the font V and 150% line spacing



APPENDIX E-3: Prototype for the Experiment II-Prototypes for the font V and 180% line spacing



APPENDIX F: Preference survey form for the experiment II