Employing Graphics to Aid Message Display on Dynamic Message Signs

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This report presents a human factors study conducted to examine the feasibility of employing graphics to aid message display on dynamic message signs (DMSs). DMSs have been increasingly used by highway traffic management to provide drivers with real-time traffic information and advice. These signs, often mounted on overhead sign bridges above arterial highways, are capable of displaying extensive textual messages which could pose a challenge to drivers' comprehension while driving at highway speeds. Since graphics are usually considered a more effective means of communication than texts, graphic-aided DMS messages were developed and tested in this study. A questionnaire survey and a lab simulation were used to assess the effects of these messages on human drivers. The former collected drivers' preferences regarding the design of graphic-aided DMS messages while the latter measured drivers' response to a selected group of test messages. A total of 127 subjects participated in the survey where they selected message designs and displays per their preference. Forty-eight subjects, from three age groups with balanced genders, partook in the simulation experiment where they made responses to simulated DMS stimuli with or without graphics. Results obtained from this study would help guide the development of graphic-aided messages to be used on US highways.
# TABLE OF CONTENTS

LIST OF TABLES .................................................................................. iv

LIST OF FIGURES .............................................................................. v

1. INTRODUCTION ............................................................................. 1

2. QUESTIONNAIRE SURVEY .......................................................... 4

3. LABORATORY DRIVING SIMULATION EXPERIMENT .................. 11

   3.1. EXPERIMENT SETUP ............................................................... 12

   3.2. EXPERIMENT DESIGN ............................................................ 16

   3.3. EXPERIMENT RESULTS ......................................................... 18

4. CONCLUSION ................................................................................. 23

5. ACKNOWLEDGEMENT ................................................................. 24

6. REFERENCES ................................................................................. 24

APPENDIX A: SURVEY QUESTIONS ............................................... 28

APPENDIX B: EXPERIMENT DATA .................................................... 61
## LIST OF TABLES

Table 1 Questionnaire survey messages…………………………………………………………… 4

Table 2 Participants’ demographic statistics………………………………………………………… 9

Table 3 Respondents’ preferences on DMS features……………………………………………… 10

Table 4 Subjects’ preferences on alternative graphic image……………………………………… 10

Table 5 Experiment factors and levels…………………………………………………………… 17

Table 6 ANOVA table results for the first model…………………………………………….. 18

Table 7 Analysis of Variance table……………………………………………………………… 19

Table 8 Accuracy analysis results……………………………………………………………… 22

Table 9 Regression statistics and ANOVA results for accuracy vs. response time……………22
LIST OF FIGURES

Figure 1 Examples of the survey questions .................................................. 6
Figure 2 Introduction slides........................................................................... 7
Figure 3 Sample survey question................................................................. 8
Figure 4 Demographic information form..................................................... 8
Figure 5 Graphic images for different messages.......................................... 11
Figure 6 Schematic diagram of lab setup.................................................... 13
Figure 7 Driving simulation test messages.................................................. 14
Figure 8 Simulation video on the screen...................................................... 15
Figure 9 Experiment computer program page on screen............................ 16
Figure 10 Main effect plots for response time............................................ 19
Figure 11 Interaction plots......................................................................... 20
Figure 12 Scatter plot between accuracy and response time.................... 23
1. INTRODUCTION

Dynamic message signs (DMSs) are programmable electronic bulletin boards often mounted on overhead sign bridges above highways to provide drivers with real-time information and advice about roadway and traffic conditions. DMSs have been increasingly used by highway authorities, not only to alleviate traffic problems but also to enhance driving safety on highways. With the state-of-the-art technology, many full size DMS system is capable of presenting extensive textual messages up to three lines with a maximum of 20 characters each line. However, drivers might find reading and reacting to such lengthy text messages challenging or even confusing in their driving. A long and complex message could demand more attention from drivers, especially to elder drivers and to drivers whose native languages are not English. Several previous studies investigated drivers’ responses to DMS messages. Using a video-based driving simulation experiment, Wang and Cao [1] studied the design and display factors of portable variable message signs (PVMS) and found that older drivers exhibit slower response and less accuracy than younger drivers. In another similar study, Wang et al. [2] also found that older subjects took longer to respond to the DMS stimuli with less accuracy than younger subjects. In Nsour’s [3] survey, he found that the task of reading DMS messages was one of the most difficult tasks for elder drivers. Slow-down effect is another issue that causes safety concerns in highway driving. Drivers often slowed down when approaching active DMSs to allow them to have more time to read and react to the message. Through driving simulation, Harder et al. [4] found that changeable message signs did significantly create slow-down effects. Boyle and Mannering [5] indicated that variable message signs cause significant speed variations. They found that warning VMS messages were significant in reducing driving speed in the area of adverse conditions. However, drivers tend to pick up speed to compensate for this speed reduction once passed the message. In another similar study about the effect of DMS on vehicle speed, Ulfarsson et al. [6]
found that DMS messages significantly increased speed deviation of the vehicles. These indicated that drivers responded to DMS but require extra time to process the information.

It is desired to present DMS messages more effectively so they could be easily comprehended by drivers. Some past studies showed that graphically presented information produced faster responses than words [7, 8, and 9]. Consequently, adding graphics to DMS messages might enhance drivers understanding of and responses to those messages. Researchers indicate that graphics have many advantages over text messages. Compared with text messages, they can be identified easier, quicker, and from a further distance; they can be seen better under adverse viewing conditions; they can also be understood by people who cannot understand the language in words [10]. Stern [11] found that graphics alone often lead to quicker completion times, but words leads to greater accuracy. Some past studies investigated the use of graphics in conventional traffic signs and found that symbolic traffic signs produced faster responses [12] and longer viewing legibility distance [13]. Through a driving simulation, Bruce et al. [7] found that the recognition of text messages took appreciably longer than symbol messages. Performance differences in recognition of the messages were not significantly varied by the age and gender of participants. In a laboratory study, Kline and Fuchs [14] investigated the legibility distances of text traffic signs and symbol signs. They found that the legibility distance of symbol signs was twice as that of text traffic signs. Aiming the information deficit at locations suffer from hazards commonly called blind spots, Wulkowicz [15] examined the use of symbols to enhance the informative signs in these spots. He used the standard warning signs faces recognized by drivers and codified in the MUTCD (Manual on Uniform Traffic Control Devices) and enhanced them by animated representations or icons that are triggered by the presence or location of the actual vehicle in the hidden area. The study noted the benefits of such a system
which he calls “enriched information system”.

In spite of conventional signs, not many studies were done on the application of graphics in DMSs. In a simulation using slides representing VMSs, Colomb et al. [16] studied the recognition of matrix sign pictograms and found that the parameters influencing symbol recognition include complexity of pictogram, type of matrix translation, matrix size, and presentation time. Alkim et al. [17] conducted driving simulation experiments to test and compare drivers’ comprehension of both regular VMSs and GRIPs (Graphical Route Information Panels) under the same driving conditions. They found that subjects initially responded faster to regular VMSs but they got used to GRIPs very quickly and made faster responses afterwards. They also found that drivers exhibited a better route choice behavior with GRIPs than with regular VMSs.

To gain insights regarding the feasibility of using graphics on DMSs, a human factors study was designed and carried out to examine the effects of graphic-aided DMSs on human drivers. This report describes two approaches employed in this study, a questionnaire survey – designed to gather drivers’ preferences concerning various features on graphic-aided DMS, and a driving simulation experiment – designed to measure drivers’ response times and accuracies to a number simulated DMS stimuli. Results obtained and conclusions drawn from the two approaches are presented.
2. QUESTIONNAIRE SURVEY

A computer-based questionnaire survey was designed using Microsoft PowerPoint®. Each question in the survey contained two to four choices and examined one feature of a DMS at a time. Four types of DMS messages were examined in the questionnaire survey: weather, construction, information, and regulatory. Table 1 shows the type and the content of the survey messages in detail.

Table 1 Questionnaire survey messages

<table>
<thead>
<tr>
<th>Type</th>
<th>Situation</th>
<th>Message Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weather</td>
<td>Slippery Road</td>
<td>SLIPPERY ROAD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 MILE AHEAD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>USE CAUTION</td>
</tr>
<tr>
<td></td>
<td>Snow</td>
<td>SNOW</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NEXT 20 MILES</td>
</tr>
<tr>
<td></td>
<td></td>
<td>USE CAUTION</td>
</tr>
<tr>
<td>Construction</td>
<td>Road Work</td>
<td>ROAD WORK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AT EXIT 12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>REDUCE SPEED</td>
</tr>
<tr>
<td></td>
<td>Lane Shift</td>
<td>ROAD WORK AHEAD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LEFT LANE CLOSED</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MERGE RIGHT</td>
</tr>
<tr>
<td>Information</td>
<td>Congestion</td>
<td>CONGESTION</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AT EXIT 23</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TUNE TO 1610AM</td>
</tr>
<tr>
<td></td>
<td>Accident</td>
<td>MAJOR ACCIDENT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AT EXIT 9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EXPECT DELAYS</td>
</tr>
<tr>
<td>Regulatory</td>
<td>Road Work</td>
<td>ROAD WORK NEXT 3 MILES</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50 MPH LIMIT</td>
</tr>
<tr>
<td></td>
<td>Seat Belt</td>
<td>SEAT BELT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SAVE LIVES</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CLICK IT OR TICKET</td>
</tr>
<tr>
<td></td>
<td>No Truck</td>
<td>NO TRUCKS AHEAD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>USE EXIT 22</td>
</tr>
</tbody>
</table>

The survey contained a total of 40 questions, eight on message type that compared graphic-aided messages vs. text-only messages (see figure 1(a)); eight on message color that compared amber,
green, and red-colored messages (see figure 1(b)); eight surveyed drivers preferences on alternative graphic images (see figure 1(c)); five on the shape of the frame around graphic image that compared diamond, square, circle, and no frame (see figure 1(d)); four on the contrast of the graphic image that compared negative contrast vs. positive contrast (see figure 1(e)); four surveyed the position of the graphic image whether on the right, left, or both sides of the text message (see figure 1(f)); and three investigated drivers’ preferences on animated messages vs. static messages (see figure 1(g)).
Figure 1 Examples of the survey questions

The survey questions are shown in appendix A in more detail. Questions were presented in a random sequence to prevent any possible bias correlated to the sequence of survey questions. At the start of the survey, the subject would first see two introduction slides about the questionnaire survey (see figure 2). Then the subject was asked to start the survey by clicking on the start button if she/he is ready. Survey questions were then presented one at a time. In each of the questions the subject was asked to choose a DMS message that she/he most preferred by clicking on the option button beside that message (see figure 3).
You are taking part in a survey to help enhance the design and display of Dynamic Message Signs (DMSs). DMS is an electronic bulletin board, usually mounted overhead on highway, which communicates real-time traffic information and travel advice to motorists. The research findings from this survey will benefit the general public and enhance driving safety on state and interstate highways.

In this survey, you will be prompted with a variety of DMS images or animations and you will choose the one that you preferred the most. There isn’t any foreseeable risk or discomfort associated with the survey. The survey will take probably 20 minutes.

Your part in this study is confidential. All records will be kept in a computer that is only accessible to the project investigators. The responses made by you will only be used in statistical analysis.

Please feel free to contact the project director, Dr. Wang (874-5195), if you have any questions or concerns.

If you read the above and agree to participate in this survey, please press the “START” button below to start the survey. Please read each question carefully and choose your best answer. Thank you!
Figure 3 Sample survey question

After the survey was completed the subject was asked to fill demographic information her/his form and click the submit button (see figure 4).

Figure 4 Demographic information form
By doing so, participants’ answers, together with her/his demographic information, were automatically stored in an MS Excel® database for later analysis. A total of 127 subjects participated in the survey. Table 2 exhibits the demographic statistics of the participants.

<table>
<thead>
<tr>
<th>Age groups</th>
<th>English</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>females</td>
<td>males</td>
</tr>
<tr>
<td>18–40 yrs. Old</td>
<td>18</td>
<td>26</td>
</tr>
<tr>
<td>22 subjects</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td>41–60 yrs. Old</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>18 females</td>
<td>18</td>
<td>7</td>
</tr>
<tr>
<td>26 males</td>
<td>18 subjects</td>
<td>11</td>
</tr>
<tr>
<td>9 females</td>
<td>9 females</td>
<td>13</td>
</tr>
<tr>
<td>13 males</td>
<td>13 males</td>
<td>12</td>
</tr>
<tr>
<td>10 females</td>
<td>10 males</td>
<td>11</td>
</tr>
<tr>
<td>10 males</td>
<td>10 males</td>
<td>11</td>
</tr>
</tbody>
</table>

Table 3 shows the subjects’ preference statistics categorized by demographic factors. Proportion tests with 5% significance level were used to analyze the survey data. These analyses found that subjects significantly preferred graphic-aided DMS to text-only DMS messages (P-value=0.000). This result was consistent across all demographic categories, gender, age, and native language. Overall, amber was the preferred color by most of the subjects. However, 45% of elder subjects preferred red, and non-native English speakers had a similar preference between amber and red. Diamond was the most preferred frame shape by the majority of people. In general, no significant difference was detected between negative and positive contrast. This result was consistent across all demographic categories except the young-age subjects who preferred the positive contrast more. Graphic-aided DMS with a graphic image on the left, was significantly preferred (P-value =0.000) by the majority of the subjects, except for elder drivers who preferred to have the same graphic images on both sides of the text message. Animated messages were significantly preferred by the subjects (P-value= 0.000). The same result was also held true across all demographic categories.
Table 3 Respondents’ preferences on DMS features

<table>
<thead>
<tr>
<th>DMS feature</th>
<th>Subjects’ gender</th>
<th>Subjects’ age</th>
<th>Subjects’ native Language</th>
<th>Overall results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Female</td>
<td>Male</td>
<td>18~40 yrs. old</td>
<td>41~60 yrs. old</td>
</tr>
<tr>
<td>Message type</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graphic-aided</td>
<td>92.65%</td>
<td>96.19%</td>
<td>95.77%</td>
<td>95.59%</td>
</tr>
<tr>
<td>Text-only</td>
<td>7.35%</td>
<td>3.81%</td>
<td>4.23%</td>
<td>4.41%</td>
</tr>
<tr>
<td>Message Color</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amber</td>
<td>48.31%</td>
<td>51.65%</td>
<td>59.68%</td>
<td>47.43%</td>
</tr>
<tr>
<td>Red</td>
<td>27.54%</td>
<td>36.21%</td>
<td>28.43%</td>
<td>27.21%</td>
</tr>
<tr>
<td>Green</td>
<td>24.15%</td>
<td>12.13%</td>
<td>11.90%</td>
<td>25.37%</td>
</tr>
<tr>
<td>Shape of the frame</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diamond</td>
<td>26%</td>
<td>30%</td>
<td>41%</td>
<td>20%</td>
</tr>
<tr>
<td>Square</td>
<td>27%</td>
<td>19%</td>
<td>19%</td>
<td>26%</td>
</tr>
<tr>
<td>Circle</td>
<td>22%</td>
<td>29%</td>
<td>20%</td>
<td>27%</td>
</tr>
<tr>
<td>None</td>
<td>25%</td>
<td>22%</td>
<td>20%</td>
<td>27%</td>
</tr>
<tr>
<td>Contrast of the graphic image</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negative contrast</td>
<td>50%</td>
<td>49%</td>
<td>44%</td>
<td>50%</td>
</tr>
<tr>
<td>Positive contrast</td>
<td>50%</td>
<td>51%</td>
<td>56%</td>
<td>50%</td>
</tr>
<tr>
<td>Position of Graphic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right side</td>
<td>3.81%</td>
<td>3.68%</td>
<td>4.84%</td>
<td>0.74%</td>
</tr>
<tr>
<td>Left side</td>
<td>60.17%</td>
<td>60.66%</td>
<td>67.34%</td>
<td>63.97%</td>
</tr>
<tr>
<td>Both sides</td>
<td>35.66%</td>
<td>36.02%</td>
<td>27.82%</td>
<td>35.29%</td>
</tr>
<tr>
<td>Animation effect</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Animated</td>
<td>81.36%</td>
<td>67.65%</td>
<td>67.74%</td>
<td>76.47%</td>
</tr>
<tr>
<td>Static</td>
<td>18.64%</td>
<td>32.35%</td>
<td>32.26%</td>
<td>23.53%</td>
</tr>
</tbody>
</table>

Table 4 presents subjects’ preferences on alternative graphic image for different message situations. For each message situation three images were examined. These images were chosen through a review over the current practices in use of images on traffic signs both inside the United States and internationally. These images are shown in figure 5.

Table 4 Subjects’ preferences on alternative graphic image

<table>
<thead>
<tr>
<th>Message Situation</th>
<th>Accident</th>
<th>Snow</th>
<th>Road work</th>
<th>Slippery Road</th>
<th>Lane shift</th>
<th>Seat belt</th>
<th>Speed limit</th>
<th>Congestion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image</td>
<td>A</td>
<td>81%</td>
<td>57%</td>
<td>93%</td>
<td>25%</td>
<td>12%</td>
<td>91%</td>
<td>57%</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>14%</td>
<td>4%</td>
<td>2%</td>
<td>58%</td>
<td>37%</td>
<td>8%</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>5%</td>
<td>39%</td>
<td>5%</td>
<td>17%</td>
<td>51%</td>
<td>1%</td>
<td>33%</td>
</tr>
</tbody>
</table>
3. LABORATORY DRIVING SIMULATION EXPERIMENT

A driving simulation experiment was developed to gauge drivers’ response times and accuracies in response to simulated DMS images. A total of 48 subjects participated in the study. Each participant was required to have a valid driver license and interstate highway driving experience.
3.1 Experiment Setup

A video-based simulation was employed in this laboratory experiment. A background video was taken while driving on a section of state highway in Rhode Island where an inactive overhead DMS was in place. Driving speed was kept constant at 50 mph while recording the video. A digital video camcorder, leveled at driver’s eye height, was used to take this video. The digital video was downloaded onto a desktop computer where individual frames were extracted by Sonic Foundry VideoFactory™. Individual DMS images were created by Vanguard® VMS Central Controller, the same system used by RIDOT to generate and control DMS messages. Using Adobe® Photoshop® software, individual DMS images were resized and pasted onto the blank DMS board in different frames of the driving video. All frames in the video were next rendered into a video clip at a rate of thirty frames per second and with a length of 27 seconds. Forty-eight video clips were created in this way to show forty-eight different DMS messages used in the experiment.

The experiment was conducted in the Driver Performance Laboratory at University of Rhode Island. The main elements of the laboratory apparatus include: a four-door 1998 Ford Taurus sedan to accommodate the test subject, a Dell Dimension 4500 server with an enhanced video processor to administer the experiment and to record experiment data, a Microsoft Sidewinder force feedback wheel to capture the subject’s responses, a BenQ PB8230 DLP digital projector to project the driving simulation video, and a Draper Cinefold wide projection screen (3.67 m wide x 2.15 m high) for video projection. Figure 6 shows a schematic diagram of laboratory setup with actual dimensions.
Prior to the start of experiment, a briefing about the simulation experiment was given to the subject. The subject was instructed to press one of the three pre-defined buttons on the Sidewinder wheel according to the content of the DMS message. She/he would press button “1” for the “MAJOR ACCIDENT AT EXIT 9 EXPECT DELAYS” messages and button “2” the “ROAD WORK NEXT 3 MILES REDUCE SPEED” messages regardless of message type or message color. Figure 7 shows the two messages exhibited in two types, text-only and graphic-aided. The subject would press button “3” for any other massage. An instruction sheet was also placed on the instrumentation panel in the test vehicle to further assist subjects with response button selection. It was stressed that both response speed and accuracy were important in the experiment. The response times were measured as the time difference between the start of a video and the moment that a subject presses the button to respond. If the subject did not make a proper response before the video finished, a warning message would appear in a window to alert the subject. The accuracy was calculated for each test subject as the ratio of the correct responses to the total number of responses that he/she made in the experiment. A short practice run was given at the beginning to help subjects get familiar with the simulation experiment as...
well as the laboratory environment. The subject could repeat the practice run as many times as she/he desired. After the practice run, the subject was asked to enter some basic demographic information and signal the research assistant to start the experiment. During the experiment, individual simulation video clips were projected onto the projection screen where the DMS image would initially appear as a small dot and gradually increase in size as seen in actual driving. Forty eight simulation videos with different DMS images were shown to each subject consecutively in a random sequence. Figure 8 shows a simulation video on the screen.

![Accident Message](image1)
![Road Work Message](image2)

**Figure 7 Driving simulation test messages**
Figure 8 Simulation video on the screen

A computer program was developed to administer this experiment. Figure 9 shows the computer program running. Subjects’ response time and accuracy for each DMS image were recorded in a Microsoft Access® database in the server computer. Each record in the database file was corresponding to a clip of DMS simulation video. It recorded the name, age, gender of the subject; the message content, message type, message color, response time, response key, and the correctness of the response for that message. The recorded data is presented in appendix B. The overall experiment took about 20 to 30 minutes to complete.
3.2 Experiment Design

Two types of factors were considered in the simulation experiment: main factors and blocking factors. Blocked factorial designs were employed to investigate the effects of the main factors, blocking factors, and their interactions. Table 5 shows these factors and their levels. Message type and message color were chosen in this study since they provided a means to gauge driver’s responses to various DMS messages while allow a comparison to be made between survey findings and lab experiment results.
Two models were employed in the analysis. The first considered both main factors; their interaction; two blocking factors, age and gender; and their interaction. The model could be stated as:

\[ T = \mu + M + C + M \times C + A + G + A \times G + \varepsilon \]  

(1)

The second considered the both main factors together with the native language; and their interactions. The second model could be stated as:

\[ T = \mu + M + C + L + M \times C + M \times L + C \times L + M \times C \times L + \varepsilon \]  

(2)

where:

- \( T \) – Subject’s response time in seconds;
- \( \mu \) – Overall mean in seconds;
- \( M \) – Message type;
- \( C \) – Message color;
- \( A \) – Subjects’ age;
- \( G \) – Subjects’ gender;
- Native Language

<table>
<thead>
<tr>
<th>Factors</th>
<th>Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main factors</td>
<td></td>
</tr>
<tr>
<td>Message type</td>
<td>Graphic-aided, Text-only</td>
</tr>
<tr>
<td>Message color</td>
<td>Green, Amber, Red</td>
</tr>
<tr>
<td>Blocking factors</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>20–40, 41–60, over 60 yrs. Old</td>
</tr>
<tr>
<td>Gender</td>
<td>Female, Male</td>
</tr>
<tr>
<td>Native Language</td>
<td>English, Other</td>
</tr>
</tbody>
</table>
L – Subjects’ native language;
\( \varepsilon \) – Error.

### 3.3 Experiment Results

Analysis of variance (ANOVA) with 5% significance level was conducted. Based on the first model, it found that message type, message color, and their interaction were significant. Subjects’ age was also found to be significant while subjects’ gender was marginal. The interaction of age and gender was not significant. Table 6 shows the ANOVA table with corresponding P-values. The main effect plots and interaction plots are exhibited in figures 3 and 4 respectively.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Seq SS</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Message Type</td>
<td>1</td>
<td>17243.7</td>
<td>17256.7</td>
<td>17256.7</td>
<td>1019.15</td>
<td>0.000</td>
</tr>
<tr>
<td>Message color</td>
<td>2</td>
<td>2552.0</td>
<td>2513.2</td>
<td>1256.6</td>
<td>74.21</td>
<td>0.000</td>
</tr>
<tr>
<td>Message Type*Message color</td>
<td>2</td>
<td>373.8</td>
<td>399.9</td>
<td>199.9</td>
<td>11.81</td>
<td>0.000</td>
</tr>
<tr>
<td>Age</td>
<td>2</td>
<td>2940.1</td>
<td>3022.7</td>
<td>1511.4</td>
<td>89.26</td>
<td>0.000</td>
</tr>
<tr>
<td>Gender</td>
<td>1</td>
<td>64.5</td>
<td>62.3</td>
<td>62.3</td>
<td>3.68</td>
<td>0.055</td>
</tr>
<tr>
<td>Age*Gender</td>
<td>2</td>
<td>43.7</td>
<td>43.7</td>
<td>21.8</td>
<td>1.29</td>
<td>0.275</td>
</tr>
<tr>
<td>Error</td>
<td>1620</td>
<td>27430.6</td>
<td>27430.6</td>
<td>16.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1630</td>
<td>50648.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The ANOVA results with 5% significance level for the second model are shown in Table 7. This analysis showed that all factors and their interactions were significant except the interaction of message color and native language and the three way interaction of message type, message color, and native language. The plots are presented in figures 10 and 11.
Table 7 Analysis of Variance table

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Seq SS</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Message Type</td>
<td>1</td>
<td>17243.7</td>
<td>16918.8</td>
<td>913.17</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Message Color</td>
<td>2</td>
<td>2552.0</td>
<td>1070.8</td>
<td>57.79</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Native Language</td>
<td>1</td>
<td>101.3</td>
<td>101.4</td>
<td>5.47</td>
<td>0.019</td>
<td></td>
</tr>
<tr>
<td>Message Type*Message Color</td>
<td>2</td>
<td>376.5</td>
<td>167.4</td>
<td>9.04</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Message Type*Native Language</td>
<td>1</td>
<td>351.2</td>
<td>351.9</td>
<td>18.99</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Message Color*Native Language</td>
<td>2</td>
<td>27.6</td>
<td>13.8</td>
<td>0.74</td>
<td>0.475</td>
<td></td>
</tr>
<tr>
<td>Message Type<em>Message Color</em></td>
<td>2</td>
<td>0.1</td>
<td>0.0</td>
<td>0.00</td>
<td>0.998</td>
<td></td>
</tr>
<tr>
<td>Native Language</td>
<td></td>
<td>1619</td>
<td>29996.1</td>
<td>18.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1630</td>
<td>50648.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 10 Main effect plots for response time

Mean of Resp Time (Sec.)

- Message Type
- Message Color
- Age
  - Graphic-aided
  - Text-only
  - Amber
  - Green
  - Red
  - 20-40 Yr.
  - 41-60 Yr.
  - over 60 Yr.

Gender

- Female
- Male

Native Language

- English
- Other
These analyses found that the graphic-aided messages were responded significantly faster than text-only messages regardless of message colors. This result was consistent across all demographic groups based on the analysis conducted for each of these groups. No significant difference was found between amber and green for both graphic-aided and text-only messages. However red-colored messages resulted in significantly slower response times than the other two colors. The response time difference between males and females were found to be marginally significant with males responding slightly faster. On average, younger subjects responded significantly faster than older subjects. Non-native English speakers exhibited faster responses than native English speakers. Further analysis revealed that for the text-only messages, no significant difference in response time was found between native and non-native English speakers; however non-native English speakers responded significantly faster to graphic-aided
messages than native English speakers. This shows that adding graphics to DMS messages has helped non-native English speaker drivers more than native English speakers.

Table 8 shows the results of the subjects’ accuracy in response to the DMS stimuli. Proportion tests with 5% significance level were conducted on these results. Overall, subjects were found to respond to the graphic-aided messages more accurately than text-only messages and the difference was significant (P-value= 0.005). However, message color did not have a significant effect on accuracy. Elder subjects, in general, responded less accurately than subjects from other age groups. Females had significantly higher accuracy than males. It was also found that non-native English speakers were more accurate than native English speakers. Message type significantly affected the accuracy of native English speakers. They had higher accuracy in response to the graphic-aided messages than text-only messages; however, it did not significantly affect non-native English speakers. Moreover, the analysis found that graphic-aided messages significantly enhanced the accuracy of elder drivers; however, they did not have any significant effect on young and middle-aged subjects. Males responded more accurately to the graphic-aided messages than text-only messages (P-value= 0.003), while females’ accuracy was not significantly affected by the message type.
Table 8 Accuracy analysis results

<table>
<thead>
<tr>
<th>DMS feature</th>
<th>Subjects’ gender</th>
<th>Subjects’ age</th>
<th>Subjects’ native Language</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Female</td>
<td>Male</td>
<td>20–40 yrs. Old</td>
<td>41–60 yrs. Old</td>
</tr>
<tr>
<td>Message type</td>
<td>Graphic-aided</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>96.03%</td>
<td>90.61%</td>
<td>94.74%</td>
<td>94.44%</td>
</tr>
<tr>
<td>Male</td>
<td>95.24%</td>
<td>84.67%</td>
<td>94.74%</td>
<td>94.44%</td>
</tr>
<tr>
<td>Text-only</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amber</td>
<td>96.43%</td>
<td>87.64%</td>
<td>95.61%</td>
<td>95.61%</td>
</tr>
<tr>
<td>Red</td>
<td>95.54%</td>
<td>86.49%</td>
<td>93.86%</td>
<td>92.98%</td>
</tr>
<tr>
<td>Green</td>
<td>94.94%</td>
<td>88.792%</td>
<td>94.74%</td>
<td>94.74%</td>
</tr>
<tr>
<td>Overall</td>
<td>95.63%</td>
<td>87.64%</td>
<td>94.74%</td>
<td>94.44%</td>
</tr>
</tbody>
</table>

A regression analysis was conducted to investigate the correlation between response time and accuracy. Regression statistics and ANOVA results are shown in table 9. No correlation was found between the response time and accuracy. In other words, accuracy is independent of response time. Figure 12 shows the scatter plot between accuracy and response time.

Table 9 Regression statistics and ANOVA results for accuracy vs. response time

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coef</th>
<th>SE Coef</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.92063</td>
<td>0.05658</td>
<td>16.27</td>
<td>0.000</td>
</tr>
<tr>
<td>Response time</td>
<td>0.002048</td>
<td>0.003400</td>
<td>0.60</td>
<td>0.550</td>
</tr>
</tbody>
</table>

S = 0.0617321  R-Sq = 0.8%  R-Sq(adj) = 0.0%

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>1</td>
<td>0.001382</td>
<td>0.001382</td>
<td>0.36</td>
<td>0.550</td>
</tr>
<tr>
<td>Residual Error</td>
<td>46</td>
<td>0.175299</td>
<td>0.003811</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>47</td>
<td>0.176681</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
A human factors study was conducted to examine the effects of employing graphics in DMS messages on drivers’ preferences of and responses to these messages. The results found from both survey and driving simulation showed that graphic-aided messages are significantly better than text-only ones in terms of preference, response time, and accuracy. It was also found that red might not be a good choice of color for DMS messages and is not recommended to be used on DMSs. Elder drivers found to be less accurate and much slower than younger drivers. But their performances were significantly improved by graphic-aided messages. Language background of the drivers was also revealed to have a significant effect on their response time and accuracy. It was found that adding graphics on DMS messages did noticeably enhance the message comprehension time for non-native English speakers. These are critical issues and additional attention must be paid in designing the content of DMS messages in order to be easily understandable by elder drivers and driver with different native languages. Further studies are

**4. CONCLUSION**

![Scatter plot between accuracy and response time](image)

Figure 12 Scatter plot between accuracy and response time
required to find out the proper specifications and design guidelines of these graphical images to be used on DMS messages. Results of this research could help traffic management authorities improve the effectiveness of DMS messages and enhance safe driving on highways.

5. ACKNOWLEDGEMENT

We would like to thank University of Rhode Island Transportation Center (URITC) and the Rhode Island Department of Transportation (RIDOT) for their support in all phases of this study.

6. REFERENCES


APPENDIX A
Survey questions

**Employing Graphics to Aid Message Display on Dynamic Message Signs**

**Questionnaire Survey**
Conducted by University of Rhode Island
Sponsored by URITC and RIDOT

You are taking part in a survey to help enhance the design and display of Dynamic Message Signs (DMSs). DMS is an electronic bulletin board, usually mounted overhead on highway, which communicates real-time traffic information and travel advice to motorists. The research findings from this survey will benefit the general public and enhance driving safety on state and interstate highways.

**Driving Questionnaire on Dynamic Message Signs**

In this survey, you will be prompted with a variety of DMS images or animations and you will choose the one that you preferred the most. There isn’t any foreseeable risk or discomfort associated with the survey. The survey will take probably 20 minutes.

Your part in this study is confidential. All records will be kept in a computer that is only accessible to the project investigators. The responses made by you will only be used in statistical analysis.

Please feel free to contact the project director, Dr. Wang (874-5195), if you have any questions or concerns.

If you read the above and agree to participate in this survey, please press the “START” button below to start the survey. Please read each question carefully and choose your best answer. Thank you!
Which of the following signs best displays a Slippery Road?

(A) SLIPPERY ROAD 1 MILE AHEAD USE CAUTION

(B) SLIPPERY ROAD 1 MILE AHEAD USE CAUTION

(C) SLIPPERY ROAD 1 MILE AHEAD USE CAUTION

Next Question →
Which of the following signs best displays a Slippery Road?

(A) SLIPPERY ROAD
    1 MILE AHEAD
    USE CAUTION

(B) SLIPPERY ROAD
    1 MILE AHEAD
    USE CAUTION

Next Question ➔
Which of the following signs do you prefer most?

- (A) SNOW
  NEXT 20 MILES
  USE CAUTION

- (B) SNOW
  NEXT 20 MILES
  USE CAUTION

Next Question

Which of the following colors do you prefer most?

- (A) ROAD WORK AHEAD
  LEFT LANE CLOSED
  MERGE RIGHT

- (B) ROAD WORK AHEAD
  LEFT LANE CLOSED
  MERGE RIGHT

- (C) ROAD WORK AHEAD
  LEFT LANE CLOSED
  MERGE RIGHT

Next Question
Which of the following signs do you prefer most?

(A) MAJOR ACCIDENT AT EXIT 9 EXPECT DELAYS

(B) MAJOR ACCIDENT AT EXIT 9 EXPECT DELAYS

Next Question →
Which of the following signs do you prefer most?

(A) MAJOR ACCIDENT AT EXIT 9 EXPECT DELAYS

(B) MAJOR ACCIDENT AT EXIT 9 EXPECT DELAYS

Which of the following signs best displays Snow?

(A) SNOW NEXT 20 MILES USE CAUTION

(B) SNOW NEXT 20 MILES USE CAUTION

(C) SNOW NEXT 20 MILES USE CAUTION
Which of the following signs best displays Snow?

- Option A: Snow, Next 20 Miles, Use Caution
- Option B: Snow, Next 20 Miles, Use Caution

Next Question →
Which of the following signs best displays Snow?

- (A) SNOW NEXT 20 MILES USE CAUTION
- (B) SNOW NEXT 20 MILES USE CAUTION

Which of the following colors do you prefer most?

- (A) LIMIT 50 ROAD WORK NEXT 3 MILES 50 MPH LIMIT
- (B) LIMIT 50 ROAD WORK NEXT 3 MILES 50 MPH LIMIT
- (C) LIMIT 50 ROAD WORK NEXT 3 MILES 50 MPH LIMIT

Next Question ➔
Which of the following signs do you prefer most?

(A) NO TRUCKS AHEAD
USE EXIT 22

(B) NO TRUCKS AHEAD
USE EXIT 22

(C) NO TRUCKS AHEAD
USE EXIT 22

(D) NO TRUCKS AHEAD
USE EXIT 22

Next Question ➔

Which of the following signs best displays Road Work?

(A) ROAD WORK AT EXIT 12
REDUCE SPEED

(B) ROAD WORK AT EXIT 12
REDUCE SPEED

(C) ROAD WORK AT EXIT 12
REDUCE SPEED

Next Question ➔
Which of the following signs best displays Road Work?

(A) ROAD WORK AT EXIT 12 REDUCE SPEED

(B) ROAD WORK AT EXIT 12 REDUCE SPEED
Which of the following signs best displays Road Work?

(A) ROAD WORK AT EXIT 12 REDUCE SPEED

(B) ROAD WORK AT EXIT 12 REDUCE SPEED

Which of the following signs best displays a Lane merging?

(A) ROAD WORK AHEAD LEFT LANE CLOSED MERGE RIGHT

(B) ROAD WORK AHEAD LEFT LANE CLOSED MERGE RIGHT

(C) ROAD WORK AHEAD LEFT LANE CLOSED MERGE RIGHT
Which of the following signs best displays a Lane merging?

(A) ROAD WORK AHEAD
LEFT LANE CLOSED
MERGE RIGHT

(B) ROAD WORK AHEAD
LEFT LANE CLOSED
MERGE RIGHT
Which of the following signs best displays a Lane merging?

(A) ROAD WORK AHEAD
    LEFT LANE CLOSED
    MERGE RIGHT

(B) ROAD WORK AHEAD
    LEFT LANE CLOSED
    MERGE RIGHT

Next Question

Which of the following signs do you prefer most?

(A) LIMIT 50
    ROAD WORK
    NEXT 3 MILES
    50 MPH LIMIT

(B) ROAD WORK
    NEXT 3 MILES
    50 MPH LIMIT

(C) LIMIT 50
    ROAD WORK
    NEXT 3 MILES
    50 MPH LIMIT

Next Question
Which of the following signs do you prefer most?

(A) ROAD WORK AT EXIT 12 REDUCE SPEED

(B) ROAD WORK AT EXIT 12 REDUCE SPEED

Which of the following signs best displays Congestion?

(A) CONGESTION AT EXIT 23 TUNE TO 1610AM

(B) CONGESTION AT EXIT 23 TUNE TO 1610AM

(C) CONGESTION AT EXIT 23 TUNE TO 1610AM
Which of the following signs best displays Congestion?

(A) CONGESTION AT EXIT 23 TUNE TO 1610AM

(B) CONGESTION AT EXIT 23 TUNE 1610AM

Next Question ➔

Which of the following signs best displays Congestion?

(A) CONGESTION AT EXIT 23 TUNE TO 1610AM

(B) CONGESTION AT EXIT 23 TUNE TO 1610AM

Next Question ➔
Which of the following signs best displays Congestion?

(A) CONGESTION AT EXIT 23 TUNE TO 1610AM

(B) CONGESTION AT EXIT 23 TUNE 1610AM

Which of the following signs do you prefer most?

(A) ROAD WORK AHEAD LEFT LANE CLOSED MERGE RIGHT

(B) ROAD WORK AHEAD LEFT LANE CLOSED MERGE RIGHT

(C) ROAD WORK AHEAD LEFT LANE CLOSED MERGE RIGHT

(D) ROAD WORK AHEAD LEFT LANE CLOSED MERGE RIGHT
Which of the following signs best displays an Accident?

(A) MAJOR ACCIDENT AT EXIT 9 EXPECT DELAYS

(B) MAJOR ACCIDENT AT EXIT 9 EXPECT DELAYS

(C) MAJOR ACCIDENT AT EXIT 9 EXPECT DELAYS

Next Question →
Which of the following signs best displays an Accident?

(A) MAJOR ACCIDENT
AT EXIT 9
EXPECT DELAYS

(B) MAJOR ACCIDENT
AT EXIT 9
EXPECT DELAYS

Next Question ➔
Which of the following signs do you prefer most?

(A) ROAD WORK AHEAD REDUCE SPEED

(B) ROAD WORK AHEAD REDUCE SPEED

Which of the following signs do you prefer most?

(A) ROAD WORK AHEAD REDUCE SPEED

(B) ROAD WORK AHEAD REDUCE SPEED LIMIT 45
Which of the following signs do you prefer most?

(A) ROAD WORK AHEAD REDUCE SPEED

(B) ROAD WORK AHEAD REDUCE SPEED

Which of the following signs do you prefer most?

(A) CONGESTION AT EXIT 23 TUNE TO 1610AM

(B) CONGESTION AT EXIT 23 TUNE TO 1610AM

(C) CONGESTION AT EXIT 23 TUNE TO 1610AM
Which of the following signs best displays a Speed Limit?

(A) 50
ROAD WORK
NEXT 3 MILES
50 MPH LIMIT

(B) 50
ROAD WORK
NEXT 3 MILES
50 MPH LIMIT

(C) 50
ROAD WORK
NEXT 3 MILES
50 MPH LIMIT
Which of the following signs do you prefer most?

(A) ROAD WORK AT EXIT 12 REDUCE SPEED
(B) ROAD WORK AT EXIT 12 REDUCE SPEED
(C) ROAD WORK AT EXIT 12 REDUCE SPEED
(D) ROAD WORK AT EXIT 12 REDUCE SPEED

Next Question ➔

Which of the following colors do you prefer most?

(A) ROAD WORK AT EXIT 12 REDUCE SPEED
(B) ROAD WORK AT EXIT 12 REDUCE SPEED
(C) ROAD WORK AT EXIT 12 REDUCE SPEED

Next Question ➔
Which of the following signs best displays *Use Seat Belt*?

- **(A)**
  - SEAT BELT
  - SAVE LIVES
  - CLICK IT OR TICKET

- **(B)**
  - SEAT BELT
  - SAVE LIVES
  - CLICK IT OR TICKET

- **(C)**
  - SEAT BELT
  - SAVE LIVES
  - CLICK IT OR TICKET

Which of the following signs best displays *Use Seat Belt*?

- **(A)**
  - SEAT BELT
  - SAVE LIVES
  - CLICK IT OR TICKET

- **(B)**
  - SEAT BELT
  - SAVE LIVES
  - CLICK IT OR TICKET

Next Question ➔
Which of the following signs best displays "Use Seat Belt"?

(A) SEAT BELT
SAVE LIVES
CLICK IT OR TICKET

(B) SEAT BELT
SAVE LIVES
CLICK IT OR TICKET

Next Question →
Which of the following signs do you prefer most?

(A) SNOW NEXT 20 MILES USE CAUTION
(B) SNOW NEXT 20 MILES USE CAUTION
(C) SNOW NEXT 20 MILES USE CAUTION
(D) SNOW NEXT 20 MILES USE CAUTION

Next Question →

Which of the following colors do you prefer most?

(A) CONGESTION AT EXIT 23 TUNE TO 1610AM
(B) CONGESTION AT EXIT 23 TUNE TO 1610AM
(C) CONGESTION AT EXIT 23 TUNE TO 1610AM

Next Question →
Which of the following signs do you prefer most?

(A) SLIPPERY ROAD
1 MILE AHEAD
USE CAUTION

(B) SLIPPERY ROAD
1 MILE AHEAD
USE CAUTION

Which of the following signs do you prefer most?

(A) ROAD WORK AHEAD
LEFT LANE CLOSED
MERGE RIGHT

(B) ROAD WORK AHEAD
LEFT LANE CLOSED
MERGE RIGHT

(C) ROAD WORK AHEAD
LEFT LANE CLOSED
MERGE RIGHT
Which of the following signs do you prefer most?

(A) SLIPPERY ROAD 1 MILE AHEAD USE CAUTION

(B) SLIPPERY ROAD 1 MILE AHEAD USE CAUTION

(C) SLIPPERY ROAD 1 MILE AHEAD USE CAUTION

Next Question →

Which of the following three animated signs do you prefer most?
Click the button to see the next animation

(A) ROAD WORK AHEAD LEFT LANE CLOSED MERGE RIGHT

Next →
Which of the following signs do you prefer most?

(A) ROAD WORK AHEAD LEFT LANE CLOSED MERGE RIGHT

(B) ROAD WORK AHEAD LEFT LANE CLOSED MERGE RIGHT

Which of the following signs do you prefer most?

(A) LEFT LANE CLOSED MERGE RIGHT

(B) ROAD WORK AHEAD LEFT LANE CLOSED MERGE RIGHT
Which of the following signs do you prefer most?

(A) MERGE RIGHT

(B) ROAD WORK AHEAD
    LEFT LANE CLOSED
    MERGE RIGHT

Which of the following signs do you prefer most?

(A) ROAD WORK AHEAD
    LEFT LANE CLOSED
    MERGE RIGHT

(B) ROAD WORK AHEAD
    LEFT LANE CLOSED
    MERGE RIGHT
Which of the following line colors do you prefer most?

- (A) NO TRUCKS AHEAD USE EXIT 22
- (B) NO TRUCKS AHEAD USE EXIT 22
- (C) NO TRUCKS AHEAD USE EXIT 22

Which of the following colors do you prefer most?

- (A) MAJOR ACCIDENT AT EXIT 9 EXPECT DELAYS
- (B) MAJOR ACCIDENT AT EXIT 9 EXPECT DELAYS
- (C) MAJOR ACCIDENT AT EXIT 9 EXPECT DELAYS
Which of the following colors do you prefer most?

(A) SLIPPERY ROAD 1 MILE AHEAD USE CAUTION

(B) SLIPPERY ROAD 1 MILE AHEAD USE CAUTION

(C) SLIPPERY ROAD 1 MILE AHEAD USE CAUTION

Which of the following signs do you prefer most?

(A) SLIPPERY ROAD 1 MILE AHEAD USE CAUTION

(B) SLIPPERY ROAD 1 MILE AHEAD USE CAUTION

(C) SLIPPERY ROAD 1 MILE AHEAD USE CAUTION

(D) SLIPPERY ROAD 1 MILE AHEAD USE CAUTION
Which of the following colors do you prefer most?

- (A) Snow Next 20 Miles Use Caution
- (B) Snow Next 20 Miles Use Caution
- (C) Snow Next 20 Miles Use Caution

Personal Data

First Name: 

Last Name: 

Age: 
- 18-40
- 41-60
- 61 and above

Gender: 
- Male
- Female

Native Language: 
- English
- Spanish
- Other

Education: 
- Primary
- Middle School
- High
- College
- Post-Graduate

Are you color blind: 
- Yes
- No

Do you wear glasses/contacts: 
- Yes
- No

Submit
APPENDIX B: Experiment Data
Following is an example of the experiment database.

<table>
<thead>
<tr>
<th>Record No.</th>
<th>Age</th>
<th>Gender</th>
<th>Message Name</th>
<th>Correct Key</th>
<th>Color</th>
<th>Graphic</th>
<th>Resp Key</th>
<th>Resp Time</th>
<th>Accuracy</th>
<th>Language</th>
<th>Driving Ex</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>41~60 Yr.</td>
<td>Female</td>
<td>Accident</td>
<td>49</td>
<td>Green</td>
<td>Text-only</td>
<td>49</td>
<td>21.73438</td>
<td>1</td>
<td>Spanish</td>
<td>more than 10 years</td>
</tr>
<tr>
<td>2</td>
<td>41~60 Yr.</td>
<td>Female</td>
<td>Accident</td>
<td>49</td>
<td>Amber</td>
<td>Text-only</td>
<td>49</td>
<td>21.3125</td>
<td>0</td>
<td>Spanish</td>
<td>more than 10 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>2736</td>
<td>20~40 Yr.</td>
<td>Male</td>
<td>Road Work</td>
<td>50</td>
<td>Green</td>
<td>Graphic-Aided</td>
<td>50</td>
<td>2.015625</td>
<td>1</td>
<td>English</td>
<td>5~10 years</td>
</tr>
</tbody>
</table>

Note:
1. In column “Response Key”, 49 stands for button “1”, 50 stands for button “2”, 51 stands for button “3”.
2. In column “Accuracy”, 0 stands for the incorrect response to a DMS message and 1 stands for the correct response to a DMS message.