

**Driver Response to  
Dynamic Message Sign Safety Campaign Messages**

Pamela Kryschtal

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Civil Engineering

Tripp Shealy

Bryan J. Katz

Susan Hotle

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### **ABSTRACT**

Unsafe driving habits increase the severity of roadway accidents. The behaviors that are generally associated with unsafe driving are influenced by drivers and their decision to engage in dangerous habits. In order to solve this problem, Departments of Transportation use roadside safety campaigns. To gain a comprehensive understanding of the effectiveness of these campaigns, this research study captured five different metrics of effectiveness to understand what messages are effective and how to target messages to different groups of people. Since reading and interpreting the messages produces cognitive activation among participants, a neuroimaging technology called functional near-infrared spectroscopy (fNIRS) was used to measure neurocognitive activation as a proxy for response. The fNIRS system captures this cognitive activation by measuring change in oxygenated blood (oxy-Hb). An increase in oxy-Hb is a proxy for increased task engagement. The first journal paper provides an understanding of what types of messages are perceived as effective, are misunderstood, are memorable, are considered inappropriate, and cause the greatest increase in cognitive engagement. Overall, drivers perceive messages to be effective at changing behavior, but particular messages are perceived as more effective than others. Messages about distracted driving and driving without a seat belt, messages that are intended to produce a negative emotional response, and messages with statistics are the behaviors, emotions, and themes that are most likely to be perceived to change driver behavior. Messages about distracted driving and messages about statistics are most likely to be remembered by drivers. In general, drivers do not find messages used in safety campaigns to be inappropriate. Drivers elicit more cognitive attention to signs about distracted driving and signs with a humorous emotion. The second journal considers the effectiveness of these messages with different target demographics by further investigating the first journal's results by different dependent variables, including age, gender, and risky driving habits of the participants. In the second study, the results from the first study are further examined to determine if some campaigns are more effective among different demographics of drivers. The behavioral results indicated that females, drivers over 65, low-risk and high-risk drivers, and urban and rural drivers perceive the safety campaigns as more effective. The neurological data revealed that younger drivers had more activation in the ventrolateral prefrontal cortex, an area

known for semantics and word processing, which might indicate more cognitive attention to these types of messages. This study provides a unique application of using neuroimaging techniques to understand driver response to safety messages. The recommendations for an effective safety campaign are to use messages about distracted driving, messages with an emotional stimulus, and messages about statistics. Messages about word play and rhyme are recommended for appealing to younger demographics.

# **Driver Response to Dynamic Message Sign Safety Campaign Messages**

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## **GENERAL AUDIENCE ABSTRACT**

Messages like “New year, new you, use your blinker” and “May the 4<sup>th</sup> be with you, text I will not” are increasingly used to catch drivers’ attention. The development and use of these non-traditional safety messages are distinctly different than messages previously displayed on highway signs because the intent of these messages is to modify driver behavior rather than just provide information. Unfortunately, there is little empirical evidence measuring how effective these messages are at changing driver behavior or guidance on how to target messages for specific groups of people. The goal of this study was to understand what types of non-traditional safety messages are effective and how to target these messages to different target audiences. Roadway collisions are made more severe when the cause of the incident involves dangerous driving habits, such as distracted, impaired, or aggressive driving. The problem is made even more severe by the fact that the habits that make driving dangerous are affected by the driver’s decision to engage in risky driving behavior. The solution to this problem is to gain an understanding of driver preferences and response, a research effort this study will address. Reading and interpreting the messages produces cognitive activation among participants. The study uses functional near-infrared spectroscopy (fNIRS), which allows researchers to capture this cognitive activation by measuring change in oxygenated blood (oxy-Hb). This provides not only the ability to gain a more detailed understanding of driver response, but the ability to triangulate this with what drivers perceive as effective in changing driver behavior. In the first study, the participants felt that campaigns targeting distracted driving, messages with a negative emotion, and campaigns about statistics were significantly more effective at changing driver behavior compared to other behaviors, emotions, and themes. The neurological data revealed that drivers respond more to campaigns about distracted driving. However, the neurological data indicates that humorous messages and messages that fit under the theme word play and rhyme elicit a greater cognitive response. The second study furthers the first study and revealed that females, drivers over 65, low-risk and high-risk drivers, and urban and rural drivers perceive the safety campaigns as more effective. The neurological data revealed that younger and older males and older high-risk drivers respond with greater peak oxy-Hb when compared to other groups of people. This study advances the applicability of fNIRS in traffic related studies.

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## INTRODUCTION

The dangerous driving behaviors that heighten the severity of driving accidents are behaviors that come about from a driver's decision to engage in risky driving behavior, such as aggressive, impaired, and distracted driving. Safety campaigns are used by Departments of Transportation in an effort to change driver behavior. These campaigns are being increasingly used and, furthermore, are employing strategies to capture driver attention such as non-traditional safety messages that use humor or fear. The development and use of these non-traditional safety messages are distinctly different than messages previously displayed on highway signs because the intent of these messages is to modify driver behavior rather than just provide information. Unfortunately, there is little empirical evidence in the effectiveness of these campaigns. This type of problem is one that requires changing behavior; therefore, understanding what messages are effective is vital for this change. Understanding this effectiveness relies on comprehensive analysis, and this comprehensive analysis can be achieved by measuring multiple measures of effectiveness, including perceived effectiveness together with neurocognitive activation.

New technologies that allow researchers to collect data on the brain have transformed the study of cognition because it allows for the collection of objective physiological data. This data can be used to provide a more qualitative explanation of what drivers are attentive to and respond to, thus allowing a more detailed understanding of what safety campaigns are effective at changing driver behavior. This data allows researchers to congruently measure behavioral data and physiological data. Ultimately, this behavioral data combined with the physiological data will provide a more comprehensive understanding of how to change driver behavior.

The neuroimaging technology used in this study was functional near-infrared spectroscopy (fNIRS). This along with capturing four other metrics of effectiveness, including perceived effectiveness, comprehension, memorability, and inappropriateness, will provide a detailed understanding of what safety campaigns are effective. Capturing information about participants' demographics will provide an understanding of how to target campaigns to different demographics including gender and age.

The first study investigates the effectiveness of these campaigns across five metrics of effectiveness. The five measures of effectiveness were perceived effectiveness, comprehension,

memorability, inappropriateness, and neurocognitive activation. 300 participants from across the state of Virginia read 80 safety campaign messages categorized by behavior, emotion, and theme. These participants wore an fNIRS cap while reading the messages to measure the neurocognitive activation. Participants revealed the perceived effectiveness and comprehension after viewing the messages and revealed the messages' memorability and inappropriateness in a post-task survey. The perceived effectiveness was that, overall, drivers perceive messages to be effective at changing behavior. Messages about distracted driving and driving without a seat belt, messages that are intended to produce a negative emotional response, and messages with statistics are the behaviors, emotions, and themes that are most likely to be perceived to change driver behavior. Drivers tend to misunderstand messages that do not have a specific target behavior, for example, messages about general driving safety. Messages about distracted driving and messages about statistics are memorable. Specific messages that were empirically tested that drivers recalled from memory were, "Nobody puts baby in a hot car," "Mom needs your hug not your text," and "You're not a firework don't drive lit." In general, drivers do not find messages used in safety campaigns to be inappropriate. The neurological data reinforced that drivers respond to messages about distracted driving and revealed that drivers are attentive to messages about humor and word play and rhyme.

The second study investigates the results of the first study more in depth by examining the differences in the five metrics of effectiveness across gender, age, and risky driving tendencies. The recruitment of 300 participants from across the state of Virginia was balanced in an attempt to gather data for an equal number of males and females equally across four different age groups, 18-25, 26-40, 41-65, and 65+. These participants read 80 safety campaign messages categorized by behavior, emotion, and theme while wearing the fNIRS cap and answering out loud their perceived effectiveness and understanding of the intended driving behavior change. The post task survey captured the demographics necessary for analysis. The study revealed that younger and older males and older high-risk drivers respond with greater peak oxy-Hb when compared to other groups of people.

Both experiments provide a detailed understanding of what makes a safety campaign effective. Both studies provide real-world implications into how to target safety campaigns that change driver behavior. The research reinforces the applicability of fNIRS in traffic related studies.

Each journal entry presented in this paper is outlined according to the journal intended for publication. Both begin with an introduction that covers the project and includes background as applicable. Next, the objectives are presented that will provide the framework for the results for both journals. Then the methods are introduced; the methods for the second paper are similar to the methods in the first paper and are treated as an extension of that methodology. The results are organized by objective and include tables and figures as necessary. Finally, a discussion of the results of each paper are provided that includes conclusive commentary.

# **Journal Paper 1: THE EFFECTIVENESS OF ROADSIDE SAFETY CAMPAIGNS USING fNIRS**

Intended Outlet for Publication:

Transportation Research Part F: Traffic Psychology and Behavior

## **ABSTRACT**

Dangerous driving habits that make road deaths a leading cause of death are habits that involve driver's deciding to engage in risky driving habits, such as aggressive, distracted, or impaired driving. Safety campaigns are increasingly used to catch drivers' attention in an effort to get them to change driver behavior. Unfortunately, there is little empirical evidence measuring how effective these messages are at changing driver behavior. The goal of this study was to measure the effectiveness of different types of non-traditional safety messages. Non-traditional safety messages were collected from across the country and categorized by their intended behavior, intended emotional response, and message theme (e.g., sports, rhymes, pop-culture). To measure the effectiveness of these non-traditional safety messages, 300 people read 80 messages grouped by their behavior, emotion, and theme. Participants were asked their perceptions of these messages' ability to change driver behavior, to identify the intent of the message, and whether they could recall types of message. A neuroimaging instrument called functional near-infrared spectroscopy (fNIRS) was also used to capture participants' neurocognitive response. An increase in cognitive activation is a proxy for increased attention. The results indicate people perceive all types of non-traditional safety messages as effective. Messages about distracted driving and driving without a seat belt, messages meant to provoke a negative or humorous emotional response, and messages using statistics and word play and rhyme are perceived to most likely change driver behavior. Messages about general safe driving are significantly misunderstood more compared to messages about distracted driving, impaired driving, and wearing a seat belt. Messages about distracted driving and impaired driving are the most recallable. The neurocognitive results indicate that messages about distracted driving, messages with humor, and messages that use word play elicit significantly higher levels of cognitive activation in the prefrontal cortex. These behavioral and neurocognitive results provide evidence that drivers find non-traditional safety messages as effective, and specific messages seem more

effective than others. Messages about distracted driving, messages that include humor, and messages that use word play and rhymes rank high among multiple measures of effectiveness.

## **1. INTRODUCTION & BACKGROUND**

Driving is made more dangerous when drivers engage in risky driving behavior. Efforts to discourage these undesirable driving habits include deploying roadside safety campaign messages on dynamic message signs, particularly messages utilizing humor or threat, to cause drivers to change behavior. However, there is little empirical evidence measuring the effectiveness of these messages to change behavior.

Research into the effectiveness of safety campaigns on changeable message signs is necessary because the development and use of these non-traditional messages are distinctly different than messages previously displayed on these signs in that the intent of these messages is to modify driver behavior rather than just provide information. Therefore, this study will use an integrated approach that considers the cognitive response of the target audience in order provide better understanding of and insight into changing driver behavior.

Prior studies in changeable messages signs include qualitative measurements of perceived effectiveness and quantitative studies that measured driver speed to determine the effectiveness of the signs at slowing down drivers. The qualitative studies used surveys and focus groups to measure perceived effectiveness of the messages in safety campaigns (Boyle et al., 2014; Rodier, Lidicker, Finson, & Shaheen, 2010; Schroeder, Plapper, Zeng, & Krile, 2016). The results of these studies showed that drivers claim to understand the messages and clarity of the message improves effectiveness. The limitations of the prior qualitative research is that respondents do not always answer surveys truthfully due to experimenter bias (i.e., the Hawthorne effect) (McCambridge, Witton, & Elbourne, 2014) and because their memories do not always represent reality. Translating these findings to real-world driving behavior is also a challenge. To move beyond measuring perceptions, two quantitative studies measured driver speed in the proximity of a non-traditional message intended to deter drivers from speeding. One study found that the message had little effect on travel speed because drivers interpreted the message to mean there

were no disruptions ahead (Haghani, Hamed, Fish, & Norouzi, 2013). The other study found that non-traditional messages lead to statistically slower driving (Harder & Bloomfield, 2008).

Other research efforts have studied the effectiveness of roadside safety campaigns by categorizing emotional appeals, either as positive or negative. Positive emotions, particularly humor, can be advantageous because the campaigns are more likely to be shared if they are funny, but disadvantageous if they become trivial and less likely to be adopted (Dun & Ali, 2018; Young Kim N. & Karim Biswas, 2018). Threat as a negative emotion can be an effective means for communicating a safety campaign, particularly because it is considered an informative tactic giving the drivers factual information (Dun & Ali, 2018). Harsh and threatening messages tend to be the most effective (Cauberghe, De Pelsmacker, Janssens, & Dens, 2009; Glendon, Lewis, Levin, & Ho, 2018; Glendon & Walker, 2013; Lewis, Watson, & White, 2010). Guilt as an emotional tactic presents conflicting results in the literature; shame and outrage provide a distraction while the thought of others being harmed because of a driver's action is a motivator for behavior change (Dun & Ali, 2018; Rodd, 2017). Related to response efficacy, participants generally feel that campaigns are not effective for themselves but are effective for other drivers (Cauberghe et al., 2009; Jeahani & Ardeshiri, 2013). The limitations of these prior studies that break down emotion are the conflicting results about whether the campaigns are effective or not effective.

A research gap that this study addresses is measuring both qualitative data about perceptions of effectiveness with quantitative measures of cognitive response to provide new insight about overall effectiveness of safety campaign messages. This study uses multiple methods of data to triangulate the effects of non-traditional safety messages. Effectiveness is defined as the perceived ability to change behavior, ability to comprehend the intent of the message, ability to recall the message, and neurocognitive response when reading and interpreting the message. The purpose of asking about memorable and inappropriate messages is because a common concern with displaying humorous messages is that they may be misunderstood, in some cases offensive, or otherwise create undesirable behavior or perceptions. The neurocognitive response provides new insight about how messages are interpreted and processed in the brain. An increase in cognitive activation is a proxy for task engagement (Verdière, Roy, & Dehais, 2018), attention

(Harrivel, Weissman, Noll, & Peltier, 2013) and working memory (Jahani et al., 2017; Rieger et al., 2019; Scheunemann, Unni, Ihme, Jipp, & Rieger, 2019). Mental activity can linearly correspond with engagement (Fishburn, Norr, Medvedev, & Vaidya, 2014), and driving attention and cognitive load are linearly related (Unni, Ihme, Jipp, & Rieger, 2018).

Previous studies demonstrate the ability to use fNIRS to measure and predict perceptions of safety (M. Hu & Shealy, 2018), risky decision making (Mo Hu & Shealy, 2019), and problem-solving (Shealy, Hu, & Gero, 2018). Specific to driver behavior, neuro-cortical activation can predict steering control, and a driver's response to changes in vehicle dynamics (Bruno et al., 2018). Neuro-cognition provides a glimpse into a driver's intent to act. Patterns of neuro-cognition when driving can identify a driver's braking intent prior to his braking operation (Zhu et al., 2018).

fNIRS provides an approach to triangulate between what participants say and what they demonstrate. For instance, in a prior study, engineers self-reported their ability to think in systems. Those who scored high on the self-report survey were more likely to perform worse on systems thinking tasks. In contrast, the fNIRS data was a positive predictor of actual performance (Mo Hu, Shealy, Grohs, & Panneton, 2019). In this study, the participant is asked what types of message they believe are most effective in changing driver behavior, and the fNIRS instrument captures physiological response. Similar to this prior research (Mo Hu et al., 2019), what participants believe and how they cognitively respond may not be the same.

The purpose of the research study was to understand the effectiveness of changeable message signs based on five different definitions of effectiveness. The study's research questions were:

1. What types of non-traditional safety messages do drivers believe will likely change driver behavior?
2. What types of non-traditional safety messages are most memorable?
3. What types of non-traditional safety messages are perceived as inappropriate?
4. What types of non-traditional safety messages drivers misunderstand?

5. How does neurocognitive activation changes when reading non-traditional safety messages, and how does this activation differ within subregions of the prefrontal cortex?

## **2. METHODS**

### *2.1 Participants*

This study was approved by the Institutional Review Board at Virginia Tech. A total of 300 participants were recruited for the study. Participants were recruited from across the state of Virginia through online advertisements and community flyers. Data collection occurred in four regions of Virginia (two rural and two urban), including Blacksburg (southwest rural), Norfolk (southeast urban), Arlington (northeast urban), and Winchester (northwest rural). Participants ranged in age between 18 and over 65 and were balanced between males and females.

Participants received \$30 for their time to participate in the experiment.

### *2.2 Materials*

#### *2.2.1 Message Selection*

The search process for non-traditional safety messages to empirically test began by creating a database of messages. The total number of unique messages collected was 1,253 from 11 states across the country, including Colorado, Illinois, Iowa, Kansas, Maryland, Minnesota, North Dakota, Oregon, Utah, Virginia, and Wisconsin.

These messages were categorized by behavior, intended emotional response, and theme by the consensus of three independent reviewers. Messages were grouped by behavior (e.g., driving without a seat belt, distracted driving, impaired driving) to identify if messages targeting different behavior are perceived as more effective than others. Messages were grouped by emotion (e.g., humor, negative emotion) because emotional stimuli may impact adoption of the behavior change (Dun & Ali, 2018; Young Kim N. & Karim Biswas, 2018, Cauberghe et al., 2009; Glendon et al., 2018; Glendon & Walker, 2013; Lewis et al., 2010). Messages were also grouped by themes (e.g., holiday/seasonal, pop culture, sports) because the theme of the message may have an effect on comprehension and recall. Messages with a miscellaneous theme were excluded from the database, for a total of 1,108 messages.



A representative sample of 80 non-traditional safety messages was selected from the 1,108 messages. Five messages with similar behavior, emotion, and theme were chosen at random to represent each possible type of behavior and emotion. Each theme is represented twice in the blocks of messages. With 8 themes in the database, a total of 16 blocks were created. The 16 blocks of five messages grouped by their behavior, emotion, and theme are provided in Table 1.

**Table 1** Message blocks grouped by behavior, emotion, and theme

<b>Block</b>	<b>Behavior</b>	<b>Emotion</b>	<b>Theme</b>
1	General Safe Driving	Emotionless	Pop Culture
2	General Safe Driving	Humor	Holiday/Seasonal
3	General Safe Driving	Negative	Statistic
4	Driving Without a Seat Belt	Emotionless	Command
5	Driving Without a Seat Belt	Humor	Saying
6	Driving Without a Seat Belt	Negative	Statistic
7	Distracted Driving	Emotionless	Sports
8	Distracted Driving	Humor	Word Play & Rhyme
9	Distracted Driving	Humor	Pop Culture
10	Distracted Driving	Negative	Null
11	Impaired & Drowsy Driving	Emotionless	Saying
12	Impaired & Drowsy Driving	Humor	Holiday/Seasonal
13	Impaired & Drowsy Driving	Negative	Word Play & Rhyme
14	General Aggressive Driving	Emotionless	Sports
15	General Aggressive Driving	Humor	Null
16	General Aggressive Driving	Negative	Command

The order of messages within each block and the order of blocks were randomized for participants to mitigate bias from the order that blocks are displayed. Messages were displayed on a computer screen with a similar font and color to a dynamic message board. The text color was yellow, and the background was black.

### 2.2.2 *fNIRS Cap*

While reading each block of messages, participants wore an fNIRS cap to measure participants' neurocognitive activation. Where neurocognitive activation occurs is critical. The prefrontal cortex (PFC), which is associated with executive function (e.g., planning, reasoning, decision

making), is a dominant region for activation for driving-related tasks. In the research presented in this report, the PFC was the region of interest because of its use in inhibition and control during driving tasks (Quintana & Fuster, 1999; Shimamura, 2000; Takano, Shimokawa, Misawa, & Hirobayashi, 2010).

Within the prefrontal cortex there are bilateral subregions, the left and right dorsolateral prefrontal cortex (dlPFC), left and right orbital prefrontal cortex (OFC), the left and right ventrolateral prefrontal cortex (vlPFC), and medial prefrontal cortex (mPFC). The dlPFC plays a critical role in cognitive flexibility and control (Kaplan et al. 2016; Mars and Groll 2007). The cognitive control function of the dlPFC is implicated in the modulation of risk attitudes (Schonberg, Fox, & Poldrack, 2011). Suppressed activation in the dlPFC corresponds to an increase in risk-seeking behavior (Fecteau et al., 2007). The OFC is generally associated with the cognitive process of decision-making, especially related to emotional choices. The OFC is interconnected with the amygdala, which is why it is involved in modulating bodily changes that are associated with emotion (e.g., a nervous feeling in a participant's stomach can be associated with an increase in OFC activation) (Tom, Fox, Trepel, & Poldrack, 2007). The vlPFC is similar to the OFC in that it is generally associated with emotional response selection (Aron, Robbins, & Poldrack, 2004). It is often recruited during tasks that involve interpreting a stimulus and trying to minimize its emotional impact on mental state (Goldin, McRae, Ramel, & Gross, 2008; McRae et al., 2009). The vlPFC helps with emotion control (He et al., 2018). The mPFC seems to play a vital role in reward-guided learning (Rushworth, Noonan, Boorman, Walton, & Behrens, 2011). Activation in the mPFC is positively correlated with rewards (Rick, 2011).

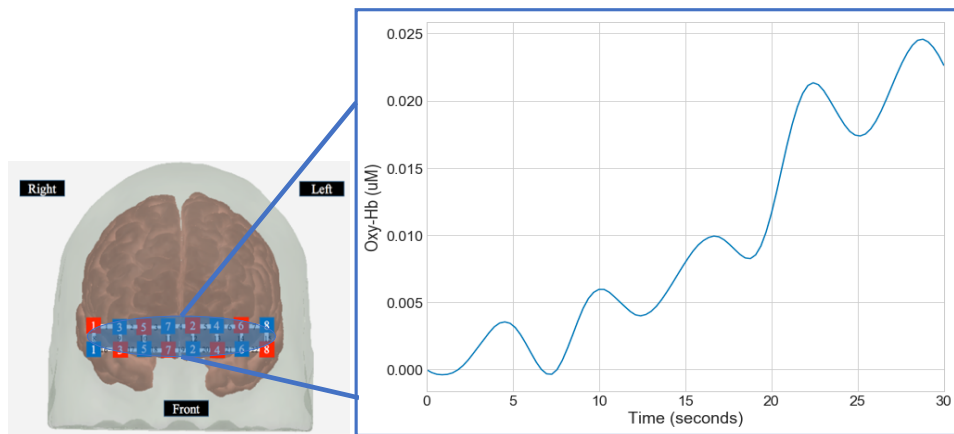
#### *2.4 Measures*

After each block of messages, participants were asked, "What is the intended behavior change of the previous messages?" and "On a scale from 0-Not Very Likely to 10-Very Likely, how likely do you think other drivers will change their behavior after seeing these messages?" The purpose of these questions was to measure participants' comprehension and perceived behavior change.

Following the experiment, participants participated in a post-task survey. The purpose of the survey was to better understand the phenomena observed in the experiment. The questions were

designed to capture memorable and inappropriate messages. In the post-task survey, participants were asked to record messages that they remembered without being given any list of messages or prompts to help them remember. After responding, participants were then given a list of all of the messages they read during the experiment and asked to mark ones they believed were inappropriate.

The fNIRS cap recorded change in oxygenated and deoxygenated blood along 22 channels in the prefrontal cortex (PFC). Peak oxy-Hb was used because of the block design of the experiment (Mo Hu & Shealy, 2019). Oxy-Hb should continue to increase with each new message displayed over the 30-second window (six seconds per message). Measuring the peak response is an indicator for the cumulative effect of messages on neurological response. This is different than an event-related design where neurological response is a result of a single or multiple independent stimulus. There are other common types of data analysis to compare variables like measuring mean values or area under the curve over a specific time period. Mean response is not an appropriate indicator for this study because it does not fully capture how each stimulus (or message) builds on the other. An example of the oxy-Hb in the PFC is illustrated in Fig. 1. This is the peak oxy-Hb for one participant while viewing one block of messages. The peak oxy-Hb occurs around 28 seconds into the block of messages. The rounding of oxy-Hb around 5 seconds, 10 seconds, 15 seconds, 23 seconds and 28 seconds might reflect new messages being read by the participant.



**Fig. 1.** Average oxy-Hb in 22 channels in the prefrontal cortex when reading five non-traditional safety messages

### 2.3 Procedure

The entire block of message display consisted of five messages, two questions that measured comprehension and perceived effectiveness, and a rest period to allow the brain to return to a rested state before continuing with the next block. Participants read the messages quietly to themselves and answered the questions out loud. The procedure's order of operations included completing the consent paperwork, receiving a practice block, being affixed with the fNIRS cap, viewing all 16 blocks, and completing a post-task survey.

Participants were given 6 seconds to read each message on the computer display and 10 seconds to respond to the two questions. Before the next block of messages, participants were asked to mentally rest for 15 seconds. A crosshair was displayed in the middle of the screen during this mental rest period prior to the next block of messages being displayed. This process is illustrated in Fig. 2. The total time for receiving all 16 blocks of messages was 17 minutes and 20 seconds.

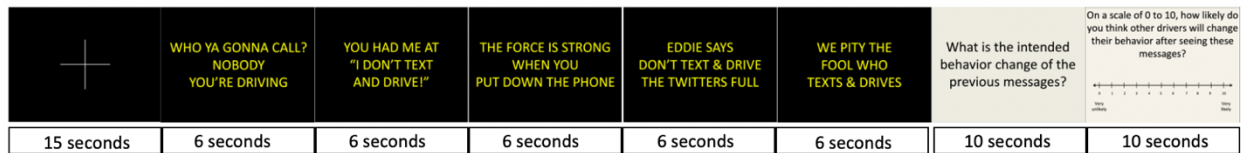


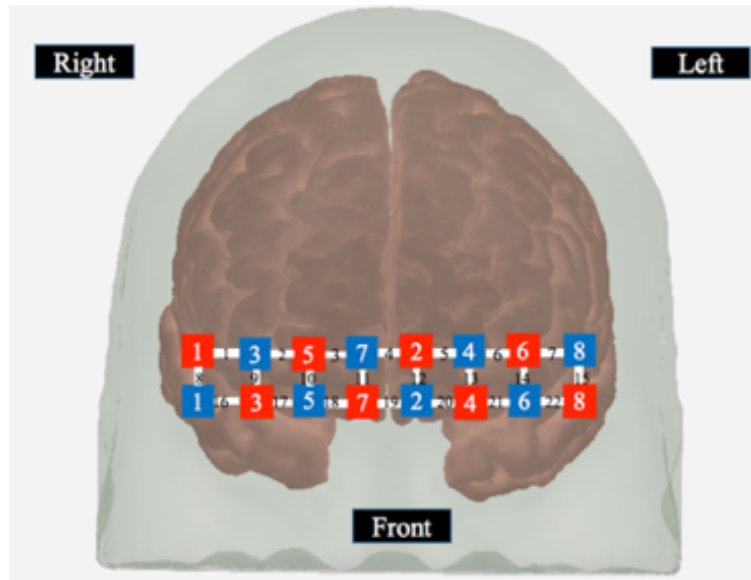
Fig. 2. Sample block sequence

### 2.5 Data Analysis

#### 2.5.1 Neurocognitive Data Analysis

The placement of the fNIRS cap on the PFC is shown in Fig. 3, with the sensors (i.e., source locations) shown in red and the detectors shown in blue. The probes connect to the fNIRS machine that measures and records change in light density. A modified Beer-Lambert Law (MBLL) was used to convert change in light absorption into change of cerebral blood flow (Scholkmann et al., 2014). Only oxy-Hb response was analyzed and reported since oxy-Hb has a relatively higher amplitude and is more sensitive to cognitive activities (Mo Hu & Shealy, 2019).

The fNIRS cap recorded change in oxygenated and deoxygenated blood along 22 channels in the prefrontal cortex (PFC) (Scholkmann et al., 2014). To answer the question about how neurocognitive activation changes when reading non-traditional safety messages, the average peak oxy-Hb was calculated for each of the 22 channels for each person for each block.



**Fig. 3.** Placement of fNIRS on the prefrontal cortex

Raw data of the change in oxy-Hb for each participant was processed using a bandpass filter (a third-order Butterworth filter) of 0.01Hz – 0.2Hz to remove high-frequency instrumental noise and low-frequency physiological noise. An independent component analysis (ICA), using a coefficient of spatial uniformity (CSU) of 0.5, was then used to remove motion artifacts. These parameters in data processing are based on prior research (Naseer & Hong, 2015; Sato, Hokari, & Wade, 2011).

Peak oxy-Hb was then averaged for each block. Data with poor channel quality (either missing, above or below three standard deviations from the mean, or notes from the data collection process describing instances of interruptions from the participant during data collection) were removed. Of the 300 participants, 58 people were removed from the analysis of oxy-Hb. In total, 242 people were included.

### 2.5.2 Statistics

An analysis of variance (ANOVA) was used to statistically compare differences in perceptions about the messages ability to change driver behavior between blocks, message behavior, message emotion, and message theme. Chi-squared was used to statistically compare differences in comprehension.

Peak oxy-Hb was averaged for each block. An analysis of variance (ANOVA) test was performed on the fNIRS data sets to compare mean differences of oxy-Hb between blocks. Blocks were then averaged based on similar intended behaviors (e.g., driving without a seat belt, general aggressive driving). Cohen's *d* was used to measure the effect size between the mean differences (Lakens, 2013). Another ANOVA test was performed to compare differences in the peak oxy-Hb between intended behaviors. A post-hoc Tukey test was used to identify statistical differences between blocks (Tukey, 1949). Blocks of messages were again grouped by emotions and themes. ANOVA and a post-hoc Tukey test with Bonferroni were used to identify specific peak differences between oxy-Hb relative to the messages intended emotional response (e.g., humor and negative) and themes (e.g., word play and sports). Bonferroni is a technique to correct for issues with multiple comparisons (Napierala, 2012).

To answer the question about how neurocognitive activation differs within subregions of the prefrontal cortex, participant oxy-Hb data was clustered into subregions, left and right dorsolateral prefrontal cortex (left dlPFC channels: 5, 6, 7, 13, 14; right dlPFC channels: 1, 2, 3, 9, 10), left and right orbitofrontal cortex (left OFC channels: 20, 21; right OFC channels: 17, 18), left and right ventrolateral prefrontal cortex (left vlPFC channels: 15, 22; right vlPFC channels: 8, 16), and medial prefrontal cortex (mPFC channels: 4 and 19). Average peak oxy-Hb was compared for each subregion. ANOVA with Tukey and Bonferroni were used to identify subregions that were statistically greater in peak activation when reading non-traditional safety messages.

### **3. RESULTS**

#### *3.1 Perceived Effectiveness to Change Behavior*

Drivers who participated in the study believe all of the messages will likely change behavior. The mean score across all blocks of messages is 6.87 (SD = 2.09) on a scale of 0-Not very likely to 10- Very likely to change driver behavior. The mean scores for each block are listed in Table 2. The difference between mean scores is significantly different ( $F = 22.9$ ,  $p < 0.0001$ ). The behaviors that drivers believe are most likely to change as a result of non-traditional safety messages are related to driving without a seat belt, distracted driving, and impaired and drowsy

driving. All three of these types of messages included negative emotions, but the themes of the messages varied, including either statistics, no theme, or word play and rhymes, respectively.

**Table 2** Average perceived effectiveness of non-traditional safety messages for each block of messages

Block	Behavior	Emotion	Theme	Mean*	SD
1	General Safe Driving	Emotionless	Pop Culture	5.41	2.15
2	General Safe Driving	Humor	Holiday/Seasonal	5.58	2.07
3	General Safe Driving	Negative	Statistic	6.68	2.41
4	Driving Without a Seat Belt	Emotionless	Command	6.63	1.97
5	Driving Without a Seat Belt	Humor	Saying	6.02	2.26
6	Driving Without a Seat Belt	Negative	Statistic	7.13	2.13**
7	Distracted Driving	Emotionless	Sports	5.83	1.99
8	Distracted Driving	Humor	Word Play & Rhyme	6.6	2.16
9	Distracted Driving	Humor	Pop Culture	6.3	2.2
10	Distracted Driving	Negative	Null	7.4	1.98**
11	Impaired & Drowsy Driving	Emotionless	Saying	5.94	1.98
12	Impaired & Drowsy Driving	Humor	Holiday/Seasonal	6.57	2.14
13	Impaired & Drowsy Driving	Negative	Word Play & Rhyme	6.94	1.95**
14	General Aggressive Driving	Emotionless	Sports	5.85	2.05
15	General Aggressive Driving	Humor	Null	5.91	2.19
16	General Aggressive Driving	Negative	Command	6.08	1.91

\*mean scores ranging from 0 - "Not Very Likely to Change Driver Behavior" to 10 - "Very Likely to Change Driver Behavior"

\*\*greater than one standard deviation from the mean (M = 6.87, SD = 0.57)

While drivers in Virginia who participated in the study feel that all of the non-traditional safety campaign messages are likely to change driver behavior (M= 6.6, SD = 1.67), certain types of messages are perceived to significantly change driver behavior more (F = 23.4, p < 0.001). When grouping the sixteen blocks into their associated behaviors, participants feel that messages about driving without a seat belt (p<0.001), distracted driving (p<0.001), impaired and drowsy driving (p<0.001), and general safe driving (p=0.002) are significantly more effective than aggressive driving messages. Cohen's d was used to measure the effect size between the mean differences. All of the messages have a small (0.2) to medium (0.5) effect compared to messages about general aggressive driving. These results are presented in

Table 3.

**Table 3** Average perceived effectiveness of behaviors in non-traditional safety messages

Behavior	Mean*	SD	p-value compared w/ Aggressive Driving	Cohen's d compared w/ Aggressive Driving
General Safe Driving	6.45	1.64	0.002	0.354
Driving Without a Seat Belt	6.6	1.65	<0.001	0.495
Distracted Driving	6.53	1.66	<0.001	0.493
Impaired / Drowsy Driving	6.48	1.73	<0.001	0.418
General Aggressive Driving	5.94	1.69	---	-----

\*mean scores ranging from 0 - "Not Very Likely to Change Driver Behavior" to 10 - "Very Likely to Change Driver Behavior"

Drivers' neurocognitive response also differs based on the emotion the message is intended to provoke. Messages intending to provoke a negative ( $M = 6.85$ ,  $SD = 2.13$ ) or humorous ( $M = 6.16$ ,  $SD = 2.2$ ) response are significantly ( $F = 75.3$ ,  $p < 0.0001$ ) more likely to be perceived as likely to change driver behavior compared to messages without an emotional response ( $M = 5.93$ ,  $SD = 2.07$ ). When comparing between negative and humor messages, messages with negative emotions are more likely to be perceived as effective compared to messages with humor. The results of the Tukey post-hoc statistical test are provided in Table 4.

**Table 4** Perception of emotions in non-traditional safety messages

Emotion One	Emotion Two	Mean Difference	SE	df	t	$p_{tukey}$
Emotionless	Humor	-0.231	0.0747	4797	-3.09	0.006
Emotionless	Negative	-0.916	0.0780	4797	-11.74	<0.0001
Humor	Negative	-0.685	0.0747	4797	-9.17	<0.0001

The theme of the message also significantly ( $F = 19.8$ ,  $p < 0.0001$ ) contributes to differences in perceptions about what messages are most likely to change driver behavior. Messages with statistics are perceived as the most likely to change driver behavior, followed by messages without a theme, and word play and rhymes. The mean scores, ranging from 0-Not very likely to 10- very likely to change driver behavior, are listed in Table 5.



**Table 5** Average perceived effectiveness of themes in non-traditional safety messages

Theme	Mean*
Statistic	6.91**
Null	6.66
Rhyme	6.49
Command	6.36
Holiday/Seasonal	6.07
Saying	6.02
Pop Culture	5.85
Sports	5.84

\*mean scores ranging from 0 - “Not Very Likely to Change Driver Behavior” to 10 - “Very Likely to Change Driver Behavior”

\*\*greater than one standard deviation from the mean (Emotion: \_\_\_\_\_ Theme: M = 6.28, SD = 0.4)

### *3.2 Memorable Messages*

Drivers who participated in the study are most likely to remember messages about distracted driving (38.5 percent of all of the messages that participants remembered) and drinking and driving (32.7 percent of the messages that participants remembered). Messages about statistics (63.3 percent of the messages that participants remembered) were the most likely to be recalled by drivers. The specific messages that were recalled the most frequently were, “Nobody puts baby in a hot car” (15 out of 105 specific messages recalled, or 14.3 percent), “Mom needs your hug not your text” (13 out of 105 specific messages recalled, or 12.4 percent), and “You’re not a firework don’t drive lit” (7 out of 105, specific messages recalled, or 6.7 percent).

### *3.3 Inappropriate Messages*

Over 90 percent of drivers who participated in the study did not perceive a single message as inappropriate. Drivers between the age of 18-25 and 41-65 represent most of the 10 percent of drives that perceived a message as inappropriate. These drivers were relatively equally split in gender, in their risky driving habits, and in the predominate driving environment (urban, rural, or suburban).

Reasons messages were cited as inappropriate were for language that was perceived as suggestive, racial, sexual, distractingly humorous, or insensitive. The messages most frequently cited as inappropriate were “Get your head out your apps” (6 out of the 63 messages perceived as inappropriate) for being “suggestive” and “Luck of the Irish won’t help if you drive drunk” (3 out of 63 messages perceived as inappropriate) as insensitive to a group of people (Irish or Irish descent).

### 3.4 Message Comprehension

There is a significant difference in the ability to comprehend messages based on the type of message ( $\chi^2 < 0.001$ ).

Table 6 lists the percent incorrect for each block.

**Table 6** Percent of message incorrect for each block of messages

Block	Behavior	Emotion	Theme	% Incorrect
1	General Safe Driving	Emotionless	Pop Culture	22.67*
2	General Safe Driving	Humor	Holiday/Seasonal	27.33*
3	General Safe Driving	Negative	Statistic	34.00*
4	Driving Without a Seat Belt	Emotionless	Command	2.67
5	Driving Without a Seat Belt	Humor	Saying	2.67
6	Driving Without a Seat Belt	Negative	Statistic	4.33
7	Distracted Driving	Emotionless	Sports	12.00
8	Distracted Driving	Humor	Word Play & Rhyme	2.67
9	Distracted Driving	Humor	Pop Culture	2.67
10	Distracted Driving	Negative	Null	2.33
11	Impaired & Drowsy Driving	Emotionless	Saying	9.00
12	Impaired & Drowsy Driving	Humor	Holiday/Seasonal	4.00
13	Impaired & Drowsy Driving	Negative	Word Play & Rhyme	3.67
14	General Aggressive Driving	Emotionless	Sports	11.67
15	General Aggressive Driving	Humor	Null	4.33
16	General Aggressive Driving	Negative	Command	10.00

\*greater than one standard deviation from the mean (M = 9.75, SD = 9.85)

Messages targeting general safe driving are significantly ( $p < 0.0001$  compared to all other behaviors) misunderstood compared to the other messages, on average, by 28 percent of the drivers who participated in the study. Messages about seatbelts were the most frequently understood. On average, only 3.22 percent of drivers who participated in the study incorrectly understood the intent of messages about distracted driving.

Table 7 reports the percent incorrect for each type of behavior and the statistical difference compared to general safe driving.

**Table 7** Percent incorrect of non-traditional safety campaign behavior

Behavior	Correct	Incorrect	% Incorrect	Z	p-value compared w/ General Safe Driving
General Safe Driving	648	252	28.00%	-	-
Driving Without a Seat Belt	871	29	3.22%	12.1	<0.0001
Distracted Driving	1141	59	4.92%	13.2	<0.0001
Impaired and Drowsy Driving	850	50	5.56%	11.6	<0.0001
General Aggressive Driving	822	78	8.67%	10.1	<0.0001

### 3.5 Neurocognitive Activation

There is no significant difference ( $F=1.03$ ,  $p=0.419$ ) in peak oxy-Hb in the PFC between blocks. The mean peak oxy-Hb for each block is displayed in Table 8. The average peak oxy-Hb is 0.00668303, and the standard deviation is 0.00046868.

**Table 8** Mean peak oxy-Hb for each block of messages

Block	Behavior	Emotion	Theme	Mean Peak Oxy-Hb
1	General Safe Driving	Emotionless	Pop Culture	0.00676627
2	General Safe Driving	Humor	Holiday/Seasonal	0.00750583*
3	General Safe Driving	Negative	Statistic	0.00658285
4	Driving Without a Seat Belt	Emotionless	Command	0.00684671
5	Driving Without a Seat Belt	Humor	Saying	0.00557463
6	Driving Without a Seat Belt	Negative	Statistic	0.00665028
7	Distracted Driving	Emotionless	Sports	0.00615090
8	Distracted Driving	Humor	Word Play & Rhyme	0.00660543
9	Distracted Driving	Humor	Pop Culture	0.00647716
10	Distracted Driving	Negative	Null	0.00726896*

11	Impaired & Drowsy Driving	Emotionless	Saying	0.00714219
12	Impaired & Drowsy Driving	Humor	Holiday/Seasonal	0.00720874*
13	Impaired & Drowsy Driving	Negative	Word Play & Rhyme	0.00656725
14	General Aggressive Driving	Emotionless	Sports	0.00667776
15	General Aggressive Driving	Humor	Null	0.00627561
16	General Aggressive Driving	Negative	Command	0.00662786

\*greater than one standard deviation from the mean (M = 0.00668303, SD = 0.00046868)

The average peak oxy-Hb for each behavior, emotion, and theme is in Table 9. While there is no significant difference in peak oxy-Hb between blocks, differences do exist when blocks are combined by their intended behavior, their intended emotional response, and the theme of the message. There is a significant difference in the peak oxy-Hb in the PFC when participants read messages with different types of intended behavior ( $F=4.85$ ,  $p<0.001$ ). Distracted driving has the highest peak activation, and this difference is significant when compared to all other behaviors ( $p<0.05$ ). Driving without a seat belt has the smallest peak activation.

**Table 9** Mean peak oxy-Hb for each behavior, emotion, and theme

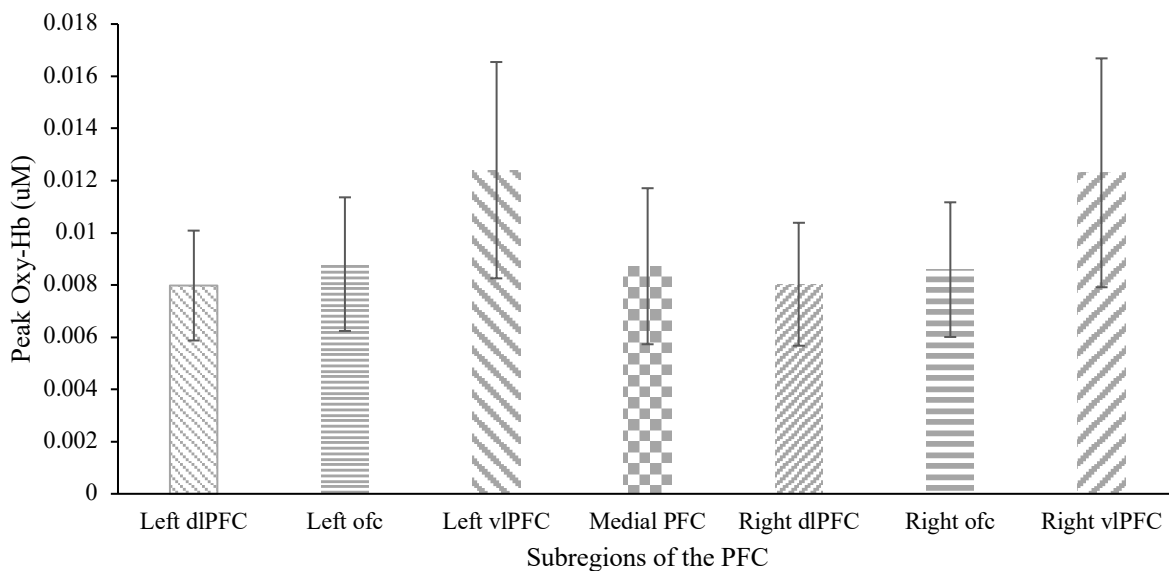
		Mean Peak Oxy-Hb	SD
Behavior	Distracted Driving	0.0251	0.0194
	Driving Without a Seatbelt	0.0177	0.0137
	General Aggressive Driving	0.0187	0.0154
	General Safe Driving	0.0193	0.0158
	Impaired & Drowsy Driving	0.0195	0.0145
Emotion	Humor	0.0396	0.028
	Emotionless	0.0336	0.023
	Negative	0.0337	0.023
Theme	Pop Culture	0.0132	0.012
	Holiday/Seasonal	0.0147	0.014
	Statistic	0.0132	0.011
	Command	0.0134	0.011
	Saying	0.0056	0.006
	Sports	0.0128	0.011
	Word Play	0.0203	0.015
	Null	0.0135	0.012

There is also a significant difference ( $F = 4.7, p < 0.01$ ) in peak oxy-Hb in the PFC for messages with different types of intended emotional response. Humor produces the highest peak response ( $M=0.039 \text{ uM}$ ) and is significantly greater than emotionless ( $M=0.034 \text{ uM}, p < 0.05$ ) and negative messages ( $M=0.034 \text{ uM}, p < 0.05$ ).

Drivers who participated in the study also respond significantly ( $F = 27.53, p < 0.001$ ) different based on the theme of the messages. Participants produce significantly higher peak oxy-Hb when viewing messages about word play and rhyme ( $M = 0.020 \text{ uM}$ ) compared to all other themes. Messages with sayings produced the smallest peak oxy-Hb ( $M = 0.005 \text{ uM}$ ) compared to all other messages.

*How does the difference in neurocognitive activation differ within subregions of the prefrontal cortex?*

Channels were grouped into specific regions, including the dorsolateral prefrontal cortex (dlPFC), ventrolateral (vlPFC), orbital prefrontal cortex (OFC), and the medial prefrontal cortex (mPFC). The peak activation in the left vlPFC ( $M=0.0124 \text{ uM}, SD = 0.00829$ ) and right vlPFC ( $M=0.0123 \text{ uM}, SD = 0.00877$ ) is significantly higher compared to the other regions in the PFC ( $F = 23.4, p < 0.0001$ ). The average peak oxy-Hb for each subregion in the PFC is illustrated in Fig. 4.



**Fig. 4.** Average Peak oxy-Hb for subregions within the prefrontal cortex

Similar trends in effectiveness of messages by driving behavior and by emotion are seen in the vIPFC, but the activation is higher in the vIPFC than the mean for the whole PFC. Messages about distracted driving produce the highest peak oxy-Hb in the right and left vIPFC. The peak oxy-Hb about distracted driving is significantly higher in the left vIPFC ( $F = 5$ ,  $M=0.0966$  uM,  $p<0.001$ ) and right vIPFC ( $F = 4.19$ ,  $M=0.0957$  uM,  $p=0.002$ ) compared to the other subregions within the PFC. The differences in peak oxy-Hb between emotions remain significant when isolating the peak oxy-Hb in the left and right vIPFC. Messages intended to provoke negative emotional response elicited the highest peak response.

Similar differences are also observed in peak oxy-Hb for themes. Messages with word play and rhymes are significantly greater ( $F = 23.4$ ,  $p < 0.0001$ ). What's notable is the average percent difference between messages with word play and rhymes compared to the mean of the other messages is greater in the left vIPFC (67 percent increase in peak oxy-Hb compared to mean) compared to the whole PFC average (64 percent increase in peak oxy-Hb compared to mean of other message themes). In other words, the effect of word play and rhymes is more pronounced in the left vIPFC than the whole PFC or right vIPFC (61 percent increase in peak oxy-Hb compared to mean of other messages).

To summarize, differences are observable in subregions of the PFC when viewing non-traditional safety messages. The greatest activation occurs in the left and right vIPFC compared to other subregions. Messages about distracted driving that use humor and include word play or rhymes produce the largest peak response among participants. When comparing between the left and right vIPFC for message theme, the percent increase in activation compared to the mean of other messages is greatest in the left vIPFC compared to the right vIPFC.

#### **4. DISCUSSION**

Messages about distracted driving, messages intended to provoke an emotional response (humor or negative emotion), and messages including statistics or word play and rhymes are more effective than other types of messages.

Messages about distracted driving are the most effective because it ranked high on all metrics of effectiveness (perceived likelihood to change driver behavior, comprehension, recall, and ability to elicit high levels of peak oxygenated blood (oxy-Hb) in the prefrontal cortex (PFC)). If drivers can comprehend and recall, then there is a higher perceived effectiveness. Distracted driving also appeared in the messages that were cited as inappropriate, but measures of effectiveness seem to outweigh the small percentage of participants (six participants out of 300 ) who view this type of message as inappropriate.

One explanation for the increase in oxy-Hb when viewing messages about distracted driving is that these messages increase cognitive attention among participants. Oxy-Hb increases significantly for these types of messages regardless of the associated emotion or theme. Observations during data collection provide a possible explanation for this increase. Participants frequently commented during data collection about society's addiction to phones. Participants vocalized the urgency to correct cell phone use while driving. The increase in oxy-Hb about distracted driving messages may reflect this observed concern and urgency among participants to want to correct this behavior.

The results indicate that drivers perceive messages with a negative or humorous emotion as likely to be more effective at changing behavior than messages not using any emotion, i.e. emotionless. This is consistent with prior literature that indicates driving performance is differentially affected by negative and positive emotional content compared to neutral emotional content (Chan & Singhal, 2013). Drivers display lower speeds when emotional (positive or negative) words are present compared to neutral words.

A prior study differentiates humor and negative emotional arousal. It finds driver speeds slowed longer when there were positive words being displayed compared to negative words (Chan & Singhal, 2013). Negative messages may influence perception about behavior and recall (Walker & Trick, 2019), but positive messages seem to influence actual behavior change observed in field and simulation experiments. The results presented in this study support this claim. Mean scores about perception of changing driver behavior in this study find that messages intended to provoke a negative emotional response are perceived as greater than humorous messages but

humorous messages provoke the largest increase in neurocognitive activation. This may be due to distraction effects on driving behavior, which are greater for positive arousing stimuli (Chan & Singhal, 2013). Messages with positive emotions command more attention (Costa et al., 2019), and the neurocognitive data supports this possible explanation.

Messages that include humor provoke a high level of oxy-Hb in the PFC and this is consistent with prior literature that finds humor elicits distinct neurocognitive response (X. Hu et al., 2019) and that viewing humorous messages seems to change behavior indirectly by altering attentional effects on driving (Steinhauser et al., 2018). Peak oxy-Hb is a proxy for increased attention (Causse, Chua, Peysakhovich, Campo, & Matton, 2017), and humorous messages increase peak oxy-Hb compared to negative and emotionless messages. This is also consistent with prior research that finds response times are faster for positive arousal messages compared to negative arousal messages (Walker & Trick, 2019). Humorous messages can also be advantageous because the campaigns are more likely to be shared (Dun & Ali, 2018; Young Kim N. & Karim Biswas, 2018).

The theme of the message also contributes to the effectiveness of the message. Messages that use statistics are perceived as likely to influence behavior change, but the neurocognitive data identifies word play and rhymes as significantly more likely to increase attention. While many regions of the brain are coactivated (Wearne, 2018), messages with word play and rhymes produced the largest increase of oxy-Hb in the left vIPFC. This might be related to the vIPFC's role in semantic processing (Nozari & Thompson-Schill, 2016). The left vIPFC plays a specific role in deciphering words with multiple meanings (Bedny, Hulbert, & Thompson-Schill, 2007; Nozari & Thompson-Schill, 2016; Swaab, Brown, & Hagoort, 1998).

The use of the neuroimaging technique and the identification of greater activation across the PFC and, more specifically, in the vIPFC associated with distract driving messages, messages that include humor, and word play and rhyme are indicators of their effectiveness to elicit a neurocognitive response. This increase in response is similar to other transportation studies that found the ability to predict driving function with brain behavior (Rieger et al., 2019; Yamamoto, Takahashi, Sugimachi, & Suda, 2018). Here, the results, specifically in the vIPFC, begin to



suggest an increase in emotional control and semantic processing when viewing messages that include humor and word play and rhyme.

## **5. CONCLUSION**

This research project uses both qualitative data about perceptions of effectiveness and neurocognitive data to quantitatively measure driver response to safety campaigns on roadside dynamic message signs. The results show that drivers perceive safety campaigns as effective. From the behavioral data, drivers consider campaigns about distracted driving as significantly more effective than those aimed at targeting other behaviors. Additionally, messages eliciting an emotional reaction are significantly more effective than emotionless campaigns. The neurocognitive data supports this by revealing that drivers are more attentive to signs about distracted driving and signs with a humorous emotion.

The results of the behavior data show that comprehension increases when the intended behavior is specific. Drivers significantly misunderstand safety campaigns about general safe driving compared to the other specific target behavior. This suggests that safety campaigns should have clarity in their message in order to have a greater impact on changing driver behavior.

A unique application of using neuroimaging techniques in traffic related studies was used to compare the behavioral data with neurological data. Drivers perceived as effective was distracted driving, which is also the behavior that drivers were attentive to based on the neurological data. While the neurological data supports the behavioral data's findings of effectiveness for any type of emotional stimuli, the neurological data revealed that drivers are more attentive to humorous messages even though they perceive negative emotions are more effective. This suggests that campaigns can be successful using either positive or negative emotions in safety campaigns to change driver behavior as they will appeal to both perceived effectiveness and neurocognitive response.

There are several limitations of this study. The fNIRS instrument only measured the change in oxygenated blood in the prefrontal cortex. Other brain regions (e.g., anterior cingulate cortex) likely also contribute to differences between messages. However, this is a limiting factor with all

neuroimaging studies that do not capture whole head differences (Ferrari & Quaresima, 2012). To include whole head differences would require using fMRI, which has its own limitations, including lack of mobility to recruit in diverse locations and costs associated with enrolling 300 participants.

Another limitation is that effectiveness in this study does not include actual behavior change. Indicators for effectiveness measure potential behavior change through perceived effectiveness, comprehension of messages, recall, appropriateness, and peak cognitive response. Conclusions are drawn using all of these indicators, not just one. Future research could test how these indicators for effectiveness correspond with actual behavior change through field trials. Though, field trials introduce their own limitations. Observing behavior change, for example, about distracted driving or aggressive driving, presents challenges. Prior studies have observed driver speeds pre and post messages about speeding but with varying results (Haghani et al., 2013; Harder & Bloomfield, 2008).

Another limitation to this study is messages were shown once to drivers and their initial reaction was collected. The use of non-traditional safety messages is relatively new for drivers. Repeated exposure could have an effect on behavior change. Future research could test the effectiveness of repeated non-traditional safety messages on behavior change. Similarly, the temporal distance between messages and behavior change was not collected. How long after exposure to messages is behavior influenced? Evidence of recall provides some preliminary evidence suggesting some messages are more memorable than others. Does memorability extend behavior change over time? Future research can begin to answer this question.

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## **Journal Paper 2: INFLUENCE OF AGE AND GENDER ON EFFECTIVENESS OF ROADSIDE SAFETY CAMPAIGNS**

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### **ABSTRACT**

According to the World Health Organization, death due to road injury is a leading cause of death. Safety campaigns are increasingly used to catch drivers' attention in an effort to get them to change driver behavior. The development and use of these non-traditional safety messages are distinctly different than messages previously displayed on highway signs because the intent of these messages is to modify driver behavior rather than just provide information. Unfortunately, there is little empirical evidence on how to target messages for specific groups of people. The goal of this study was to measure how non-traditional safety messages effect specific groups of people. To develop guidelines for use of these non-traditional safety messages, 300 people balanced by age and gender read 80 messages grouped by their behavior, emotion, and theme. Participants were asked their perceptions of these messages' ability to change driver behavior and whether they could recall types of message. A neuroimaging instrument called functional near-infrared spectroscopy (fNIRS) was also used to capture participants' neurocognitive response. An increase in cognitive activation is a proxy for increased attention. The results suggest females are significantly more likely to believe non-traditional safety messages are effective than males. However, males have a significantly higher neurocognitive response to safety campaign messages. A higher neurocognitive response is a proxy for increased task engagement. Drivers over the age of 65 have a higher perceived effectiveness, and drivers under 65 have higher neurocognitive response. Low- and high-risk drivers are more likely to perceive non-traditional safety messages as effective compared to medium-risk drivers, and these high-risk drivers are also significantly more likely to demonstrate higher levels of cognitive activation compared to other groups. Males, younger drivers, and high-risk drivers display an increase in task engagement to non-traditional safety messages. This increased task engagement provides initial evidence for effectiveness of these types of messages for safety campaigns.

## **1. INTRODUCTION & BACKGROUND**

Road injury is a leading cause of death, and males represent the majority of these fatalities (WHO, 2018). It is well known that unfavorable driving habits, such as not wearing seatbelts, aggressive driving, distracted driving, and impaired driving, can greatly increase crash severity. Younger males, in particular, are more likely to engage in these risky driving habits (Jonah 1990). There is little empirical evidence measuring how drivers respond to non-traditional safety messages, and there is little guidance on how to target messages for specific groups of people. Therefore, understanding how to target different demographics with effective safety campaigns that change driver behavior can increase overall roadway safety culture. This study investigates how drivers of different gender and age respond to safety campaigns in an effort to improve overall roadway safety. This additional investigation into the understanding of targeting different demographics is critical for reducing engagement in risky driving behavior (Glendon & Walker, 2013).

Driver characteristics, particularly gender and age, play a role in whether or not drivers adopt behavior change. Males tend to find safety campaigns more effective for the general public, and females find campaigns more relevant to themselves and close family (Glendon et al., 2018; Trick, Brandigampola, & Enns, 2012). Additionally, males prefer campaigns with humor, and women prefer campaigns with an authoritarian or guilty message (Trick et al., 2012). Generally, campaigns geared towards analyzing the impact of age conclude that young drivers are riskier drivers in need of a more creative intervention, and older drivers are less at risk but require longer to comprehend complicated messages (Falk & Montgomery, 2007; Inman, Bertola, & Philips, 2015).

The prior studies that measure effectiveness of safety campaigns across different demographics are limited because they present conflicting results. For instance, negative messages targeting a reduction in driver speed were more effective than positive emotions in one study, while another study revealed that positive emotions are better at commanding attention (Chan & Singhal, 2013; Costa et al., 2019). These conflicting outcomes demonstrate that the meaning behind the message, reasons for complying with the message, and how driver behavior changes are complex and likely depends on context, location, and driver demographics.

Two notable theoretical frameworks help inform why and how differences likely occur between people, Protection Motivation Theory (PMT) and Reinforcement Sensitivity Theory (RST). PMT provides context for why people are motivated to protect themselves, particularly when driving. PMT has two main components: threat appraisal and coping appraisal. Threat appraisal is the perceived severity, vulnerability, and reward associated with an unsafe behavior (e.g., speeding). For example, the severity of a crash could motivate a driver to drive within the speed limit because the threat of a crash is heightened by driver speed (Jeihani & Ardeshiri, 2013). Coping appraisal describes a driver's self-efficacy, response efficacy, and perceived costs associated with changing their behavior. Based on PMT, behavior change occurs when a driver perceives strong self-efficacy (e.g., "I can drive within the speed limit") and response efficacy (e.g., "Driving within the speed limit will reduce my chances of crashing"), as well as associating few costs with performing the behavior (e.g., "Speeding will not cause me to be late to work") (Glendon & Walker, 2013).

Reinforcement Sensitivity Theory (RST) attempts to determine driver motivation, such as whether they are motivated by losses or conflict resolution systems (Kahneman & Tversky, 1984). RST explains that risky driving occurs when there is a strong motivation toward reward-seeking behavior. Controlling impulsive behavior (e.g., speeding) is a challenge among drivers with high reward sensitivity, lower risk perception, and preference for immediate rather than delayed rewards (Constantinoua, Panayiotoua, Konstantinoua, Loutsiou-Ladda, & Kapardisb, 2011). Generally, these types of behavioral traits are most common among young male drivers (Castell & Prez, 2004).

A research gap that this study addresses is to use quantitative measures to further inform the differences between different groups of people and what motivates them to change their behavior. This will be accomplished by understanding what campaigns are effective for different demographics of drivers, such as age and gender. Effectiveness is defined as the perceived ability to change behavior, ability to recall the message, and neurocognitive response when reading and interpreting the message. The neurocognitive response will reveal how attentive drivers are to the messages and, ultimately, provide a new proxy for how likely they will change their behavior.

The research presented in this report measured neurocognitive response to non-traditional safety messages using a neuroimaging technique called functional near-infrared spectroscopy (fNIRS). The purpose of capturing neurocognitive response to non-traditional safety messages was to understand how messages are interpreted and processed in the brain. An increase in cognitive activation is a proxy for task engagement (Verdière et al., 2018), attention (Harrivel et al., 2013) and working memory (Jahani et al., 2017; Rieger et al., 2019; Scheunemann et al., 2019). Mental activity can linearly correspond with engagement (Fishburn et al., 2014), and driving attention and cognitive load are linearly related (Unni et al., 2018).

Previous studies demonstrate the ability to use fNIRS to measure and predict perceptions of safety (M. Hu & Shealy, 2018), risky decision making (Mo Hu & Shealy, 2019), and problem-solving (Shealy, Hu, & Gero, 2018). Specific to driver behavior, neuro-cortical activation can predict steering control, and a driver's response to changes in vehicle dynamics (Bruno et al., 2018). Neuro-cognition provides a glimpse into a driver's intent to act. Patterns of neuro-cognition when driving can identify a driver's braking intent prior to his braking operation (Zhu et al., 2018).

fNIRS provides an approach to triangulate between what participants say, and what they demonstrate. For instance, in a prior study, engineers self-reported their ability to think in systems. Those who scored high on the self-report survey were more likely to perform worse on systems thinking tasks. In contrast, the fNIRS data was a positive predictor of actual performance (Mo Hu et al., 2019). In this study, the participant is asked what types of message they believe are most effective in changing driver behavior, and the fNIRS instrument captures physiological response. Similar to this prior research (Mo Hu et al., 2019), what participants believe and how they respond cognitively may not be the same.

The study will investigate the effectiveness of roadside safety campaigns across different demographics in order to understand if gender and age groups are influenced differently by safety campaign messages. The study's objective was to answer the following four research questions:

1. How does perceived effectiveness in the ability of non-traditional safety messages to change driver behavior vary based on gender, age, risky driving behavior, driving environment (i.e. urban, rural, suburban)?
2. How does memorability of non-traditional safety messages vary based on the age, gender, risky driving behavior, and driving environment (i.e., urban, rural, suburban) of drivers?
3. How does comprehension of the behavior in non-traditional safety messages vary based on the age and gender of the driver?
4. How does neurocognitive activation vary by gender, age, and risky driving behavior, and driving environment (i.e., urban, rural, suburban) when reading non-traditional safety messages?

## 2. METHODS

### 2.1 Participants

A total of 300 participants were recruited for the study through online advertisements and distributed flyers. Participants received \$30 for their time to participate in the study. Data collection took place across four regions in the state of Virginia in two rural and two urban sites. The cities included Blacksburg (rural, Southwest VA), Norfolk (urban, Southeast VA), Arlington (urban, Northeast VA), and Winchester (rural, Northwest VA). Participants ranged in age between 18 and over 65. The number of participants by age group and gender is listed in Table 1, and the number of participants by the predominate driving environment is also included and listed in Table 2.

**Table 1** Participants by age group and gender

Age	Female	Male	Prefer not to say	Total
18-25	40	36	0	76
26-40	30	19	2	51
26-40	29	23	1	53
41-65	44	52	2	98
over 65	4	18	0	22
Total	147	148	5	300

**Table 2** Participants by predominate driving environment

Driving Environment	N
Rural	55
Suburban	171
Urban	74

## 2.2 Materials

### 2.2.1 Message Selection

The search process for non-traditional safety messages to empirically test began by creating a database of messages. The total number of unique messages collected was 1,253 from 11 states across the country, including Colorado, Illinois, Iowa, Kansas, Maryland, Minnesota, North Dakota, Oregon, Utah, Virginia, and Wisconsin.

These messages were categorized by behavior, intended emotional response, and theme by three independent reviewers. If conflict in categorization of messages occurred then the category was determined based on the majority (i.e. two out of three reviewers) who agreed. Messages were grouped by behavior (e.g., driving without a seat belt, distracted driving, impaired driving) to identify if messages targeting different behavior are perceived as more effective than others across different target audiences. Messages were grouped by emotion (e.g., humor, negative emotion) because emotional stimuli may impact adoption of the behavior change, particularly between males and females (Dun & Ali, 2018; Young Kim N. & Karim Biswas, 2018) (Dun & Ali, 2018) (Cauberghe et al., 2009; Glendon et al., 2018; Glendon & Walker, 2013; Lewis et al., 2010). Messages were also grouped by themes (e.g., holiday/seasonal, pop culture, sports) because the theme of the message may have an effect on comprehension and recall. Messages that target younger age groups, such as pop culture or sports, may not be as easily understood by older demographics. Messages with a miscellaneous theme were excluded from the database, for a total of 1,108 messages.

A representative sample of 80 non-traditional safety messages was selected from the 1,108 messages. Five messages with similar behavior, emotion, and theme were chosen at random to represent each possible type of behavior and emotion. Each theme is represented twice in the blocks of messages. With 8 themes in the database, a total of 16 blocks, i.e. groups, was created.



The 16 blocks of five messages grouped by their behavior, emotion, and theme can be seen in Table 3.

**Table 3** Message blocks grouped by behavior, emotion, and theme

<b>Block</b>	<b>Behavior</b>	<b>Emotion</b>	<b>Theme</b>
1	General Safe Driving	Emotionless	Pop Culture
2	General Safe Driving	Humor	Holiday/Seasonal
3	General Safe Driving	Negative	Statistic
4	Driving Without a Seat Belt	Emotionless	Command
5	Driving Without a Seat Belt	Humor	Saying
6	Driving Without a Seat Belt	Negative	Statistic
7	Distracted Driving	Emotionless	Sports
8	Distracted Driving	Humor	Word Play & Rhyme
9	Distracted Driving	Humor	Pop Culture
10	Distracted Driving	Negative	Null
11	Impaired & Drowsy Driving	Emotionless	Saying
12	Impaired & Drowsy Driving	Humor	Holiday/Seasonal
13	Impaired & Drowsy Driving	Negative	Word Play & Rhyme
14	General Aggressive Driving	Emotionless	Sports
15	General Aggressive Driving	Humor	Null
16	General Aggressive Driving	Negative	Command

The order of messages within each block and the order of blocks were randomized for participants with four different variations to mitigate error due to fatigue. Messages were displayed on a computer screen with a similar font and color to a dynamic message board. The text color was yellow, and the background was black.

### 2.2.2 fNIRS Cap

While reading each block of messages, participants wore an fNIRS cap to measure participants' neurocognitive activation. Where neurocognitive activation occurs is critical. The prefrontal cortex (PFC), which is associated with executive function (e.g., planning, reasoning, decision making), is a dominate region for activation for driving-related tasks. In the research presented in this report, the PFC was the region of interest because of its use in inhibition and control during driving tasks (Quintana & Fuster, 1999; Shimamura, 2000; Takano et al., 2010).

Within the prefrontal cortex there are bilateral subregions, the left and right dorsolateral prefrontal cortex (dlPFC), left and right orbital prefrontal cortex (OFC), the left and right ventrolateral prefrontal cortex (vlPFC), and medial prefrontal cortex (mPFC). The bilateral vlPFC is associated with emotional response to stimuli (Aron et al., 2004), goal-directed behavior (Sakagami & Pan, 2007), and semantic processing (Nozari & Thompson-Schill, 2016). It is often recruited during tasks that involve interpreting a stimulus and trying to minimize its emotional impact (Goldin et al., 2008; McRae et al., 2009). In other words, the vlPFC helps with emotional control (He et al., 2018; Marques, Morello, & Boggio, 2018) and semantics (Nozari & Thompson-Schill, 2016).

#### *2.4 Measures*

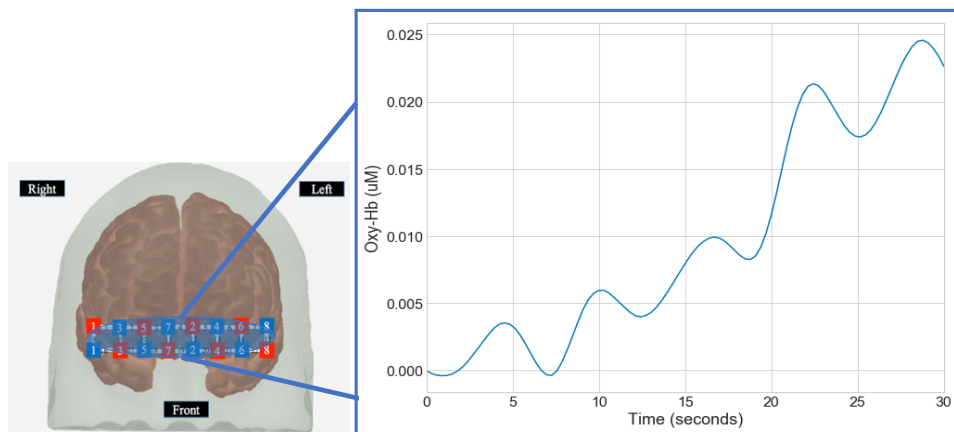
After each block of messages, participants were asked, “What is the intended behavior change of the previous messages?” and “On a scale from 0-Not Very Likely to 10-Very Likely, how likely do you think other drivers will change their behavior after seeing these messages?” The purpose of these questions was to measure participants’ comprehension and perceived behavior change.

Following the experiment, participants participated in a post-task survey and provided information about their demographics. The purpose of the survey was to better understand the phenomena observed in the experiment. The questions were designed to capture memorable messages. In the post-task survey, participants were asked to record messages that they remembered without being given any list of messages or prompts to help them remember.

When analyzing responses to these questions, participants were grouped based on their age, gender, risky driving behavior, driving environment (urban, suburban, or rural), if a family member had recently been involved in a collision, and whether they have children in their household. The purpose of grouping participants by demographics was to understand differences in comprehension, perceived effectiveness, and memorability between groups.

The fNIRS cap recorded change in oxygenated and deoxygenated blood along 22 channels in the prefrontal cortex (PFC). Peak oxy-Hb was used because of the block design of the experiment

(Mo Hu & Shealy, 2019). Oxy-Hb should continue to increase with each new message displayed over the 30-second window (six seconds per message). Measuring the peak response is an indicator for the cumulative effect of messages on neurological response. This is different than an event-related design where neurological response is a result of a single or multiple independent stimulus. There are other common types of data analysis to compare variables like measuring mean values or area under the curve over a specific time period. Mean response is not an appropriate indicator for this study because it does not fully capture how each stimulus (or message) builds on the other. An example of the oxy-Hb in the PFC is illustrated in Figure 1. This is the peak oxy-Hb for one participant while viewing one block of messages. The peak oxy-Hb occurs around 28 seconds into the block of messages. The rounding of oxy-Hb around 5 seconds, 10 seconds, 15 seconds, 23 seconds and 28 seconds might reflect new messages being read by the participant.



**Fig. 1.** Average oxy-Hb in 22 channels in the prefrontal cortex when reading five non-traditional safety messages

### 2.3 Procedure

The entire block of message display consisted of five messages, two questions that measured comprehension and perceived effectiveness, and a rest period to allow the brain to return to a rested state before continuing with the next block. Participants read the messages quietly to themselves and answered the questions out loud. The procedure's order of operations included completing the consent paperwork, receiving a practice block, being affixed with the fNIRS cap, viewing all 16 blocks, and completing a post-task survey.

Participants were given 6 seconds to read each message on the computer display and 10 seconds to respond to the two questions. Before the next block of messages, participants were asked to mentally rest for 15 seconds. A crosshair was displayed in the middle of the screen during this mental rest period prior to the next block of messages being displayed. This process is illustrated in Fig. 2. The total time for receiving all 16 blocks of messages was 17 minutes and 20 seconds.

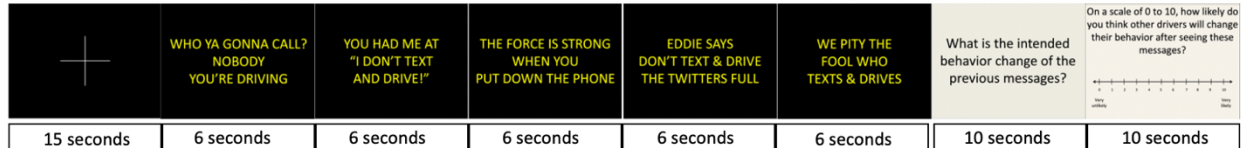


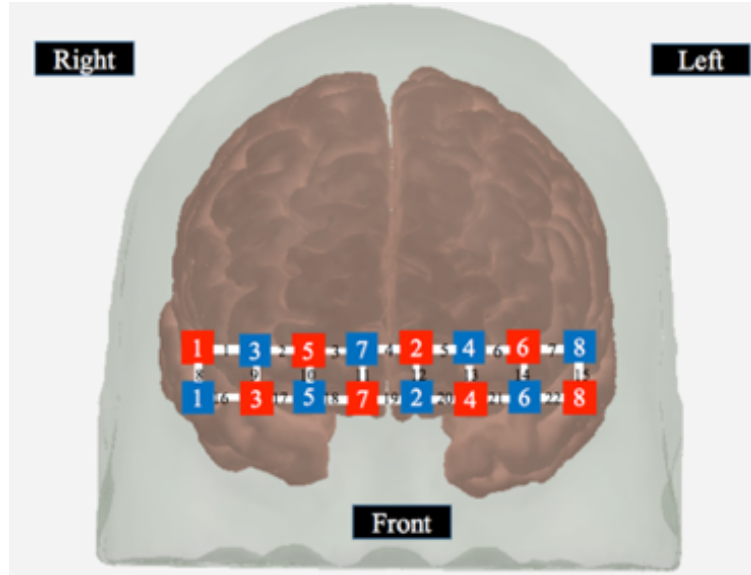
Fig. 2. Sample block sequence

## 2.5 Data Analysis

### 2.5.1 Neurocognitive Data Analysis

The placement of the fNIRS cap on the PFC is shown in Figure 3, with the sensors (i.e., source locations) shown in red and the detectors shown in blue. The probes connect to the fNIRS machine that measures and records change in light density. A modified Beer-Lambert Law (MBLL) was used to convert change in light absorption into change of cerebral blood flow (Scholkmann et al., 2014). Only oxy-Hb response was analyzed and reported since oxy-Hb has a relatively higher amplitude and is more sensitive to cognitive activities (Mo Hu & Shealy, 2019).

The fNIRS cap recorded change in oxygenated and deoxygenated blood along 22 channels in the prefrontal cortex (PFC) (Scholkmann et al., 2014). To answer the question about how neurocognitive activation changes when reading non-traditional safety messages, the average peak oxy-Hb was calculated for each of the 22 channels for each person for each block.



**Fig. 3.** Placement of fNIRS on PFC

Raw data of the change in oxy-Hb for each participant was processed using a bandpass filter (a third-order Butterworth filter) of 0.01Hz – 0.2Hz to remove high-frequency instrumental noise and low-frequency physiological noise. An independent component analysis (ICA), using a coefficient of spatial uniformity (CSU) of 0.5, was then used to remove motion artifacts. These parameters in data processing are based on prior research (Naseer & Hong, 2015; Sato et al., 2011).

Peak oxy-Hb was then averaged for each block. Data with poor channel quality (either missing, above or below three standard deviations from the mean, or notes from the data collection process describing instances of interruptions from the participant during data collection) were removed. Of the 300 participants, 58 people were removed from the analysis of oxy-Hb. In total, 242 people were included.

To answer the question about how neurocognitive activation varies by gender, age, and risky driving behavior, participants were grouped by these dependent variables, and then their peak oxy-Hb data was averaged. Only participants who indicated gender as male or female were included in the analysis. Only participants that indicated an age between 18-25, 26-40, 41-65, and 65 plus were included in analysis.

Risky driving behavior was determined from a combination of responses to survey questions. The questions asked “How often do you go the following behaviors;” the behaviors being “wear your seatbelt,” “drive greater than 15 mph over the speed limit,” “text while driving,” “follow another care too closely,” “merge quickly in front of other drivers,” “use a cell phone for navigation while driving,” “driver within one hour of having one or more alcoholic beverages.” Participants responded with never, rarely, sometimes, often, or always. These questions were developed from prior literature (Morris, Lynch, Swinehart, & Lanza, 1994). A risk score for each person was created by averaging scores from these seven questions. The maximum possible score was 4 and the minimum score was 0. The mean score was 1.04. The highest risk score among participants was 2.71 and the lowest score was 0. Participants were grouped into low, medium, and high risk groups based on their relative percentile (< 33<sup>rd</sup>, 33<sup>rd</sup> - 66<sup>th</sup>, > 66<sup>th</sup>). People below 33<sup>rd</sup> percentile, with a combined risk score from 0 to 0.857, were categorized as low-risk drivers. People between 33<sup>rd</sup> and 66<sup>th</sup> percentile, with a combined risk score from 0.858 to 1.29, were categorized as medium-risk drivers. People above 66<sup>th</sup> percentile, with a combined risk score from 1.29 to 2.71, were categorized as high-risk drivers. The number of participants in each group, the mean score, and range of scores is provided in Table 4. Percentiles were used to cluster participants into groups because no absolute scale with pre-define high, medium, and low risk ranges exists.

**Table 4** Risk Scores Grouped to Low, Medium, and High by Percentile

<b>Risk Group</b>	<b>Range</b>	<b>N</b>	<b>Mean</b>
Low	0 - 0.857	88	0.498
Medium	0.858 – 1.29	144	1.09
High	1.3 - 4	68	1.64

### 2.5.2 Statistics

An analysis of variance (ANOVA) was used to statistically compare differences in perceptions about the messages ability to change driver behavior between blocks, message behavior, message emotion, and message theme. Chi-squared was used to statistically compare differences in comprehension.

Peak oxy-Hb was averaged for each block. An analysis of variance (ANOVA) test was performed on the fNIRS data sets to compare mean differences of oxy-Hb between blocks. Blocks were then averaged based on similar intended behaviors (e.g., driving without a seat belt, general aggressive driving). Cohen's d was used to measure the effect size between the mean differences (Lakens, 2013). Another ANOVA test was performed to compare differences in the peak oxy-Hb between intended behaviors. A post-hoc Tukey test was used to identify statistical differences between blocks (Tukey, 1949). Blocks of messages were again grouped by emotions and themes. ANOVA and a post-hoc Tukey test with Bonferroni were used to identify specific peak differences between oxy-Hb relative to the messages intended emotional response (e.g., humor and negative) and themes (e.g., word play and sports). Bonferroni is a technique to correct for issues with multiple comparisons (Napierala, 2012).

### 3. RESULTS

#### *3.1 Differences in gender, age, risky driving behavior, and driving environment and perceived effectiveness to change driver behavior*

Perceptions about effectiveness are significantly different based on the participant's gender, age, and risky driving habits ( $p < 0.001$ ). Females ( $M=6.52$ ,  $SD = 1.69$ ) are significantly ( $p=0.003$ ) more likely to believe these messages are more effective than males ( $M=6.25$ ,  $SD = 1.65$ ). Although, the effect size between female and male is small. Cohen's d is 0.162 (small is 0.2, medium is 0.5, and large is 0.8). In other words, while statistically significant differences between females and males the absolute difference between means (6.52 to 6.25) is small (between 0 and 10). Drivers that are 65 plus in age ( $M = 6.87$ ,  $SD = 1.57$ ) are also significantly ( $p=0.015$ ) more likely to believe these messages are more effective than 18-25 ( $M=6.38$ ,  $SD = 1.49$ , Cohen's d = 0.32), 26-40 ( $M = 6.27$ ,  $SD = 1.78$ , Cohen's d = 0.36), and 41-65 ( $M = 6.45$ ,  $SD = 1.74$ , Cohen's d = 0.25) aged drivers. While the differences are significant the effect size is between small and medium for each group.

Both low-risk ( $M=6.76$ ,  $SD = 1.59$ , Cohen's d = 0.38) and high-risk ( $M = 6.53$ ,  $SD = 1.61$ , Cohen's d = 0.24) drivers believe the messages are significantly ( $p<0.001$ ) more effective than medium ( $M=6.12$ ,  $SD = 1.74$ ) risk drivers. The effect sizes between the groups are small to medium. The predominant driving environment does have an effect on perceptions of

effectiveness. Rural (M=6.51, SD = 2.2, Cohen’s d = 0.17) and urban drivers (M = 6.51, SD = 2.09, Cohen’s d = 0.17) are significantly (F = 17.6, p < 0.0001) more likely to perceive messages are more effective than suburban drivers (M = 6.14, SD = 2.17) but the effect size is small. The results of the analysis of variance comparing mean values of scores ranging from 0-Not very likely to 10- Very likely to change driver behavior are listed in Table 5.

**Table 5** Results of the analysis of variance comparing mean values of scores ranging from 0 (not very likely to change driver behavior) to 10 (very likely to change driver behavior)

	Sum of Squares	df	Mean Square	F	p
Gender	686	1	685.81	255	<0.0001
Age	940	3	313.18	116	<0.0001
Risk Score	2391	2	1195.59	444	<0.0001
Driving Environment	164	2	81.85	17.5	<0.0001

### *3.2 Differences in gender, age, risky driving behavior, location and driving environment and memorability of the safety campaign message’s behavior*

While messages about drinking and driving (32.7 percent), distracted driving (38.5 percent), and statistics (63.3 percent) are the most memorable across all demographics, females are more likely to remember messages about distracted driving (43.6 percent of females), and males are more likely to remember messages about drinking and driving (36.4 percent of males). Age also plays a role in memorability. Drivers that are 18-25 and over 65 varied in the messages that they remember, but drivers 26-40 predominately remember messages about drinking and driving (40.7 percent of drivers 26-40), and participants aged 41-65 predominately remember messages about distracted driving (47.1 percent of drivers 41-65). Low-risk drivers recall more messages about drinking and driving, and medium-risk drivers recall more messages about distracted driving. High-risk drivers vary in the types of messages they are able to recall. The predominate driving environment (urban, rural, or suburban) has no effect on memorability.

### *3.3 Differences in gender and age and the comprehension of the safety campaigns behavior*

The ability to comprehend the message behavior does not seem to differ based on age or gender. Participants across all age groups and genders incorrectly identified approximately the same



amount of message behavior. The percentage incorrect for age and gender are provided in Table 6 and 7.

**Table 6** Percent of message incorrect based on age

Age	% Incorrect
18-25	8.3
26-40	10.1
41-65	10.0
over 65	11.9

**Table 7** Percent of message incorrect based on gender

Gender	% Incorrect
Female	9.5
Male	10.1

*3.4 Differences in gender, age, risky driving behavior, and driving environment and neurocognitive activation when viewing safety campaign messages*

Neuro-cognitive activation seems to differ among drivers based on gender. Males are significantly ( $F=18.2$ ,  $p<0.0001$ , Cohen’s  $d = 0.28$ ) more likely to have a higher peak oxy-Hb ( $M= 0.0221$  uM,  $SD = 0.0152$  uM) compared to females ( $M= 0.0176$  uM,  $SD =0.0165$  uM). The effect size between males and females is small. In other words, the differences between these groups, while significant, is marginal. Participants with a high ( $F = 4.48$ ,  $p <0.012$ ,  $M = 0.0213$  uM,  $SD = 0.0186$ , Cohen’s  $d = 0.2$ ) and medium ( $M = 0.0211$  uM,  $SD = 0.0161$ , Cohen’s  $d = 0.21$ ) risk score are also significantly more likely to have a higher peak oxy-Hb than participants with low ( $M = 0.0179$  uM,  $SD = 0.0137$ ) risk scores, but again the effect size is small between the groups. These results are listed in Table 8 and Table 9.

**Table 8** Peak oxy-Hb between gender

Gender	Mean Peak oxy-Hb	Standard Deviation	F	p
Males	0.0221	0.0152	18.72	<0.001
Females	0.0176	0.0165	-	<0.001

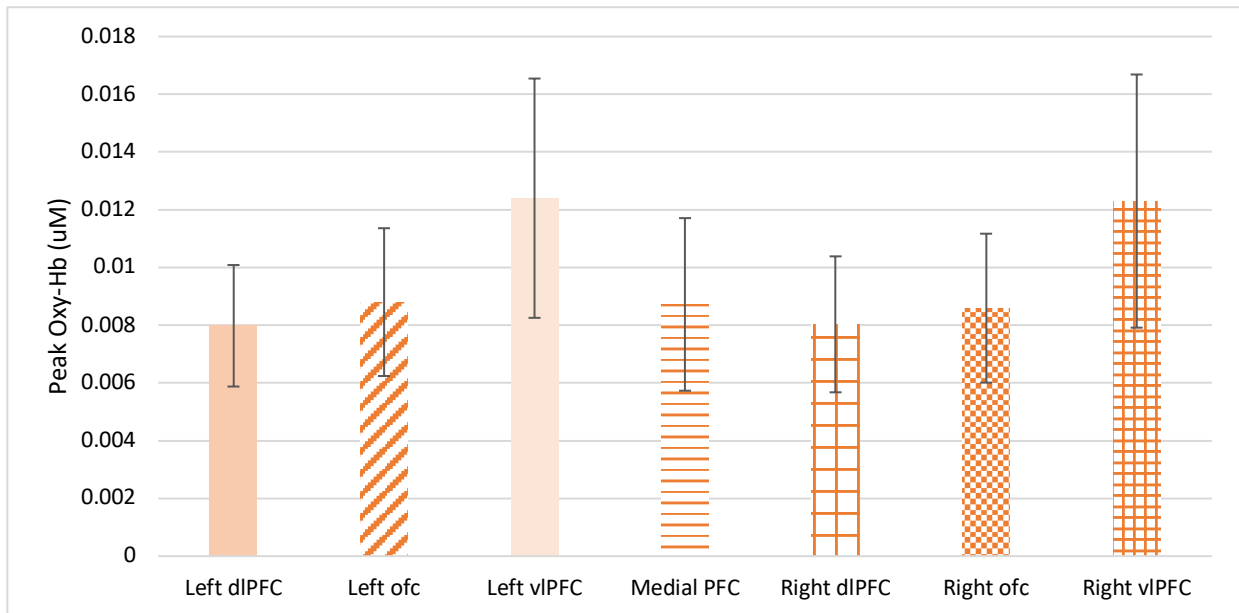
**Table 9** Peak oxy-Hb between risk level

<b>Risk Level</b>	<b>Mean Peak oxy-Hb</b>	<b>Standard Deviation</b>	<b>F</b>	<b>p</b>
High Risk	0.0213	0.0186	3.52	<0.0001
Medium Risk	0.0211	0.0161	-	<0.0001
Low Risk	0.0179	0.0137	-	<0.0001

No differences in peak oxy-Hb are observed between age groups ( $F = 2.14$ ,  $p = 0.093$ ). However, age does play a role when combined with gender. Younger and older males elicit more cognitive attention when viewing non-traditional safety messages compared to other groups of people. Males 18-25 ( $M = 0.0233$  uM) and males over 65 ( $M = 0.0237$  uM) produce the highest peak oxy-Hb compared to all other age groups of people ( $p < 0.001$ ). These differences between groups suggest males, and males 18-25 and over 65, elicit more cognitive attention, or engagement with messages than other groups of people.

While the predominant driving environment (urban, rural, suburban) for participants is a significant factor in perceptions of effectiveness, it is not a significant ( $F = 0.69$ ,  $p = 0.5$ ) factor in how participants express cognitive attention or engagement with messages. Drivers from urban, rural, and suburban areas cognitively respond to messages with a similar level of oxy-Hb.

Channels were grouped into specific regions, including the dorsolateral prefrontal cortex (dlPFC), ventrolateral (vlPFC), orbital prefrontal cortex (OFC), and the medial prefrontal cortex (mPFC). The peak activation in the left vlPFC ( $M = 0.0124$  uM,  $SD = 0.00829$ ) and right vlPFC ( $M = 0.0123$  uM,  $SD = 0.00877$ ) is significantly higher compared to the other regions in the PFC ( $F = 23.4$ ,  $p < 0.0001$ ). The bilateral vlPFC is associated with emotional response to stimuli (Aron et al., 2004), goal-directed behavior (Sakagami & Pan, 2007), and semantic processing (Nozari & Thompson-Schill, 2016). It is often recruited during tasks that involve interpreting a stimulus and trying to minimize its emotional impact (Goldin et al., 2008; McRae et al., 2009). In other words, the vlPFC helps with emotional control (He et al., 2018; Marques et al., 2018) and semantics (Nozari & Thompson-Schill, 2016). The average peak oxy-Hb for each subregion in the PFC is illustrated in Figure 4.



**Fig. 4.** Average Peak oxy-Hb for Subregions within the Prefrontal Cortex

The observed increase in peak oxy-Hb in the left and right vlPFC is consistent with the results from the whole PFC. The peak oxy-Hb for distracted driving is significantly higher in the left vlPFC ( $F = 5$ ,  $M=0.0966$  uM,  $p<0.001$ ) and right vlPFC ( $F = 4.19$ ,  $M=0.0957$  uM,  $p=0.002$ ) compared to the other subregions within the PFC. The differences in peak oxy-Hb for emotional response also remains significant when isolating the peak oxy-Hb in the left and right vlPFC. Messages intended to provoke a humorous emotional response elicited the highest peak response in the left and right vlPFC. Similar differences are also observed in peak oxy-Hb in the left and right vlPFC for messages with varying themes. Messages with word play and rhymes are significantly greater ( $F = 23.4$ ,  $p < 0.0001$ ) in the left and right vlPFC than other sub-regions. The average percent difference between messages with word play and rhymes compared to the mean peak oxy-Hb for other messages is greater in the left vlPFC (67 percent increase in peak oxy-Hb compared to mean) compared to the whole PFC average (64 percent increase in peak oxy-Hb compared to mean of other message themes) and right vlPFC (61 percent increase in peak oxy-Hb compared to mean of other messages). In other words, the effect of word play and rhymes is most pronounced in the left vlPFC.

Peak oxy-Hb is significantly different in the left ( $F= 26.1, p<0.0001$ ) and right ( $F=25.5, p<0.0001$ ) vIPFC based on driver age. The younger the driver the greater the peak oxy-Hb in the left and right vIPFC. Mean peak oxy-Hb for each age group is listed in Tables 10 and 11. Drivers 18-25 and 26-40 are significantly more likely to express higher peak oxy-Hb in the left and right vIPFC compared to drivers that range in age between 41-65 and over 65. Drivers 18-25 are significantly more likely to elicit higher peak oxy-Hb in the left and right vIPFC compared to drives between 26-40 years old. Peak oxy-Hb is not significantly different based on gender (left  $F= 0.03, p= 0.86$ ; right  $F= 0.61, p=0.43$ ) or risky driving behavior (left  $F= 2.84, p= 0.06$ ; right  $F=1.75, p=0.174$ )

**Table 10** Peak oxy-Hb between age groups in the left vIPFC

Age	Mean Peak oxy-Hb	Standard Deviation	$p_{\text{Tukey}} (t)$		Cohen's d
18-25	0.105	0.08	-	-	-
26-40	0.0814	0.06	<0.0001 (4.78)	-	0.33
41-65	0.0651	0.06	<0.0001 (8.20)	0.002 (3.58)	0.56
over 65	0.0599	0.05	<0.0001 (6.21)	0.013 (3.04)	0.68

Note: Post-hoc Tukey tests compare drivers between the ages of 18-25 and 26-40 to 41-65 and over 65

**Table 11** Peak oxy-Hb between age groups in the right vIPFC

Age	Mean Peak oxy-Hb	Standard Deviation	$p_{\text{Tukey}} (t)$		Cohen's d
18-25	0.102	0.08	-	-	-
26-40	0.0832	0.07	0.002 (3.64)	-	0.25
41-65	0.0621	0.06	<0.0001 (7.90)	<0.0001 (4.49)	0.56
over 65	0.0558	0.05	<0.0001 (6.12)	0.001 (3.74)	0.69

#### 4. DISCUSSION

Differences in message effectiveness varies based on gender, age, risky driving behavior, and predominant driving environment (rural, urban, or suburban). However, the effect of these variables on effectiveness of messages is small and not consistent across measures. Some of the differences do align with prior research. Males tend to prefer safety campaigns with humor, and

females tend to prefer campaigns with an authoritarian or guilty message (Trick et al., 2012). The results from this study provide supporting evidence for these gender differences. Males are more likely to demonstrate an increase in oxy-Hb to humorous messages, and females are significantly more likely to perceive negative messages as more effective.

Safety campaigns measuring the influence of age on effectiveness generally conclude that young drivers are riskier drivers and are in need of more creative interventions (Falk & Montgomery, 2007; Inman et al., 2015; Inman & Philips, 2015). Older drivers are less at risk and require longer to comprehend complicated messages (Falk & Montgomery, 2007; Inman et al., 2015; Inman & Philips, 2015). Age also appear to be a factor in the results of this study. Drivers 65 years of age or older are more likely to believe non-traditional safety messages will be effective compared to other age groups. However, attention and engagement with messages across the whole prefrontal cortex is not significantly different between age groups. Difference, however, from age do become observable when isolating the bilateral vLPFC regions. The differences in oxy-Hb to this region has a medium effect size between age groups. The younger the driver the higher the peak oxy-Hb in this region of the PFC. The largest increase of oxy-Hb in the vLPFC occurs most among males, not females, and within the ages of 18-25. Males 18-25 are often the riskiest drivers (Constantinoua et al., 2011). The results presented here begin to suggest that these types of messages may be effective in reaching this subgroup of drivers, at least capturing more of their attention (Harrivel et al., 2013) and eliciting an emotional response (Glitzbach et al., 2011; X. Hu et al., 2019).

The results of the perceived effectiveness broken down by propensity for risk revealed that low-risk and high-risk drivers found these types of messages a more effective than medium-risk drivers. A possible explanation for why the low-risk drivers perceived them as effective is that clearly the efforts to curb risky driving tendencies had a lasting impact on those drivers and their decision to engage in risky driving habits, and therefore, it could work for others. A possible explanation for why high-risk drivers found them more effective is that high risk drivers are likely to see themselves as good drivers and that the general public is in need of intervention.

While there were differences in the perceived effectiveness of safety campaign messages based on age and gender, differences were not seen in ability to comprehend the message behavior based on these demographics. Younger drivers are known to take less time to respond to messages and with higher accuracy (Falk & Montgomery, 2007). The ability to comprehend may not have been affected by ages group because participants had more time to read the messages, and therefore, increase their understanding.

While many regions of the brain are coactivated (Wearne, 2018) when reading non-traditional safety messages, messages with word play and rhymes produced the largest increase of oxy-Hb in the left and right vIPFC. The significant difference in peak oxy-Hb in the left and right vIPFC is likely contributing the significant difference observed in the whole PFC. The left and right vIPFC is involved in word processing (Nozari & Thompson-Schill, 2016) and emotional response to stimuli (Aron et al., 2004). It is often recruited during tasks that involve interpreting a stimulus and trying to minimize its emotional impact (Goldin et al., 2008; McRae et al., 2009).

One explanation for this noticeable increase in the bilateral vIPFC compared to other regions is messages with humor require more emotional control (Weintraub-Brevda & Chua, 2018). The right lateral vIPFC is known to be associated with positive emotional control. Individuals who cannot express positive emotion exhibit less activation in this region (Light et al., 2011) and the left vIPFC is generally more associated with supporting controlled access to stored conceptual representations (Badre & Wagner, 2007) and processing of words and sentences (Nozari & Thompson-Schill, 2016).

The use of the neuroimaging technique and the identification of greater activation across the PFC and, more specifically, in the vIPFC associated with distract driving messages, messages that include humor, and word play and rhyme are indicators of their effectiveness to elicit a neuro-cognitive response. This increase in response is similar to other transportation studies that found the ability to predict driving function with brain behavior (Rieger et al., 2019; Yamamoto et al., 2018). Here, the results, specifically in the vIPFC, begin to suggest an increase in emotional control and semantic processing when viewing messages that include humor and word play and rhyme.

## 5. CONCLUSION

This research project uses both qualitative data about perceptions of effectiveness and neurocognitive data to quantitatively measure driver response to safety campaigns on roadside dynamic message signs. This response, preferences, and comprehension were investigated based on the target demographics of the safety campaigns. The behavioral results indicated that females, drivers over 65, low-risk and high-risk drivers, and urban and rural drivers perceive the safety campaigns as more effective. The neurological data revealed that younger and older males and older high-risk drivers respond with greater peak oxy-Hb when compared to other groups of people.

The results of this analysis reveal that safety campaigns can appeal to different demographics. Since females are significantly more likely to believe non-traditional safety messages are effective than males and males have higher neurocognitive response to safety campaign messages, both genders appear to benefit from this type of safety campaign because one measure of effectiveness is observed for each group. Drivers over the age of 65 have a higher perceived effectiveness, and drivers under 65 have higher neurocognitive response. Again, both younger and older drivers either perceive the campaign is effective or are observed to increase attention for safety campaigns. This study provides a framework for developing effective safety campaigns and for further research in changing driver behavior.

Limitations in this study include that only perceived effectiveness was measured, not actual behavior change, only the initial reaction was captured, and only the blood in the PFC was measured. Other brain regions (e.g., anterior cingulate cortex) likely also contribute to differences between messages. However, this is a limiting factor with all neuroimaging studies that do not capture whole head differences (Ferrari & Quaresima, 2012). Indicators for effectiveness measure potential behavior change through perceived effectiveness, recall, and peak cognitive response. Future research could test how these indicators for effectiveness correspond with actual behavior change through field trials. Since repeated exposure could have an effect on behavior change, future research could test the effectiveness of repeated non-traditional safety messages on behavior change.

This study provides an opportunity for future research, as the demographics could be further investigated. The combination of demographics could be continued to find out what ever further refined demographics prefer. For example, this project discusses what young males responded to, but further refinement could investigate several layers of dependent variables, such as young high-risk males that drive in an urban environment and follow sports everyday with children in the household, and so on.

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## LESSONS LEARNED

Throughout the research process, including the literature review, experiment design, and data collection, I learned several lessons.

The beginning of the research project consisted of the literature review. The uniqueness of this research project made it easy to identify gaps but difficult to find prior studies that aligned with the intent of the project. The literature review ended up helping to inform the dependent variables and research design and still proved to be a vital step.

Valuable lessons learned during the research design are ubiquitous in any research project, that organization from the beginning is vital to the success of the project and pilot testing should be carefully considered. For organization, establishing a consistent naming convention and keeping track of different iterations of design will help keep everything organized and set up for success. The pilot testing informed the timing of the message display, but there should have been more of an emphasis on testing the rest of the experiment design with pilot participants. The question in the post task survey, “From the list of messages you saw today, which message(s) were the most memorable and why?” was interpreted different ways. Participants answered this with exact messages or behaviors or themes they found memorable. While this did not prove to be problematic, a more precise question could have produced more consistent data; a detail that could have been picked up on with several pilot participants.

The data collection process was another platform for lessons learned, particularly as they pertain to the hardware and participants. The hardware, i.e. the fNIRS device, does not calibrate easily when participants have hair features such as wigs and weaves. Not that this could have been filtered through the recruitment process, but being aware of this stipulation from participants might be helpful for future research studies using fNIRS.



## CONCLUSION

This research study triangulates effectiveness of safety campaigns by using fNIRS along with driver preference, comprehension, and recall to determine driver response to safety campaigns on roadside dynamic message signs.

In the first journal paper, the results showed that drivers perceive safety campaigns as being overall effective. From the behavioral data, drivers consider campaigns about distracted driving as significantly more effective than those aimed at targeting other behaviors. Additionally, messages eliciting an emotional reaction are significantly more effective than emotionless campaigns. The neurocognitive data supports this by revealing that drivers are more attentive to signs about distracted driving and signs with a humorous emotion. Messages about statistics were perceived as an effective campaign.

Additionally, the first paper showed that drivers significantly misunderstand safety campaigns about general safe driver compared to the other specific target behavior. This suggests that safety campaigns should have clarity in their message in order to have a greater impact on changing driver behavior.

In the second journal paper, the results from the first study are further examined to determine if some campaigns are more effective among different demographics of drivers. The behavioral results indicated that females, drivers over 65, low-risk and high-risk drivers, and urban and rural drivers perceive the safety campaigns as more effective. The neurological data revealed that younger and older males and older high-risk drivers respond with greater peak oxy-Hb when compared to other groups of people.

This research contains certain limitations. First, the results show the triangulated effectiveness of non-traditional safety campaign categories compared to other categorized messages; the study did not test against a control (e.g. no category or traditional safety messages). Additionally, these triangulated measurements of effectiveness did not include actual behavior change, just metrics that would indicate likely behavior change. Additionally, these metrics only captured the initial reaction, not the reaction over time or a measure of how long after exposure the behavior is

changed. Finally, only the PFC was selected for analysis, while other brain regions (e.g., anterior cingulate cortex) could also contribute to differences between messages. However, this is a limiting factor with all neuroimaging studies that do not capture whole head differences (Ferrari & Quaresima, 2012).

Future studies could be used to address some of these limitations. A correspondence analysis and testing against a control could be used to further refine the current results. Including the whole head in an analysis would provide further understanding of the differences in the results.

However, to include whole head differences would require using fMRI, which has its own limitations, including lack of mobility to recruit in diverse locations and costs associated with enrolling 300 participants. Future research could also test how the indicators for effectiveness (e.g. perceived effectiveness, memorability, etc.) correspond with actual behavior change through field trials. However, field trials introduce their own limitations. Observing behavior change, for example, about distracted driving or aggressive driving, presents challenges. Prior studies have observed driver speeds pre and post messages about speeding but with varying results (Haghani et al., 2013; Harder & Bloomfield, 2008).

The final results from these journals provide behavioral and neurocognitive evidence that drivers perceive non-traditional safety message as effective and particular messages increase cognitive attention or engagement more than other types of messages. Messages about distracted driving, messages that include humor, and messages that include word play and rhymes are the most effective based on drivers' perceptions, their ability to understand the intent of the message, their ability to recall messages, and their neuro-cognitive response.

This study provides a unique application of using neuroimaging techniques in future research applications. The behavioral data being supported by the neurological data advances the applicability of using fNIRS in traffic related studies. This research project, in particular, could be further investigated. The combination of demographics could be continued to find out what further refined demographics prefer. For example, this project discusses what young males responded to, but further refinement could investigate several layers of dependent variables, such

as young high-risk males that drive in an urban environment and follow sports everyday with children in the household, and so on.