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Driver Response to Dynamic Message Sign Safety Campaign Messages

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Final Report VTRC 20-R16

VIRGINIA TRANSPORTATION RESEARCH COUNCIL
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Standard Title Page - Report on Federally Funded Project

1. Report No.: FHWA/VTRC 20-R16	2. Government Accession No.:	3. Recipient's Catalog No.:
4. Title and Subtitle: Driver Response to Dynamic Message Sign Safety Campaign Messages		5. Report Date: January 2020 6. Performing Organization Code:
7. Author(s): Tripp Shealy, Ph.D., Pamela Kryschtal, Kaitlyn Franczek, and Bryan J. Katz, Ph.D., P.E.		8. Performing Organization Report No.: VTRC 20-R16
9. Performing Organization and Address: Virginia Transportation Research Council 530 Edgemont Road Charlottesville, VA 22903		10. Work Unit No. (TRAIS): 11. Contract or Grant No.: 114510
12. Sponsoring Agencies' Name and Address: Virginia Department of Transportation 1401 E. Broad Street Richmond, VA 23219	Federal Highway Administration 400 North 8th Street, Room 750 Richmond, VA 23219-4825	13. Type of Report and Period Covered: Final Contract 14. Sponsoring Agency Code:
15. Supplementary Notes: This is an SPR-B report.		

16. Abstract:

Messages like "May the 4th be with you, text I will not" are increasingly used to catch drivers' attention. The development and use of non-traditional safety messages are distinctly different than messages previously displayed on highway signs. These message attempt to provoke an emotional response and may reference themes like popular culture, sports, or use rhymes to increase their effectiveness. 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 being displayed across the country, measure their effectiveness, and identify any potential negative impacts of these messages on drivers.

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. Messages were grouped by their behavior, emotion, and theme. Participants were asked about their perception of these messages to change driver behavior, to identify the intent of the message, and to recall messages. Participants' neuro-cognitive response when reading the messages was also observed. A neuroimaging instrument called functional near-infrared spectroscopy was used to quantify the differences in how non-traditional messages elicit cognitive attention among drivers.

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 emotion, and messages using statistics are perceived to most likely change driver behavior. Gender, age, and driving behavior have a small effect on perception. Females are significantly more likely to believe non-traditional safety messages are effective compared to males. Drivers over the age of 65 compared drivers below the age of 65 are significantly more likely to believe non-traditional safety messages are effective. Low-risk and high-risk drivers compared to medium risk drivers are significantly more likely to believe non-traditional safety messages are effective.

Messages about general safe driving and general aggressive driving are significantly misunderstood compared to messages about distracted driving, impaired driving, and wearing a seat belt. Messages about distracted driving and impaired driving are the most recallable. Messages about distracted driving, messages with humor, and messages that use word play and rhyme elicit significantly higher levels of cognitive activation in the brain. An increase in cognitive activation is a proxy for increased attention. The highest level of cognitive activation when reading messages occurred in the region of the brain associated with emotional control and word processing. The younger the driver, the greater the increase in message engagement in this region of the brain.

These results provide evidence that drivers find non-traditional safety messages as effective, and specific messages are 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. Recommendations for creating new messages and targeting specific groups of people are provided.

17 Key Words: Non-traditional safety messages, dynamic message signs, DMS, functional near-infrared spectroscopy, fNIRS	18. Distribution Statement: No restrictions. This document is available to the public through NTIS, Springfield, VA 22161.		
19. Security Classif. (of this report): Unclassified	20. Security Classif. (of this page): Unclassified	21. No. of Pages: 60	22. Price:

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

FINAL REPORT

DRIVER RESPONSE TO DYNAMIC MESSAGE SIGN SAFETY CAMPAIGN MESSAGES

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In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Virginia Transportation Research Council
(A partnership of the Virginia Department of Transportation
and the University of Virginia since 1948)

Charlottesville, Virginia

January 2020
VTRC 20-R16

DISCLAIMER

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INTRODUCTION

Dynamic message signs, also known as changeable message signs and variable message signs, are a communication tool. They have been used by transportation agencies for over 50 years to inform drivers about road conditions (Shroeder and Demetsky, 2010). Recently, state transportation agencies across the country developed non-traditional, more humorous bulletins of information to share on these dynamic message signs. For example, to remind drivers to signal, the Arizona Department of Transportation posts “New year, new you, use your blinker” (Kennedy, 2017). To remind drivers not to text and drive, the Iowa Department of Transportation posts, “May the 4th be with you, text I will not” (Iowa, 2015).

The development and use of these non-traditional messages are distinctly different than messages previously displayed on these signs. The intent of these messages is to modify driver behavior often by provoking an emotional response and may reference themes like popular culture, sports, or use rhymes in an attempt to increase effectiveness. However, there is little empirical evidence measuring the effectiveness of these messages to change behavior. Prior studies employed surveys and focus groups to measure effectiveness (Boyle et al., 2014; Rodier, Lidicker, Finson, and Shaheen, 2010; Schroeder, Plapper, Zeng, and Krile, 2016). However, respondents do not always answer surveys truthfully due to experimenter bias (i.e., the Hawthorne effect) (McCambridge, Witton, and Elbourne, 2014) or because their memories do not 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, Hamedi, Fish, and Norouzi, 2013). The other study found the non-traditional message led to statistically slower driving (Harder and Bloomfield, 2008).

One reason for conflicting results is some safety messages may change driver behavior and other messages may not have the same behavioral effect. For instance, the Iowa Department of Transportation found the messages "Texting while driving? Oh cell no" and "Drive hammered, get nailed" to be useful, but the Utah Department of Transportation found them to be distracting (Saal, 2015). 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. Another limitation of these prior studies is the narrow focus on the types of messages and behaviors. Both prior field studies (Haghani et al., 2013) and (Harder and Bloomfield, 2008) only measure the effect of messages about speed. The deployment of non-traditional safety messages now includes many varied intended behaviors, including messages about impaired driving, aggressive driving, distracted driving, and others. There is little guidance on how to target these messages to be effective and if these messages are more or less effective on specific groups of drivers (Mitran, Cummins, and Smithers, 2018).

The research presented in this report offers empirical evidence about the effectiveness of non-traditional messages and offers perspective of effectiveness for specific groups of drivers. Empirical experiments with drivers in Virginia were conducted to measure the effect of multiple types of messages on perceived behavior change and cognition. Drivers were surveyed about perceptions, asked about appropriateness, comprehension, and recall of messages. A novel neuroimaging instrument called functional near-infrared spectroscopy (fNIRS) was used to quantify the differences in how non-traditional messages are received, processed, and cognitively interpreted by drivers. The results provide supporting evidence for the types of messages and specific groups of people that are influenced by non-traditional messages.

PURPOSE AND SCOPE

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. The goals of this study are to objectively measure how drivers respond to non-traditional safety messages, to identify which messages to use for specific groups of people, and to identify any potential negative impacts of these non-traditional messages on drivers.

The scope of work included collecting and creating a database of non-traditional safety messages (Phase I) and empirically testing the effectiveness of these messages to change driver behavior (Phase II). Effectiveness is defined as (1) the perceived ability to change driver behavior, (2) the ability of drivers to comprehend the intent of the message, (3) the ability to recall messages, (4) perceived appropriateness of messages, and (5) an increase in neuro-cognitive activation when reading and interpreting messages compared to other messages. The empirical tests and post-task survey included 300 participants from four counties in Virginia (four distinct geographic locations, two rural and two metropolitan).

Recommendations for developing new messages based on the empirical findings and any negative impacts of these non-traditional messages observed during the empirical studies are included. This scope of work did not include driver simulation or on-road human factors testing. The empirical studies involved showing participants non-traditional safety messages using a display screen and capturing their cognitive response using fNIRS. Through a post-task survey, perspectives about the perceived effectiveness and any possible negative effects from these messages related to inappropriate messages were captured and reported.

Research Questions

The research scope is further defined by 13 research questions that were answered in two phases. The research questions for each phase are listed below:

Phase I: Message Content

1. What are the most frequent intended behaviors in non-traditional safety messages?
2. What type of emotional (e.g., humor) response is most frequently conveyed in non-traditional safety messages?
3. What types of themes (e.g., sports, holidays, word play) are most frequently used in non-traditional safety messages?

Phase II (A): Perception of Messages

4. What types of non-traditional safety messages do participants believe will likely change driver behavior?
5. How does perceived effectiveness in the ability to change driver behavior vary based on gender, age, risky driving behavior, driving environment (i.e. urban, rural, suburban), racial group, a family member recently involved in a collision, and whether they have children in their household?
6. What types of non-traditional safety messages are most memorable?
7. How does memorability vary based on the age, gender, risky driving behavior, driving environment (i.e., urban, rural, suburban) of drivers, and racial group?
8. What types of non-traditional safety messages are perceived as inappropriate? How do perceptions of inappropriate messages vary by age, gender, risky driving behavior, driving environment (i.e., urban, rural, suburban), and racial group?
9. What types of non-traditional safety messages do drivers misunderstand? How does comprehension vary with education level and English as a second language?

Phase II (B): Neuro-Cognitive Response from Messages

10. How does neuro-cognitive activation change when reading non-traditional safety messages?
11. How does neuro-cognitive activation vary by gender, age, risky driving behavior, driving environment (i.e., urban, rural, suburban) of drivers, and racial group?
12. How does neuro-cognitive activation differ within subregions of the prefrontal cortex?
13. How do these subregions vary by gender, age, and risky driving behavior?

LITERATURE REVIEW

Non-Traditional Safety Messages

Two notable theoretical frameworks that informed this research are 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 and 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 and Walker, 2013).

RST attempts to determine driver motivation, such as whether they are motivated by losses or conflict resolution systems (Kahneman and Tversky, 1984). RMT 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, and Kapardisb, 2011). Generally, these types of behavioral traits are most common among young male drivers (Castell and Prez, 2004).

The emotional tone of messages can reinforce PMT or RST. For example, threating messages might suggest others are being harmed because of a driver's action and this can work as a motivator for behavior change that aligns with PMT (Dun and Ali, 2018; Rodd, 2017). Messages with a positive emotional tone, particularly humor, can also be advantageous because the campaigns are more likely to be shared if they are funny. Messages with positive emotional tones can align with RST when reinforcing a reward for safe driving practices (Dun and Ali, 2018; Young Kim and Biswas, 2018).

Driver characteristics, particularly gender and age, also play a role in whether or not drivers adopt behavior change. Male drivers prefer safety campaigns with humor, and female drivers perceive safety campaigns with an authoritarian tone or messages that elicit a feeling of guilt as more effective (Trick, Brandigampola, and Enns, 2012). Male drivers tend to find safety campaigns more effective for the general public, while female drivers tend to find safety campaigns more relevant to themselves and close family (Glendon, Lewis, Levin, and Ho, 2018; Trick et al., 2012). Young drivers are riskier drivers in need of a more creative intervention, or creative messages, and older drivers are less at risk but require longer to comprehend complicated messages (Falk and Montgomery, 2007; Inman, Bertola, and Philips, 2015).

A common trait among these prior campaign studies, including about gender and age, is the use of surveys and interviews to measure perceptions of effectiveness (Cauberghe, De Pelsmacker, Janssens, and Dens, 2009; Dun and Ali, 2018; Glendon et al., 2018; Glendon and Walker, 2013; Lewis, Watson, and White, 2010). A limitation of surveys and interviews is how drivers perceive themselves may not align with actual performance or behavior change. For example, drivers generally report in surveys that campaigns are not effective for themselves but are effective for other drivers (Cauberghe et al., 2009; Jeihani and Ardeshiri, 2013). One approach to overcome this limitation is through empirical studies observing behavior or performance with and without the presence of a stimuli. However, empirical studies also come with limitations: sample size (Gwyther and Holland, 2012; Hill Corey, Elefteriadou Lily, and Kondyli Alexandra, 2015), recruitment of diverse drivers (Glendon and Walker, 2013; Harbeck, Glendon, and Hine, 2018), and the time to complete this type of study (Harms, Dijksterhuis, Jelijs, de Waard, and Brookhuis, 2018). Generally, observational studies are also limited to one instance of observation and may lack generalizability (Dun and Ali, 2018). Confounding variables like car speed, type of roadway, time of day, car type, and the presence of surrounding vehicles can also influence performance and behavior change (Chan and Singhal, 2013).

Neuro-Cognitive Response to Non-Traditional Safety Messages

To overcome the limitations of empirical studies and surveys, transportation researchers have begun to adopt new instruments from neuroscience that provide a more direct measure of cognition than surveys and offer an increased ability to control potential confounding variables compared to empirical studies that observe driving behavior. Measuring neuro-cognition provides a glimpse into a driver's intent to act. For example, patterns of neuro-cognition when driving can identify a driver's braking intent prior to his braking operation Less cognitive activation in the region of the brain associated with executive function, called the prefrontal cortex (PFC), correlates with poor driving performance (Li et al., 2009; Yoshino, Oka, Yamamoto, Takahashi, and Kato, 2013) and is a predictor for higher accident rates (Foy, Runham, and Chapman, 2016).

Measuring neuro-cognition is a reliable measure (Jahani et al., 2017) that can scale linearly with attention (Fishburn, Norr, Medvedev, and Vaidya, 2014). An increase in activation in the prefrontal cortex (PFC) is a proxy for task engagement (Ferrari and Quaresima, 2012; Harrivel, Weissman, Noll, and Peltier, 2013) and cognitive load (Causse, Chua, Peysakhovich, Campo, and Matton, 2017; Fishburn et al., 2014). A drop in cognitive activation corresponds with a drop in performance, potentially from disengaging from the task (Bunce et al., 2011). For instance, when automobile speeds were set on cruise control, driver attention decreased, and this was observable by a decrease in cognitive activation in the PFC (Shimizu et al., 2009).

Where neuro-cognitive activation occurs is also critical. Frustration among drivers is observed to correlate with an increase in activation in the inferior frontal and occipital-temporal cortices (Ihme, Unni, Zhang, Rieger, and Jipp, 2018). A driving simulator and subsequent field test finds that the parietal cortex and the prefrontal cortex are activated when trying to recognize information in the drivers' environment (Yamamoto, Takahashi, Sugimachi, Nakano, et al., 2018; Yamamoto, Takahashi, Sugimachi, and Suda, 2018). Car acceleration is also connected to activity in the PFC of the brain (Yamamoto, Takahashi, Sugimachi, Nakano, et al., 2018). In all of these prior studies, the PFC is a dominant region for activation for driving-related tasks.

Within the PFC 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). While the activation among these regions is related, some nuanced differences exist. The dlPFC plays a critical role in cognitive flexibility and control (Kaplan et al. 2016; Mars and Grol 2007). The cognitive control function of the dlPFC is implicated in the modulation of risk attitudes (Schonberg, Fox, and 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, and Poldrack, 2007). The vlPFC is similar to the OFC in that it is generally associated with emotional response selection (Aron, Robbins, and 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, and Gross, 2008; McRae et al., 2009). The mPFC seems to play a vital role in reward-guided learning (Rushworth, Noonan, Boorman, Walton, and Behrens, 2011). Activation in the mPFC is positively correlated with rewards (Rick, 2011).

There are certainly more regions of the brain required for drivers to interpret and process the information from a non-traditional safety message than just these regions of the PFC (Glimcher and Fehr, 2013). However, the PFC plays a dominant role in this type of cognitive function (Christopoulos, Tobler, Bossaerts, Dolan, and Schultz, 2009). Differences in how messages are interpreted and processed and how this relates to task engagement and cognitive attention generally focus on changes in the PFC (Shimamura, 2000).

The purpose of describing this prior research and regions of interest is to demonstrate the additional understanding gained from collecting neurological data. Based on these prior studies, the expectation is to observe a significant difference in the PFC based on the type of message being displayed. Messages about drowsy driving, driving without a seat belt, and texting while driving might be interpreted and processed in cognitively distinct regions of the brain given the varying associations of subregions, emotion, inhibition, and control. The purpose of capturing neuro-cognitive response to non-traditional safety messages was to understand how messages are interpreted and processed in the brain.

Functional Near-Infrared Spectroscopy

There are generally three neuroimaging instruments used to study cognition: electroencephalography (EEG), functional magnetic resonance imaging (fMRI), and functional near-infrared spectroscopy (fNIRS). EEG has excellent temporal resolution but poor spatial resolution (Burle et al., 2015; Niedermeyer and Silva, 2005). The temporal resolution of fMRI is not as good as EEG, but the spatial resolution is very high and thus able to locate changes within specific brain regions. Data collection, however, is constraining because the fMRI scanner encloses participants. The low spatial resolution of EEG and the unrealistic setting of fMRI makes fNIRS a more appropriate instrument to measure neuro-cognitive response to non-traditional safety messages (Shealy and Hu, 2017). A summary of the positive and negative attributes of each instrument is presented in Table 1.

fNIRS works similar to fMRI by recording the change in oxygenated blood, or hemoglobin (oxy-Hb), which is a proximation for cognitive activation (Ferrari and Quaresima, 2012). Unlike fMRI, which requires participants to lay on their back, fNIRS is worn as a cap and participants can sit upright or even move around (Hu and Shealy, 2018; Strait and Scheutz, 2014). fNIRS emits a near-infrared light into the human cortex, and refracted light that is not absorbed is detected by sensors (Ferrari and Quaresima, 2012). fNIRS provides relatively good spatial and temporal resolution and can be used in more natural settings than fMRI (Strait and Scheutz, 2014). Previous studies demonstrate the ability to use fNIRS to measure and predict perceptions of safety (Hu and Shealy, 2018), risky decision making (Hu and Shealy, 2019), and problem-solving (Shealy, Hu, and Gero, 2018). Specific to driver behavior, measuring change in oxygenated blood in the brain can predict steering control, and a driver's response to changes in vehicle dynamics (Bruno et al., 2018).

Table 1. Comparison of Neuroimaging Instruments

Criteria	EEG	fMRI	fNIRS
Spatial resolution	Poor	High	Moderate
Temporal resolution	High	Poor	Moderate
Mobility	Participants sit upright	Participants lay down	Participants sit upright
Data processing	Moderate	Intensive	Low
Cost to operate	$0 (after purchase)	~$500 per hour	$0 (after purchase)
Ease of use	Time intensive placing electrodes	Requires technician	Less time-intensive than EEG

EEG = electroencephalography; fMRI = functional magnetic resonance imaging; fNIRS = functional near-infrared spectroscopy

METHODS

The research and findings are presented in two phases. Phase I develops a database of non-traditional messages and identifies trends from the messages. The outcome of Phase I is a database and summary of messages that are used nationally. Phase II empirically tests the effectiveness of these messages. Effectiveness is defined as (1) the perceived ability to change behavior, (2) ability to comprehend the intent of the message, (3) ability to recall the message, (4) appropriateness of the message, and (5) increased neuro-cognitive activation when reading and interpreting the message. This two-phased approach informs recommendations provided at the end of this report.

Message Database (Phase I)

The purpose of Phase I was to develop a database of non-traditional safety messages. To develop this database, the search process for messages began by scanning social media and state Department of Transportation (DOT) news outlets to identify states who previously posted non-traditional safety messages on dynamic message boards. In total, 21 states were identified as either currently or previously posting non-traditional safety messages. These state DOTs were contacted by email asking if they would be willing to share their list of non-traditional safety messages. In total, 11 states responded that they were willing to share their messages. A total of 964 messages were collected from these 11 states. Virginia's DOT provided 289 messages. The total number of messages collected was 1,253. Out of the 1,253 messages, 1,108 were unique.

These messages were categorized by behavior (e.g., driving without a seat belt, distracted driving, impaired driving), intended emotional response (e.g., humor, negative emotion), and theme (e.g., holiday/seasonal, pop culture, sports). Messages were grouped by behavior to identify if specific messages are perceived as more effective than others. Messages were grouped by emotion because positive emotions, particularly humor, are more likely to be shared but may be perceived as trivial and less likely adopted (Dun and Ali, 2018; Young Kim N. and Biswas, K. 2018). Threat and negative emotions can be an effective means for communicating a safety campaign, particularly because it is considered an information tactic (Dun and Ali, 2018). Negative messages tend to be the most effective (Cauberghe et al., 2009; Glendon et al., 2018; Glendon and Walker, 2013; Lewis et al., 2010). Messages were also grouped by themes, like sports, word play, and pop culture, because the theme of the message may have an effect on comprehension and recall.

The 1,108 messages were coded by behavior, emotion, and theme by three independent reviewers. Any discrepancies in coding between reviewers were discussed until a consensus was reached. In several instances when consensus could not be reached, messages were categorized based on the majority opinion between the three reviewers. To answer the three research questions about what behaviors, emotions, and themes are most frequently targeted in non-traditional safety messages, several frequency tables were produced to compare between groups of messages.

Based on the frequency tables, the categories for messages to be used in empirical testing was formed through clustering and excluding some behaviors and themes. Speeding, aggressive driving, and tailgating were clustered into one group called, "general aggressive driving." Messages about impaired or drowsy driving were clustered together. General safe driving, driving without a seat belt, and distracted driving were also included as clusters. Behaviors that fell outside of these five clusters were excluded in Phase II.

When clustering messages by the intended emotion that the message is trying to provoke, clusters initially included seven types of emotions like threat, joy, fear, guilt, and sadness. The difference between threat and fear is slight and likely not detectable by fNIRS. The difference between positive and negative is much greater, and prior studies in transportation also report differences in behavior change from more general positive and negative safety campaigns (Walker and Trick, 2019). As a result, emotions empirically tested include humor, negative, and emotionless messages.

Themes were also condensed into broad categories. The themes: book, movie, Pokémon, song, and TV were clustered into one group called "pop culture." Word play and rhyme were clustered together. Command, no theme, holiday/seasonal, sports, statistics, and sayings were also included as themes. There were some miscellaneous messages that did not logically fit into a theme. Miscellaneous messages were excluded in Phase II because they did not represent a large enough sample of messages to empirically test.

Empirical Testing (Phase II)

A representative sample of 80 non-traditional safety messages was selected from the unique set of 1,108 messages. These messages were grouped by their associated behavior (e.g., general safe driving, driving without a seat belt), their emotion (e.g., humor), and theme (e.g., sports, statistics). 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.

In total, five behaviors are represented in the list of 80 messages, including: general safe driving, driving without a seat belt, impaired and drowsy driving, general aggressive driving, and distracted driving. Within each of these five behaviors, three emotions are represented at least once, including: humor, negative, and emotionless. The five behaviors and three emotions equate to 15 blocks of messages. These blocks also include themes associated with each behavior and emotion. The themes include commands, word play and rhymes, sports, pop-culture, statistics, and sayings. Themes are represented in two blocks of messages. To ensure each theme was represented twice, an additional block was added. So, the total number of blocks is 16 (5 similar messages and 16 blocks of messages equates to 80 messages). The 16 blocks of five messages grouped by their behavior, emotion, and theme can be seen in Table 2. The order of messages within each block and the order of blocks were randomized for each participant. Appendix A includes the complete list of messages that were used for empirical testing with drivers.

Table 2. Messages Grouped by Behavior, Emotion, and Theme

Block	Behavior	Emotion	Theme
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 and Rhyme
9	Distracted Driving	Humor	Pop Culture
10	Distracted Driving	Negative	No Theme
11	Impaired and Drowsy Driving	Emotionless	Word Play and Rhyme
12	Impaired and Drowsy Driving	Humor	Holiday/Seasonal
13	Impaired and Drowsy Driving	Negative	Word Play and Rhyme
14	General Aggressive Driving	Emotionless	Sports
15	General Aggressive Driving	Humor	No Theme
16	General Aggressive Driving	Negative	Command

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. Participants were given 6 seconds to read each message on the computer display. This time of 6 seconds was determined through face validity checks with a group of graduate students at Virginia Tech. Individually, ten graduate students with and without English as their first language were asked to read the messages without being given a time limit. On average, students read each message in 4 seconds. So, 6 seconds provided a 50 percent increase in reading time compared to the average reading time among students.

The length per message aligns with prior driver readability studies and dynamic message signs (Garvey and Kuhn, 2011). At speeds of 50-61 miles per hour, the reading time is 4-5 seconds for signs with the number of words between 1 and 3 (Garvey and Kuhn, 2011). The time to read a sign increases to 5.5-7.0 seconds if the number of words increases to 4-8. At speeds of 61-70 miles per hour, the average reading time is 4-5 seconds if 1-3 words are displayed and 5.5 seconds if 4-8 words are displayed (Garvey and Kuhn, 2011). The upper limit of this readability range was used in this study because participants were seated, not moving, and viewing these signs on a computer screen without other distractions. To display 1 block of 5 messages required 30 seconds. The entire time to read all 16 blocks of messages was 8 minutes.

While reading each block of messages, participants wore the fNIRS cap, as seen in Figure 1. The fNIRS cap recorded change in oxygenated and deoxygenated blood along 22 channels in the prefrontal cortex (PFC) (Scholkmann et al., 2014). The PFC was the region of interest because of its use in inhibition and control during driving tasks (Quintana and Fuster, 1999; Shimamura, 2000; Takano, Shimokawa, Misawa, and Hirobayashi, 2010).The placement is shown in Figure 1, 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 oxygenated blood from the fNIRS data are reported since it is the most sensitive signal to changes in cerebral blood flow (Zhang, Liu, Pelowski, and Yu, 2017), deoxygenated blood has a relatively lower amplitude than oxygenated blood (Cazzell et al. 2012), and oxygenated and deoxygenated blood are usually inversely related (Chu, Breite, Ciraolo, Franco, and Low, 2008). An increase in oxygenated blood is a proxy for task engagement (Verdière, Roy, and Dehais, 2018), attention (Harrivel et al., 2013) and working memory (Jahani et al., 2017; Rieger et al., 2019; Scheunemann, Unni, Ihme, Jipp, and Rieger, 2019). Oxygenated blood can linearly correspond with engagement (Fishburn et al., 2014), and driving attention (Unni, Ihme, Jipp, and Rieger, 2018). Thus, oxygenated blood was used as a proxy to measure attention. More specifics about how fNIRS was processed and analyzed are provided in the subsection, titled Neuro-cognitive data.

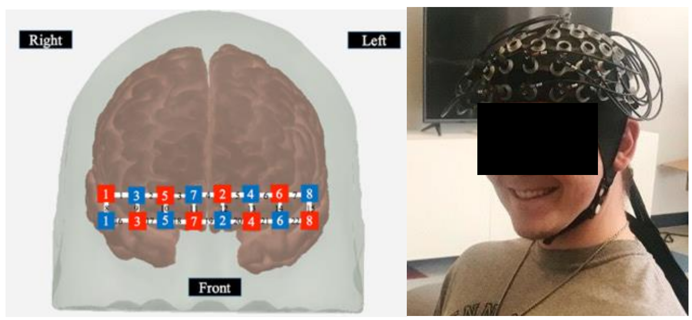

Figure 1. fNIRS Placement Along the Prefrontal Cortex.

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. The question about perceived behavior change was asked about other people, instead of themselves because drivers generally feel that campaigns are not effective for themselves but are effective for other drivers (Cauberghe et al., 2009; Jeihani and Ardeshiri, 2013). The responses to these questions address research question number four about what types of behaviors do drivers believe non-traditional safety messages can help change, and research question nine about what types of behaviors, emotions, or themes of non-traditional safety messages do drivers not fully understand.

When analyzing responses to these questions, participants were also 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 and perceived effectiveness between groups. Prior studies about safety campaigns report age and gender are independent variables for the effectiveness of safety campaigns (Morris, Lynch, Swinehart, and Lanza, 1994). An analysis of variance (ANOVA) and post-hoc Tukey tests were used to statistically compare differences in perceptions about the messages ability to change driver behavior between groups. ANOVA compares the mean between groups and post-hoc Tukey test helps identify where differences exist with multiple groups.

Participants were given 10 seconds to respond to these two questions. Participants responded to both questions verbally. 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 Figure 2.

Figure 2. Sample Block Sequence.

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 survey can be found in Appendix B. The questions were designed to capture memorable and inappropriate messages. Participant responses to these questions answered research question six about what types of non-traditional safety messages are most memorable, and research question eight about what types of non-traditional safety messages are perceived as inappropriate. The purpose of asking about memorable and inappropriate messages is because a common concern with displaying humorous messages is that they may be misunderstood, deemed in some cases to be offensive, or otherwise create undesirable behavior or perceptions about the Department of Transportation.

When analyzing responses to these questions, participants were clustered into groups based on their age, gender, driving environment (urban, suburban, or rural), and risky driving behavior. Risky driving behavior was determined through a set of survey questions previously developed by Morris et al. (1994). The purpose of grouping participants and comparing their responses was to understand if the messages are more memorable or perceived as inappropriate for different groups of people. Protection Motivation Theory (PMT) and Reinforcement Sensitivity Theory (RST) provided the motivation to capture characteristics about drivers' previous car accidents that may influence threat appraisal and reward associated with an unsafe behavior (e.g., speeding) (i.e., PMT) and risky driving behaviors (i.e., associated with RMT).

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. In addition to questions about messages, participants were asked to complete several demographic questions to capture whether they are predominantly urban, suburban, or rural drivers, their risky driving behaviors, education level, racial background, and if English is a second language.

Recruitment for participation included posting online advertisements. In addition, flyers were posted with church organizations and at community events. Data collection occurred in four regions of Virginia (two rural and two urban), including Blacksburg and Christiansburg (rural, Southwest VA), Norfolk (urban, Southeast VA), Fairfax (urban, Northeast VA), and Winchester (rural, Northwest VA). The total number of participants was 300. Participants ranged in age between 18 and over 65. The number of participants by age group and gender is listed in Table 3. Participants were predominately white but racial groups did vary and are listed in Table 4. Participants also varied by their predominant driving environment, which is listed in Table 5. The majority of participants drive in suburban environments. All participants received $30 for their time to participate in the experiment.

Table 3. Participants by Age Group and Gender

Age	Female	Male	Prefer not to say	Total	Percent
18-25	40	36	0	76	25.3
26-40	59	42	3	104	34.7
41-65	44	52	2	98	32.7
over 65	4	18	0	22	7.3
Total	147	148	5	300	100

Table 4. Participants by Racial Group

Race	N	Percent
Asian / Pacific Islander	17	5.7
Black or African American	42	14.0
Hispanic or Latino	18	6.0
Other	10	3.3
White	213	71.0
Total	300	100

Table 5. Participants by Predominant Driving Environment

Driving Environment	N	Percent
Rural	55	18.3
Suburban	171	57
Urban	74	24.7
Total	300	100

Data was collected in the mobile Human Factors Laboratory, shown in Figure 3. The van provided a climate-controlled space with a 65” display screen. Participants approached the van to learn about the study and completed the Institutional Review Board (IRB) consent form. After consenting, participants entered the van and were given instructions about viewing messages and wearing the fNIRS cap. The entire data collection process, including IRB paperwork, fNIRS setup and calibration, data collection, and post-task survey response, took 40 minutes per participant.

Figure 3. Mobile Human Factors Lab in Winchester, VA.

Analysis of Neuro-Cognitive Data

Reading and interpreting the messages produces cognitive activation among participants. The fNIRS system captures this cognitive activation by measuring change in oxygenated blood (oxy-Hb). The units of change in oxy-Hb is measured in micro meters, denoted by µM. Raw data of the change in oxy-Hb for each participant was processed using a filter (a third-order Butterworth filter) to remove high-frequency instrumental noise (using 0.01Hz – 0.2Hz) 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 and Hong, 2015; Sato, Hokari, and Wade, 2011). Only oxy-Hb response was analyzed and reported since oxy-Hb has a relatively higher amplitude and is more sensitive to cognitive activities (Hu and Shealy, 2019).

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. Peak oxy-Hb was used because of the block design of the experiment (Hu and 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. The difference between an independent event and a block of sequential events is illustrated in Figure 4.

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. Figure 4 illustrates the difference between block and event related designs and why peak response is an appropriate measure for neuro-cognitive activation as a result of message stimuli.

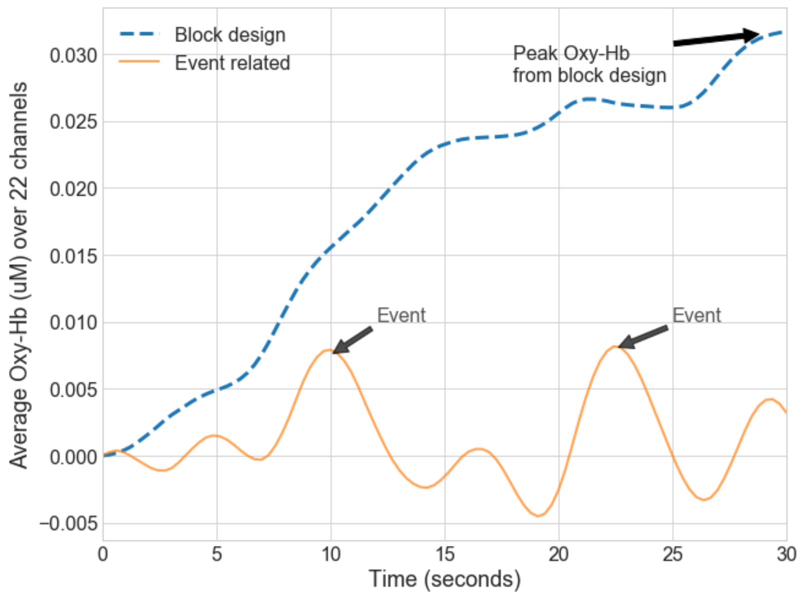

Figure 4. Block Versus Event Design and Corresponding Increase in oxy-Hb Over Time.

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, so 242 people were included. An analysis of variance (ANOVA) test was performed on the remaining data sets to compared 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). Cohen's d describes the size of the difference, where a Cohen's d of 0.2 is small, 0.5 is medium, and 0.8 is a large effect. 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 neuro-cognitive 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 a combination of responses to seven survey questions. The questions are listed in Appendix B, from question 4 to question 10. These questions were originally developed by Morris et al., (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 (< 33rd, 33rd - 66th, > 66th). People below 33rd percentile, with a combined risk score from 0 to 0.857, were categorized as low-risk drivers.

People between 33rd and 66th percentile, with a combined risk score from 0.858 to 1.29, were categorized as medium-risk drivers. People above 66th 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 6. Percentiles were used to cluster participants into groups because no absolute scale with pre-define high, medium, and low risk ranges exists.

Table 6. Risk Scores Grouped by Low, Medium, and High Percentile

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

ANOVA tests with post-hoc analysis using Tukey compared the average peak oxy-Hb in the prefrontal cortex between groups of people by gender, age, and risky driving behavior and types of messages by intended behavior, emotional response, and theme. ANOVA tests also compared the interaction effects between variables. To answer the question about how neuro-cognitive 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. To answer the question about how subregions vary by gender, age, and risky driving behavior, participants were grouped by these variables and the average peak oxy-Hb was compared using ANOVA and post-hoc Tukey with Bonferroni.

RESULTS

Phase I

What are the most frequent intended behaviors in non-traditional safety messages?

Driving without a seat belt is the most frequent behavior in the non-traditional safety messages collected from across the country (23.2 percent of messages). General safe driving (21.6 percent), distracted driving (22.4 percent), and impaired and drowsy driving (18.8 percent) represented similar proportions of messages. Aggressive driving was the least frequently targeted behavior (14 percent). Aggressive driving messages include messages pertaining to speeding, driving in the left lane, tailgating, and general aggressive driving. Table 7 reports the message frequency by behavior.

Table 7. Frequency of Intended Behaviors in Non-traditional Safety Messages

Behavior	National Count	National Percent	Virginia Count	Virginia Percent
Driving Without a Seat Belt	257	23.2	39	18.1
Distracted Driving	248	22.4	32	14.9
General Safe Driving	239	21.6	103	47.9
Impaired and Drowsy Driving	209	18.8	40	18.6
Aggressive Driving	155	14.0	1	< 0.5
Total	1108	100	215	100

What type of emotional (e.g., humor) response is most frequently conveyed in non-traditional safety messages?

Messages that elicit no emotion were the most frequent nationally (48.7 percent) and in Virginia (73 percent). An example of an emotionless message is "Talk less drive more." Of the two emotions, humor accounted for 32 percent of the messages nationally and 24 percent in Virginia, and negative emotion accounts for 19.3 percent of the messages nationally and 3 percent in Virginia. An example of a humorous message is "Texting and driving is not wreckommended." Negative messages included messages that elicit fear, guilt, and sadness, for example, "Fast drive could be last drive." Table 8 reports the frequencies of messages by emotion.

Table 8. Frequency of Emotions in Non-traditional Safety Messages

Emotion	National Count	National Percent	Virginia Count	Virginia Percent
Emotionless	539	48.7	157	73
Humor	355	32.0	51	24
Negative Emotion	214	19.3	7	3
Total	1108	100	215	100

What types of themes (e.g., sports, holidays, word play) are most frequently used in non-traditional safety messages?

The most frequent themes nationally are Holiday/Seasonal (22.7 percent) and Command (19.7 percent). Holiday/Seasonal messages include messages related to Christmas, Fall, and Mother's Day. Command messages dictate an order to the driver, such as "Put the phone away I'm going to count to 3." The most frequent themes in Virginia were no themes, Holiday/Seasonal and Word Play and Rhyme. The least frequent theme nationally and in Virginia is Saying (2.7 percent and 2.3 percent, respectively). An example of a saying message is "Dance like no one is watching/Drive like we are." Table 9 shows the message frequency by theme.

Table 9. Frequency of Themes in Non-traditional Safety Messages

Theme	National Count	National Percent	Virginia Count	Virginia Percent
Holiday/Seasonal	252	22.7	39	18.1
Command	218	19.7	30	14.0
Word Play and Rhyme	188	17.0	39	18.1
Pop Culture	154	13.9	38	17.7
No Theme	124	11.2	46	21.4
Sports	88	7.9	8	3.7
Statistic	54	4.9	10	4.7
Saying	30	2.7	5	2.3
Total	1108	100	215	100

Table 10 lists the frequency of all 1,108 messages by the intended behavior, theme, and emotion. Only message categories that were included in the random selection process for Phase II are represented.

Table 10. Frequency of Messages by Behavior, Theme, and Emotion

Behavior	Theme	Emotionless	Negative	Humor
Driving Without Seat Belt	Command	25	31	6
	No Theme	9	4	11
	Holiday/Seasonal	42	7	26
	Pop Culture	28	0	19
	Word Play and Rhyme	7	1	7
	Sports	15	0	3
	Statistic	0	7	0
	Saying	2	2	5
General Safe Driving	Command	26	12	3
	No Theme	14	13	3
	Holiday/Seasonal	24	4	20
	Pop Culture	6	1	13
	Word Play and Rhyme	23	8	8
	Sports	15	2	1
	Statistic	3	30	0
	Saying	4	2	4
Impaired and Drowsy Driving	Command	15	5	4
	No Theme	8	7	3
	Holiday/Seasonal	36	10	16
	Pop Culture	11	0	9
	Word Play and Rhyme	18	19	14
	Sports	19	1	4
	Statistic	1	7	0
	Saying	0	0	2
Aggressive Driving	Command	15	8	8
	No Theme	6	5	12
	Holiday/Seasonal	9	0	16
	Pop Culture	8	0	19
	Word Play and Rhyme	13	2	11
	Sports	12	0	6
	Statistic	0	1	0
	Saying	2	0	2
Distracted Driving	Command	35	6	19
	No Theme	11	7	11
	Holiday/Seasonal	23	0	19
	Pop Culture	14	0	26
	Word Play and Rhyme	31	7	19
	Sports	7	1	2
	Statistic	1	4	0
	Saying	1	0	4

Phase II (A)

What types of non-traditional safety messages do participants believe will likely change driver 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 11. Blocks with a mean score above one standard deviation of the total mean are presented as bold in the table. The mean scores are significantly different (F = 22.9, p <0.0001) from each other. 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. The following subsections compare the significant differences between behavior, emotion, and theme.

Table 11. Mean Scores for Each Block

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 and Rhyme	6.6	2.16
9	Distracted Driving	Humor	Pop Culture	6.3	2.2
10	**Distracted Driving**	**Negative**	**No Theme**	**7.4**	**1.98**
11	Impaired and Drowsy Driving	Emotionless	Word Play and Rhyme	5.94	1.98
12	Impaired and Drowsy Driving	Humor	Holiday/Seasonal	6.57	2.14
13	**Impaired and Drowsy Driving**	**Negative**	**Word Play and Rhyme**	**6.94**	**1.95**
14	General Aggressive Driving	Emotionless	Sports	5.85	2.05
15	General Aggressive Driving	Humor	No Theme	5.91	2.19
16	General Aggressive Driving	Negative	Command	6.08	1.91

Note: Bold indicates greater than one standard deviation (SD) from the overall mean (M = 6.87, SD = 0.57)

While drivers 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 12.

Table 12. Average Perceived Effectiveness of Non-Traditional Safety Messages to Change Driver Behavior

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	---	---

SD = standard deviation

Drivers' neuro-cognitive 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 13.

Table 13. Drivers Perceive Messages with Negative Emotions as the Most Likely to Change Driver Behavior

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

SE = standard error; df = degrees of freedom

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 14. Messages in bold represent the themes greater than one standard deviation from the mean (M = 6.28, SD = 0.4).

Table 14. Mean Scores Ranging from 0-Not Very Likely to 10- Very Likely to Change Driver Behavior

Theme	Mean
Statistic	**6.91**
No Theme	6.66
Word Play and Rhyme	6.49
Command	6.36
Holiday/Seasonal	6.07
Saying	6.02
Pop Culture	5.85
Sports	5.84

Note: Bold indicates greater than one standard deviation from the overall mean (M = 6.28, SD = 0.4)

In summary, 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.

How does perceived effectiveness in the ability to change driver behavior vary based on the dependent variables: gender, age, risky driving behavior, driving environment (i.e., urban, rural, suburban), racial groups, a family member recently involved in a collision, and whether they have children in their household?

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. Racial group is also a factor that influences perceptions of effectiveness in changing driver behavior. All racial groups perceive messages as effective but drivers who are Black or African American (M = 6.91, SD = 2.28) are significantly ($F = 19.1$, $p <0.001$) more likely to perceive messages as more effective than participants who identify as Asian (M = 6.27, SD = 2.59, Cohen's d = 0.26), Hispanic or Latino (M = 5.75, SD = 2.38, Cohen's d = 0.5), white (M = 6.23, SD = 2.06, Cohen's d = 0.31), and other (M = 6.33, SD = 2.26, Cohen's d = 0.26). The effect size between Black or African American drivers and Hispanic or Latino drivers is medium. The effect size between Black or African American drivers and non-Hispanic or Latino drivers is small. Drivers who are Black or African American perceive messages about distracted driving (M = 7.48, SD = 2.05) and impaired and drowsing driving (M = 7.45, SD = 2.09) as the most likely to change driver behavior. Messages with word play or rhymes (M = 7.35, SD = 2.19) also rank high in perceptions among Black or African American drivers of the types of messages that will change driver behavior. Perceptions are not significantly different based on whether a family member was involved in a recent collision, or they have children in their household ($p > 0.05$). 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 15.

Table 15. 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

Factor	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
Racial Group	354	4	88.48	19.1	<0.001

df = degrees of freedom

What types of non-traditional safety messages are most memorable?

Drivers who participated in the study are more 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) compared to messages with other intents. Messages about statistics (63.3 percent of the messages that participants remembered) were the most likely to be recalled by drivers compared to other message themes. The specific messages that were recalled the most frequent are, “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).

How does memorability vary based on the age, gender, risky driving behavior, geographic location, driving environment (i.e. urban, rural, suburban), and racial group?

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. No differences are observable in memorability of messages based on racial groups. Similarly, the predominant driving environment (urban, rural, or suburban) has no effect on memorability.

What types of non-traditional safety messages are perceived as inappropriate? How do perceptions of inappropriate messages vary by age, gender, risky driving behavior, driving environment (i.e. urban, rural, suburban), and racial group?

Over 90 percent of drivers (272 out of 300) 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 drivers that perceived a message as inappropriate. These drivers were relatively equally split in gender and in their risky driving habits. There were no observable differences in the predominant driving environment (urban, rural, or suburban) or racial groups (75- 90 percent of people in each racial group did not report a single message as inappropriate).

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” for being “suggestive” (6 participants out of the 28 participants who perceived a message as inappropriate) and “Luck of the Irish won’t help if you drive drunk” as insensitive to a group of people (Irish or Irish descent) (3 participants out of the 28 participants who perceived a message as inappropriate). The remaining messages perceived as inappropriate were selected only one time.

What types of non-traditional safety messages do drivers misunderstand? How does comprehension vary with education level and English as a second language?

There is a significant difference in the ability to comprehend messages based on the type of message ($\chi^2 < 0.001$). Table 16 lists the percent incorrect for each block.

Table 16. Percent of Message Incorrect for Each Block

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 and Rhyme	2.67
9	Distracted Driving	Humor	Pop Culture	2.67
10	Distracted Driving	Negative	No Theme	2.33
11	Impaired and Drowsy Driving	Emotionless	Word Play and Rhyme	9.00
12	Impaired and Drowsy Driving	Humor	Holiday/Seasonal	4.00
13	Impaired and Drowsy Driving	Negative	Word Play and Rhyme	3.67
14	General Aggressive Driving	Emotionless	Sports	11.67
15	General Aggressive Driving	Humor	No Theme	4.33
16	General Aggressive Driving	Negative	Command	10.00

Note: Bold indicates greater than one standard deviation from the overall 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 distracted driving were the most frequently understood. On average, only 4.92 percent of drivers who participated in the study incorrectly understood the intent of messages about distracted driving. Table 17 reports the percent incorrect for each type of behavior and the statistical difference compared to general safe driving.

Table 17. Percent Incorrect and Statistical Difference Between Behaviors

Behavior	Correct	Incorrect	% Incorrect	Z	p
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

Education is a factor in the ability to comprehend messages. Participants with an eighth-grade education or less are significantly ($\chi^2<0.0001$) more likely to incorrectly understand the intent of the message. Table 18 reports the percent of participants who correctly identified the intended behavior with a high school diploma, associate's degree, bachelor's degree, or graduate degree. Drivers who participated in the study with an eighth grade or less education are about 20 percent more likely to incorrectly understand the intent of the message than participants with any post-high school education.

Table 18. Percent Incorrect by Education

Education	Correct	Incorrect	% Incorrect
Eighth Grade or Less	22	10	31.25%
High School Diploma	955	149	13.50%
Associate's Degree	677	59	8.02%
Bachelor's Degree	1674	150	8.22%
Graduate Degree	988	100	9.19%

English as a second language (ESL) is also a significant factor (χ^2<0.016) to comprehend messages. ESL increases the chance of incorrect comprehension, reported in Table 19.

Table 19. Percent of Incorrectly Comprehending Intent of the Message when English is a Second Language

ESL	Correct	Incorrect	% Incorrect
No	4068	428	9.52%
Yes	248	40	13.89%

Phase II (B)

How does neuro-cognitive activation change when reading non-traditional safety messages?

There is no significant difference (F=1.03, p=0.419) in peak oxy-Hb in the PFC between blocks. Peak oxy-Hb in the prefrontal cortex (PFC) is a proxy for task engagement (Ferrari and Quaresima, 2012; Harrivel et al., 2013) and it can scale linearly with attention (Fishburn et al., 2014). The mean peak oxy-Hb for each block is displayed in Table 20. The average peak oxy-Hb is 0.00668303 μM, and the standard deviation is 0.00046868 μM.

Table 20. Percent of Message Incorrect for Each Block

Block	Behavior	Emotion	Theme	Mean Peak Oxy-Hb (μM)
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 and Rhyme	0.00660543
9	Distracted Driving	Humor	Pop Culture	0.00647716
10	**Distracted Driving**	**Negative**	**No Theme**	**0.00726896**
11	Impaired and Drowsy Driving	Emotionless	Word Play and Rhyme	0.00714219
12	**Impaired and Drowsy Driving**	**Humor**	**Holiday/Seasonal**	**0.00720874**
13	Impaired and Drowsy Driving	Negative	Word Play and Rhyme	0.00656725
14	General Aggressive Driving	Emotionless	Sports	0.00667776
15	General Aggressive Driving	Humor	No Theme	0.00627561
16	General Aggressive Driving	Negative	Command	0.00662786

Note: Bold indicates greater than one standard deviation from the overall mean (M = 0.00668303, SD = 0.00046868)

Table 20 represents the average peak oxy-Hb for each block. An example of the oxy-Hb in the PFC is illustrated in Figure 5. This is the peak oxy-Hb for one participant while viewing one block of messages. The oxy-Hb continues to increase with time and each new message. The peak oxy-Hb occurs around 28 seconds. The rounding of oxy-Hb observed in Figure 5 at around 5 seconds, 10 seconds, 15 seconds, 23 seconds and 28 seconds might reflect new messages being read by the participant. With each new message, the oxy-Hb appears to increase and this may represent an increase in task engagement and attention.

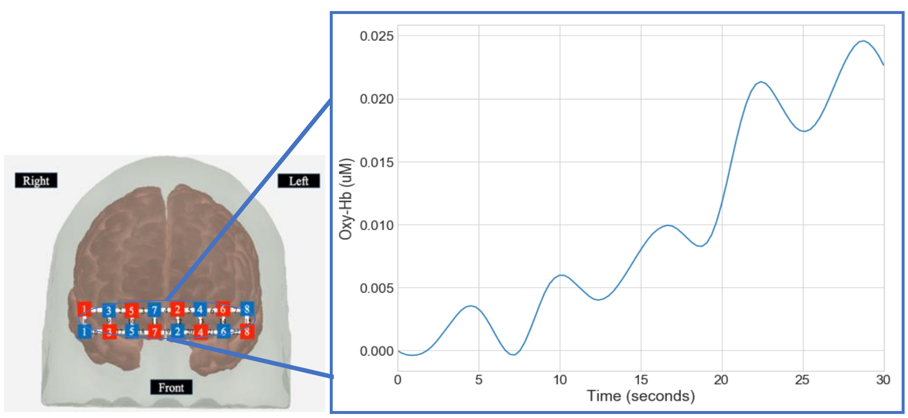

Figure 5. Average oxy-Hb in Prefrontal Cortex when Reading Five Non-Traditional Safety Messages.

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 ($p<0.05$). An explanation for this increase in oxy-Hb when viewing messages about distracted driving might be that these messages increase cognitive attention among participants more than other types of messages. The results suggest that oxy-Hb increases significantly for messages about distracted driving regardless of the associated emotion or theme. Driving without a seat belt has the smallest peak activation compared to the intent of other messages. The average peak oxy-Hb for each behavior is illustrated in Figure 6.

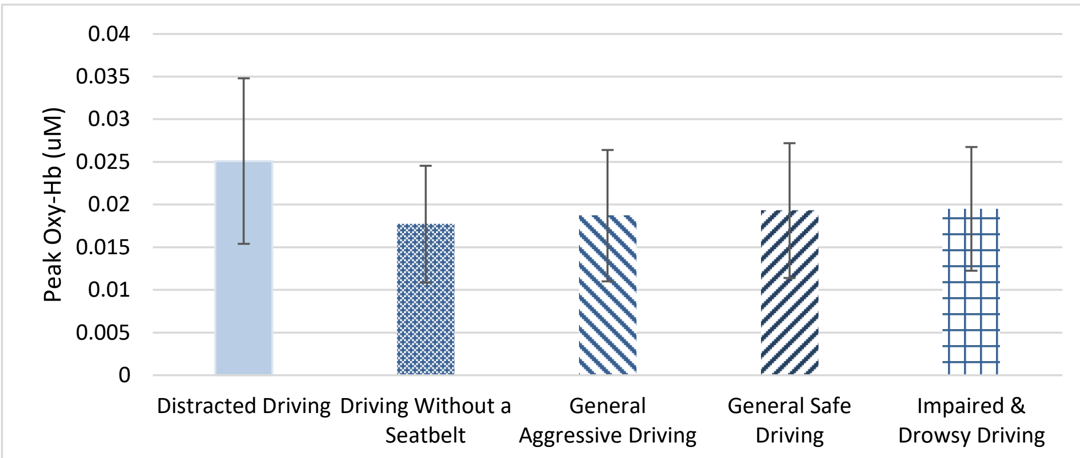

Figure 6. Average Peak oxy-Hb for Messages Grouped by the Intended Behavior Change.

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 ($M=0.039$ µM) and is significantly greater than emotionless ($M=0.034$ µM, $p < 0.05$) and negative messages ($M=0.034$ µM, $p < 0.05$). The increase in peak oxy-Hb for humorous messages compared to messages with negative or no intended emotional response might suggest humor increases drivers’ engagement, or their attention, with these types of messages. The mean response and standard deviation are illustrated in Figure 7.

Figure 7. Average Peak oxy-Hb for Messages Grouped by the Intended Emotional Response.

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 (M = 0.020 µM) compared to all other themes. One interpretation is messages that use word play demand more cognitive engagement or attention than other types of messages. More engagement, however, does not correspond with comprehension. Messages about word play were equally understood compared to other types of messages. Messages with sayings produced the smallest peak oxy-Hb (M = 0.005 µM) compared to all other messages. The peak oxy-Hb for each theme is presented in Figure 8.

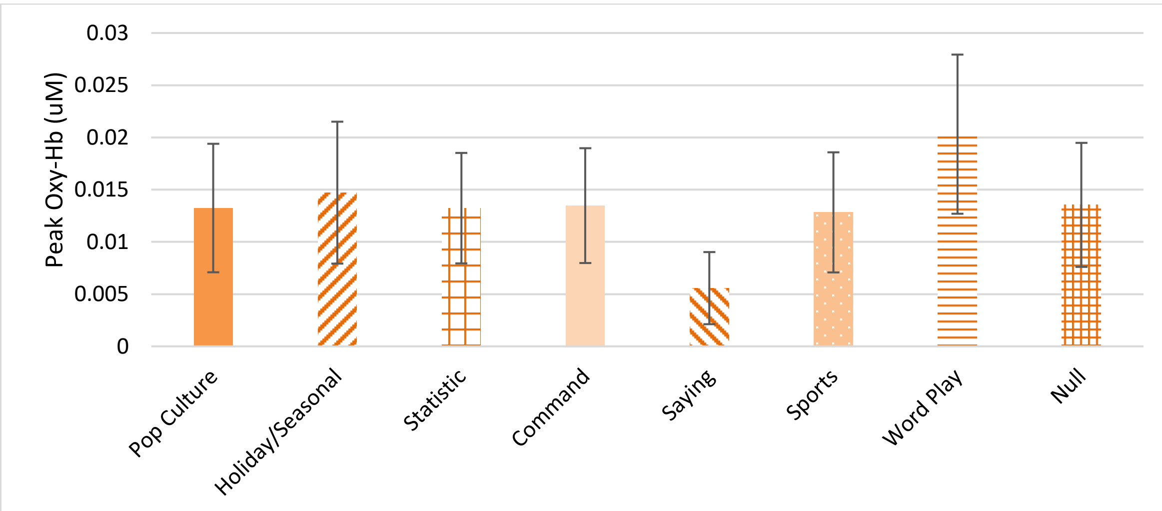

Figure 8. Average Peak oxy-Hb for Messages Grouped by Theme.

How does neurocognitive activation vary by gender, age, risky driving behavior, driving environment (urban, rural, suburban), and racial group?

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 µM, SD = 0.0152 µM) compared to females (M= 0.0176 µM, SD =0.0165 µM). 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 µM, SD = 0.0186, Cohen's d = 0.2) and medium (M = 0.0211 µM, 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 µM, SD = 0.0137) risk scores, but again the effect size is small between the groups. 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 µM) and males over 65 (M= 0.0237 µM) 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. Racial group is also not a significant factor ($F = 1.55$, $p=0.19$) for how participants express cognitive attention or engagement with messages. Drivers from varying racial groups cognitively respond to messages with a similar level of oxy-Hb.

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 μM, SD = 0.00829) and right vlPFC (M=0.0123 μM, 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 and Pan, 2007), and semantic processing (Nozari and 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, and Boggio, 2018) and semantics (Nozari and Thompson-Schill, 2016). The average peak oxy-Hb for each subregion in the PFC is illustrated in Figure 9.

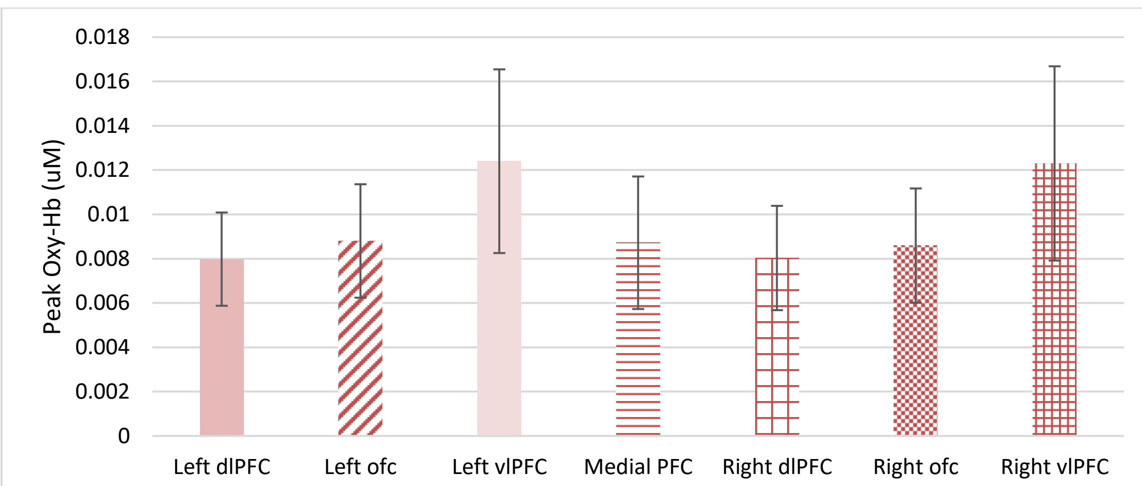

Figure 9. Average Peak oxy-Hb for Subregions within the Prefrontal Cortex.

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 about distracted driving is significantly higher in the left vlPFC ($F = 5$, M=0.0966 μM, $p<0.001$) and right vlPFC ($F = 4.19$, M=0.0957 μM, $p=0.002$) 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. This difference in peak oxy-Hb in each sub-region for themes is illustrated in Figures 10 and 11.

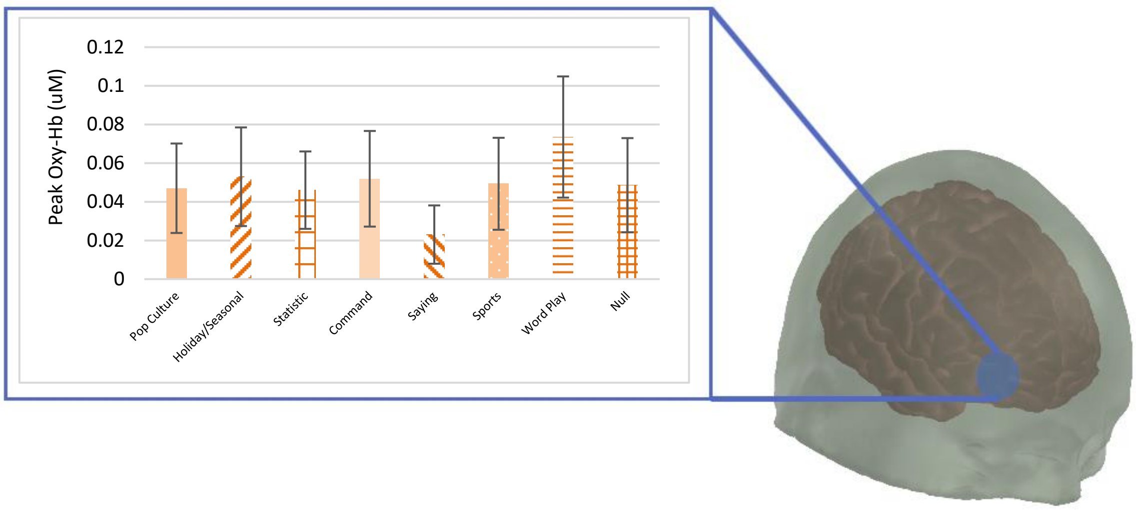

Figure 10. Average Peak oxy-Hb in the Right vlPFC for Themes.

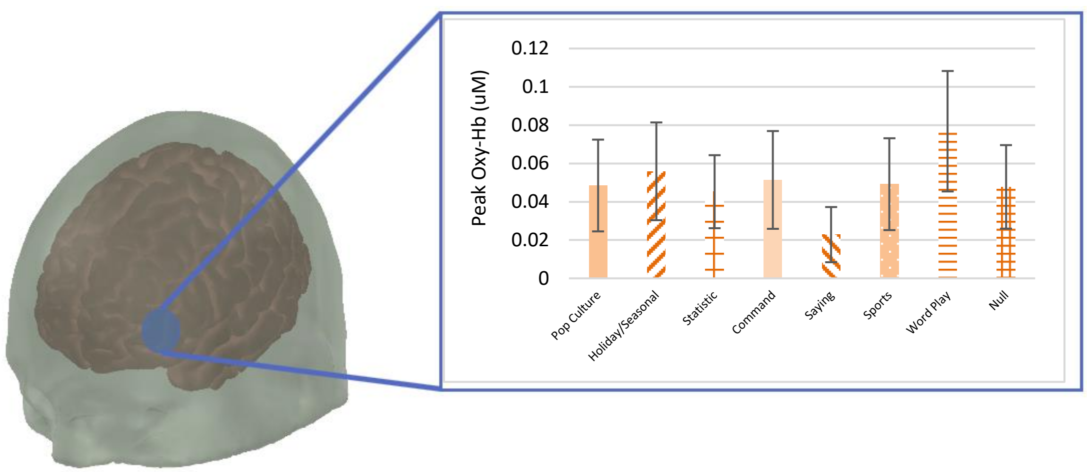

Figure 11. Average Peak oxy-Hb in the Left vlPFC for Themes.

To summarize the findings about subregions, the greatest activation occurs in the left and right vlPFC compared to other subregions. The vlPFC is generally described for its help with emotional control (He et al., 2018; Marques et al., 2018) and semantics (i.e. word processing) (Nozari and Thompson-Schill, 2016). An increase in activation in this region suggests an increase in emotional control or increased effort in word processing. Messages about distracted driving, messages that use humor, and messages that include word play or rhymes produce the largest peak response among participants in this subregion of the PFC. When comparing between the left and right vlPFC, the percent increase in activation is greatest in the left vlPFC compared to the right vlPFC for messages that include word play and rhymes. The left vlPFC is generally more closely associated with supporting controlled access to stored conceptual representations (Badre and Wagner, 2007) and processing of words and sentences (Nozari and Thompson-Schill,

2016) and the right vlPFC is generally more closely associated with emotional control (Light et al., 2011).

How do these subregions vary by gender, age, and risky driving behavior?

Peak oxy-Hb is significantly different in the left ($F= 26.1$, $p<0.0001$) and right ($F=25.5$, $p<0.0001$) vlPFC based on driver age. The younger the driver the greater the peak oxy-Hb in the left and right vlPFC. Mean peak oxy-Hb for each age group is listed in Tables 21 and 22. Drivers 18-25 and 26-40 are significantly more likely to express higher peak oxy-Hb in the left and right vlPFC 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 vlPFC 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 21. Peak oxy-Hb between Age Groups in the Left vlPFC

Age	Mean Peak oxy-Hb	Standard Deviation	p_{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 22. Peak oxy-Hb between Age Groups in the Right vlPFC

Age	Mean Peak oxy-Hb	Standard Deviation	p_{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

DISCUSSION

Messages about distracted driving, messages intended to provoke an emotional response (humor or negative emotion), and messages that include statistics or word play and rhymes are more effective than other types of messages. These messages are effective because they consistently perform well across multiple measures. For example, messages about distracted driving rank high on multiple measures of effectiveness, including 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). High peak oxy-Hb is a proxy for increased task engagement (Ferrari and Quaresima, 2012; Harrivel et al., 2013) and attention (Fishburn et al., 2014). Messages about distracted driving appear to increase task engagement and attention.

Drivers understand the intent of the messages about distracted driving. Comprehension increases when the behavior the message is intending to change is clear. Messages more broadly about general safe driving were the least correctly understood, followed by general aggressive driving. One instance that distracted driving did not perform above other types of messages was appropriateness. One of the distracted driving messages, "get your head out of your apps," was mentioned as inappropriate by 6 out of the 300 participants, or 2 percent of the sample. Messages about distracted driving and, in particular, "get your head out of your apps", are also more likely to be remembered. Thus, the multiple measures indicating effectiveness for messages about distract driving seem to outweigh the small percentage of participants who view this type of message as inappropriate.

Messages about distracted driving also significantly increase engagement and attention. This is consistent regardless of the associated emotion or theme. Observations during data collection provide a possible explanation for the observed increase in attention to messages about distracted driving. 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.

In addition to messages about distracted driving, messages meant to provoke humor led to high levels of peak oxy-Hb in the PFC compared to messages with a negative emotion or no emotion. This is consistent with prior studies that suggest humor elicits a distinct cognitive response (X. Hu et al., 2019), commands more attention (Costa et al., 2019), and leads to peak cognitive response faster than negative arousal messages (Walker and Trick, 2019). Message that use humor also hold a greater effect on behavior change compared to messages intended to provoke no emotional response (Chan and Singhal, 2013). Viewing humorous messages seems to change behavior indirectly by altering attentional effects on driving (Steinhauser et al., 2018). A drop in oxy-Hb corresponds with a drop in performance, potentially from disengaging from the task (Bunce et al., 2011), and the inverse is likely true in this study where an increase in peak oxy-Hb represents an increase in task engagement.

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 neuro-cognitive data identifies word play and rhymes as significantly more likely to increase attention. Messages with statistics also performed well in recall. The corresponding emotion in both blocks displaying statistics was negative. These messages generally displayed facts about death and crash rates. Harsh and threatening messages tend to be perceived as more effective (Cauberghe et al., 2009; Glendon et al., 2018; Lewis et al., 2010). From a Protection Motivation Theory perspective, a negative emotional response can be effective in communicating a safety campaign, particularly because it is considered an informative tactic to provide drivers with factual information (Dun and Ali, 2018). And the results here about statistics and negative emotions being recalled more frequently corresponds to prior literature that finds negative messages are more freely recalled (Walker and Trick, 2019).

Subregion in Prefrontal Cortex

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 vlPFC. The significant difference in peak oxy-Hb in the left and right vlPFC is likely contributing the significant difference observed in the whole PFC. The left and right vlPFC is involved in word processing (Nozari and 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 vlPFC compared to other regions is messages with humor require more emotional control (Weintraub-Brevda and Chua, 2018). The right lateral vlPFC 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 vlPFC is generally more associated with supporting controlled access to stored conceptual representations (Badre and Wagner, 2007) and processing of words and sentences (Nozari and Thompson-Schill, 2016).

The use of the neuroimaging technique and the identification of greater activation across the PFC and, more specifically, in the vlPFC 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, Takahashi, Sugimachi, and Suda, 2018). Here, the results, specifically in the vlPFC, begin to suggest an increase in emotional control and semantic processing when viewing messages that include humor and word play and rhyme. This increase in activation is perceived as beneficial because this increase corresponds with other positive measure of effectiveness. Similarly, an increase in cognitive activation corresponded with increased performance among drivers (Shimizu et al., 2009).

Driver Characteristics

Differences in message effectiveness varies based on gender, age, racial group, 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. The differences in perceptions of effectiveness to change driver behavior between racial groups provides another layer of insight. Prior research finds black and Hispanic adolescents view substance use while driving as less hazardous than white adolescents (Ginsburg et al., 2008). Non-traditional safety messages may provide a tool to change perception and subsequent behavior. Black or African American drivers in the study presented in this report perceive non-traditional safety messages as more effective than other racial groups of drivers.

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 and Montgomery, 2007; Inman et al., 2015; Inman and Philips, 2015). Older drivers are less at risk and require longer to comprehend complicated messages (Falk and Montgomery, 2007; Inman et al., 2015; Inman and 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 (Glotzbach et al., 2011; X. Hu et al., 2019).

Representation of Messages Nationally and in Virginia

Messages that include humor only compose 32 percent of the total messages collected across the country, and just 24 percent in Virginia, yet these messages are most effective based on the results presented in this report. The least effective messages are emotionless, which make up 48.7 percent nationally and 73 percent of the messages used in Virginia. Messages about distracted driving are the most effective, yet these messages only make up a quarter of the messages nationally, and just 14.9 percent in Virginia. Messages about word play and rhymes make up about 17 percent of the total messages nationally and 18.1 of messages in Virginia. Messages about statistics also rank high on several measures of effectiveness but make up just 5 percent of total messages nationally and 4.7 percent in Virginia.

Currently, messages that include holiday and seasonal themes are the most abundant message type across the country. The most abundant message themes in Virginia are messages without a theme. Messages that include holiday and seasonal themes are more likely to include humor than negative or an emotionless tone. However, messages that include holiday and seasonal themes do not rank high in any measure of effectiveness. Similarly, messages without a theme do not consistently rank high in multiple measures of effectiveness. Messages with pop culture, sports, commands, and sayings did not rank high in multiple measures of effectiveness. Messages about sports may contribute to miscomprehension. More than 10 percent of participants did not correctly interpret the intent of the message when sports themes were included.

Limitations

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 how messages are interpreted. However, this is a limiting factor with all neuroimaging studies that do not capture whole head differences (Ferrari and 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 measures of effectiveness do not include actual behavior change or any measures of distractedness. 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. Increased task engagement and attention measured from the increase in oxy-Hb were assumed to be positive indicators of effectiveness because the purpose is for drivers to read and respond. Future research could test how these indictors for effectiveness correspond with actual behavior change through field trials and how these measures of effectiveness relate to distractedness. Although, field trails 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 and 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 effect 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.

CONCLUSIONS

- *Non-traditional messages from across the country cover a broad range of topics including, driving without a seatbelt (23 percent), distracted driving (22.4 percent), safe driving (21.6 percent), impaired and drowsy driving (18.8 percent), and aggressive driving (14 percent). Nationally, about half of these messages are meant to provoke humor (32 percent) or a negative emotional response (19.3 percent). Messages meant to provoke humor or a negative emotional response previously used in Virginia make up just 27 percent of non-traditional safety messages. Nearly a quarter of messages nationally include a holiday or seasonal theme. In Virginia, the most abundant group of messages includes no theme.* A library of these non-traditional safety messages was created.

- *Participants in the study believe these non-traditional safety messages are effective at changing driver behavior*. Although, some messages are perceived as more effective than others. Messages about distracted driving, driving without a seat belt, and impaired or drowsy driving are perceived as the most effective at changing behavior. Messages meant to provoke emotional arousal, either with humor or a negative emotion (i.e., fear, threat, sadness), are perceived by participants as more effective at changing driver behavior than messages without an emotional appeal. Messages that use statistics (e.g., the number of deaths on the roadway this year) are perceived by participants to be the most effective at changing driver behavior. Messages that use word play and rhyme are perceived by participants to be effective at changing driver behavior. Differences about perception do vary by gender, age, risky driving behavior, and driving environment (i.e., urban, rural, suburban) but the differences are small.

- *Non-traditional safety messages are perceived as appropriate and perceived as effective across the state of Virginia.* Urban, suburban, and rural drivers all perceive non-traditional safety messages will change driver behavior. There is no difference in how drivers cognitively process messages based on their urban, suburban, or rural driving environment.

- *Messages about distracted driving, drinking and driving, and messages that include statistics are most memorable compared to other message intents and themes. Females are more likely to remember messages about distracted driving, and males are more likely to remember messages about drinking and driving.*

- *Inappropriateness of messages is not a concern for most participants.* Nine out of ten drivers who participated in the study did not find a single message to be inappropriate. If inappropriateness is a concern for message creators, some suggestions are to not develop messages that single out groups of people, e.g., people of Irish descent. Several participants (6 out of 300) commented that "Get your head out of your apps" was inappropriate because of what it was "suggesting" another word with "apps." However, the results from this research suggest this type of message (about distracted driving, includes humor, and world play) is effective, both in its perceived effectiveness among drivers and effectiveness in its ability to command a high level of cognitive attention.

- *The more specific the intended behavior change, the more likely drivers comprehend the intent of the message.* For example, only about 3 percent of drivers who participated incorrectly understood the intent of messages about seat belt use, but nearly 25 percent did not fully comprehend the intent of messages about general safe driving. Education and English as a second language are factors in comprehension. Drivers with an eighth-grade education or less are about 20 percent more likely to not understand the intent of messages compared to drivers with some level of higher education. Drivers whose first language is not English are about 5 percent more likely to incorrectly comprehend the messages.

- *Messages about distracted driving, messages than include humor, and messages that use word play or rhyme command the most cognitive attention or engagement compared to other types of messages.* Activation in the prefrontal cortex is greatest in an area called the ventrolateral prefrontal cortex (vlPFC). This region is associated with emotional response to stimuli (Aron et al., 2004) and word processing (Nozari and Thompson-Schill, 2016). One explanation is these messages provoke an emotional response and this is observed by this increase in activation. In addition, word play and rhymes likely required more advanced word processing than other message themes. The increase in activation in the vlPFC is an indicator of this increased task engagement. The younger the driver, the greater increase in task engagement in this region of the brain, with a medium effect size.

- *The results provided in this report offer 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 non-traditional safety 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.

- *Specific groups of people perceive non-traditional safety messages as more effective and command a high level of cognitive attention.* Black or African American drivers and drivers from urban or rural driving environments perceive messages are more effective at changing driver behavior than other racial groups and suburban drivers. Younger (18-25) drivers and males elicit more cognitive attention with messages than other types of drivers. While difference by gender and age are significant, the differences have a small to medium effect. Drivers of all types are influenced by messages about distracted driving, humor, and word play and rhymes, but younger drivers and males are influenced slightly more than others.

RECOMMENDATIONS

1. *VDOT Operations Division, Communications Division, and Traffic Engineering Division should consider the following as they develop new non-traditional safety messages:*
    a. *Distracted driving messages should represent a high proportion of non-traditional safety messages.* These only represent 22 percent of the total messages nationally and just 14.9 percent in Virginia. Drivers perceive these messages as one of the most likely to change driver behavior, and these messages elicit the highest observed levels of cognitive activation among drivers. Messages about distracted driving are also the most frequent types of messages recalled by participants. Messages about distracted driving, in all of the data collection methods, elicit the intended response: high perceived effectiveness, comprehended by most drivers, the most frequent recall, and elicit the highest cognitive attention.

    b. *Messages should address a specific behavior change (e.g., wearing a seat belt, not driving impaired).* The more specific the intent, the more likely the message will be correctly understood by drivers. General messages about aggressive driving and general safe driving were the least effective at increasing cognitive attention and in their perceived effectiveness among drivers. Messages about general safe driving are the most abundant group of messages in Virginia.

    c. *A larger portion of messages should evoke an emotional response.* Messages that provoke humor or a negative emotional response outperform emotionless messages in both drivers' perceptions of effectiveness and in the cognitive attention that these messages provoke in drivers. Emotionless messages make up nearly half of the database of messages nationally but are the least effective. Emotionless messages make up 73 percent of the messages in Virginia. More humor and negative emotional messages need to be created and used.

    d. *Messages should use word play, rhyming, or statistics where possible.* Drivers cognitively attend to messages that use word play and rhyming more than other types of themes of messages, like sports, sayings, or pop culture. Word play and rhymes only make up 17 percent of messages nationally and 18 percent in

Virginia. More of these types of messages need to be created and used. Statistics are perceived as effective in changing behavior and are the most recalled among participants. Messages with statistics only make up 5 percent of the messages nationally and 4.7 percent in Virginia. Creating more of these messages should be considered because drivers perceive them as effective, and these types of messages align with prior literature on effectiveness.

e. *Messages should avoid sports.* Messages that mentioned sports were slightly less understood (by about 10 percent of participants) compared to other message themes.

IMPLEMENTATION AND BENEFITS

Implementation

With regard to the recommendation, the committee developing new innovative safety messages will begin immediately using the findings of this report to focus the development and section of new safety messages. In coordination with implementation, the research team will partner with the VDOT Communications Division to develop a communications plan for the release of the final report and its findings.

Benefits

With regards to the recommendation, the benefits of implementing the recommendation is the increased effectiveness of safety campaigns intended to create behavioral change. The research provides empirical evidence of effectiveness for specific types of messages compared to other messages. Non-traditional safety messages about distracted driving increase cognitive response among drivers by more than 30 percent compared to the other types of non-traditional safety messages. Non-traditional safety messages that include humor increase cognitive response by nearly 20 percent compared to emotionless messages and non-traditional safety messages that include word play and rhymes increase cognitive attention by nearly 65 percent compared to the other types of non-traditional safety message themes. While it is impossible to directly translate these improvements into crash reductions, implementing specific non-traditional safety messages and using these recommendations during the design of new messages should positively influence driving behavior. Furthermore, use of these messages will also help contribute to further building the safety culture on Virginia's roads.

ACKNOWLEDGMENTS

The authors express their gratitude to the study's technical review panel for their input: Daniel Taylor (Operations Division), Mark Cole (Traffic Engineering Division), Stephen Read (Traffic Engineering Division), Lindsay LeGrand (Communications Division), Chris McDonald (Southwest Region Operations), Noah Goodall (Virginia Transportation Research Council), and Ben Cottrell (Virginia Transportation Research Council).

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APPENDIX A: MESSAGES

Table A-1. List of Empirically Tested Messages in Phase II of the Research

Behavior	Emotion	Theme	Messages
General Safe Driving	Emotionless	Pop Culture	NOBODY PUTS BABY IN A HOT CAR
			DON'T YOU FORGET ABOUT ME AS YOU DRIVE ON BY
			LIFE IS A HIGHWAY DRIVE SAFELY ALL DAY LONG
			BE OUR GUEST DRIVE POLITELY
			DRIVING SAFELY? I LIKE IT I LOVE IT
	Humor	Holiday/Seasonal	BE ON SANTA'S NICE LIST DRIVE POLITELY
			WHAT'S SCARIER YOUR COSTUME OR YOUR DRIVING?
			BE A FIREWORK SPARK RESPONSIBLE DRIVING
			ZERO FATALITIES A GHOUL WE CAN ALL LIVE WITH
			SANTA'S COMING HAVE YOU BEEN A GOOD DRIVER?
	Negative	Statistic	843 VA FATALITIES THIS YEAR DRIVE SAFELY
			375 MILLION US VEHICLE INJURIES IN 2017
			843 TRAFFIC DEATHS IN VIRGINIA THIS YEAR DRIVE ALERT
			757 FATALITIES SONS, DAUGHTERS. STOP THE HEARTACHE
			843 FATALITIES ON VIRGINIA ROADS IN 2018

Behavior	Emotion	Theme	Messages
Driving Without a Seat Belt	Emotionless	Command	PROTECT YOURSELF BUCKLE UP
			SECURE THE FUTURE BUCKLE YOUR CHILD
			DON'T LEAP FROM YOUR SEAT BUCKLE UP
			SEE YOUR BFF TONIGHT BUCKLE UP
			BUCKLE UP SAVE $25 AND YOUR LIFE
	Humor	Saying	DON'T MAKE ME STOP THIS CAR! BUCKLE UP
			DUCK, DUCK, BUCKLE UP
			AWWWWW SNAP! YOUR SEAT BELT!
			BUCKLE UP AND SMELL THE ROSES
			PEACE LOVE SEATBELTS BUCKLE UP!
	Negative	Statistic	72 WERE UNBUCKLED
			9 OF 17 FATALITIES UNBUCKLED THIS YEAR
			153 ROAD DEATHS IN VA THIS YEAR 66% UNBUCKLED
			37% FATALITIES WERE NOT WEARING SEATBELTS
			60% OF TEEN ROAD DEATHS IN VIRGINIA ARE UNBUCKLED

Behavior	Emotion	Theme	Messages
Distracted Driving	Emotionless	Sports	GOLD MEDAL DRIVERS DON'T TEXT AND DRIVE
			MAKE IT TO THE END ZONE DRIVE ALERT
			DON'T LET SAFETY BE A HAIL MARY DRIVE ALERT
			PLAY BALL! STRIKE THE DISTRACTIONS
			BLOW THE WHISTLE ON DISTRACTED DRIVING
	Humor	Word Play and Rhyme	GET YOUR HEAD OUT OF YOUR APPS
			TEXTING WHILE DRIVING? OH CELL NO.
			DON'T DRIVE IN-TEXT-ICATED
			AVOID AN APPSIDENT PHONES DOWN
			TEXTING & DRIVING IS CLEVER SAID NO ONE EVER
	Humor	Pop Culture	WHO YA GONNA CALL? NOBODY YOU'RE DRIVING
			YOU HAD ME AT "I DON'T TEXT AND DRIVE!"
			THE FORCE IS STRONG WHEN YOU PUT DOWN THE PHONE
			EDDIE SAYS DON'T TEXT & DRIVE THE TWITTERS FULL
			WE PITY THE FOOL WHO TEXTS & DRIVES
	Negative	No Theme	NO TEXT IS WORTH A LIFE
			MOM NEEDS YOUR HUG NOT YOUR TEXT
			YOUR PHONE OR YOUR LIFE? YOUR CHOICE
			ONE TEXT CAN END IT ALL
			IS YOUR TEXT WORTH THE RISK?

Behavior	Emotion	Theme	Messages
Impaired and Drowsy Driving	Emotionless	Word Play and Rhyme	DON'T SNOOZE WHILE YOU CRUISE
			BE ALERT ARRIVE UNHURT
			DROWSY DRIVING IS LOUSY DRIVING
			WE'VE GOT A FEVER THE ONLY CURE IS SOBER DRIVERS
			DRINKING AND DRIVING DON'T MIX
	Humor	Holiday/Seasonal	YOU'RE NOT A FIREWORK DON'T DRIVE LIT
			LUCK OF THE IRISH WON'T HELP IF YOU DRIVE DRUNK
			A DUI WILL EMPTY THE POT O GOLD DRIVE SOBER
			DESIGNATED DRIVERS MAKE THE BEST NEW YEAR'S DATES
			DON'T BE TRICKED DUIS ARE NO TREAT
	Negative	Word Play and Rhyme	BLOWING .08 IS LIKE BLOWING $10,000
			JUST BUZZED? NICE TRY, THAT'S A DUI
			DRIVE HAMMERED GET NAILED
			DON'T LET YOUR TAILGATE END WITH A CELLMATE
			DRINKING AND DRIVING A GRAVE MISTAKE

Behavior	Emotion	Theme	Messages
General Aggressive Driving	Emotionless	Sports	SPEEDING IS UNSPORTSMANLIKE CONDUCT
			MARCH MADNESS? KEEP AGGRESSION ON THE COURT
			NO SHOT CLOCK DRIVING A CAR SLOW DOWN
			KEEP RIVALRIES OFF THE ROAD DRIVE CALM
			COMMUTING ISN'T A COMPETITIVE SPORT RELAX
	Humor	No Theme	I THINK WE NEED SOME SPACE ONE DRIVER TO ANOTHER
			IT'S OK TO BE A SLOW POKE
			IT'S A SPEED LIMIT NOT SPEED SUGGESTION
			SPEEDING CAN LEAD TO SKID MARKS
			THAT'S THE TEMPERATURE NOT THE SPEED LIMIT
	Negative	Command	DO NOT TELL A LIE OBEY THE LIMIT
			SPEED KILLS SLOW DOWN
			KEEP YOUR DISTANCE SAVE A LIFE
			LEAVE SOME SPACE SURVIVE THE DRIVE
			DON'T BE NEXT KEEP YOUR DISTANCE

APPENDIX B: POST-TASK SURVEY

Safety Campaigns

1. Given the following list of driving behavior, rank the importance of changing the behavior. (1 = lowest, 5 = highest)

___ Not wearing seat belts
___ Speeding
___ Texting and driving
___ Drinking and driving
___ Drowsy driving

2. From the list of messages you saw today, which message(s) were the most memorable and why?
<open ended>

3. Did you think that any of the messages today were inappropriate?
Yes
No
<If yes, provide list of messages to select from>

Risk Aversion

How often do you do the following behaviors?
4. Wear your seat belt while driving?
Never
Rarely
Sometimes
Often
Always

5. Drive greater than 15 mph over the speed limit?
Never
Rarely
Sometimes
Often
Always

6. Text while driving?
Never
Rarely
Sometimes
Often
Always

7. Follow another car too closely?
Never
Rarely
Sometimes
Often
Always

8. Merge quickly in front of other drivers?
Never

Rarely
Sometimes
Often
Always

9. Use a cell phone for navigation while driving?
Never
Rarely
Sometimes
Often
Always

10. Drive within one hour of having one or more alcoholic beverage?
Never
Rarely
Sometimes
Often
Always

How much do you agree or disagree with the following statement:
Virginia Department of Transportation makes an effort to improve highway safety.
Strongly agree
Agree
Neutral
Disagree
Strongly disagree

<u>Demographics</u>
11. What is your gender?
Male
Female
Prefer not to say

12. What is your age?
18-25
26-40
41-65
over 65

13. What is your highest level of education?
Eighth grade or less
High school diploma
Associate's degree
Bachelor's degree
Graduate degree

14. What is your ethnicity?
White
Hispanic or Latino
Black or African American
Native American or American Indian

Asian / Pacific Islander
Other

15. Is English your first language?
Yes
No

16. Are you a Virginia resident?
Yes
No

17. Where do you do *most* of your driving?
Rural
Suburban
Urban

Hobbies
18. How frequently do you follow sports?
Never
Once per month
Once per week
Daily

Family Life
19. Are there children living in your household?
Yes
No

20. If any of these children are over 16, do they have a driver's license?
Yes
No

21. During the past 3 years, has a member of your family been involved in a collision that required a police presence?
Yes
No