

## A. COVER PAGE

<b>Project Title:</b> Coordination of Vehicle Lighting and Markings for Improved Worker Safety	
<b>Grant Number:</b> 5R21OH012465-02	<b>Project/Grant Period:</b> 11/01/2021 - 10/31/2023
<b>Reporting Period:</b> 11/01/2022 - 10/31/2023	<b>Requested Budget Period:</b> 11/01/2022 - 10/31/2023
<b>Report Term Frequency:</b> Final	<b>Date Submitted:</b> 02/01/2024
<b>Program Director/Principal Investigator Information:</b> MARK S REA , PHD  <b>Phone Number:</b> 518-366-3918 <b>Email:</b> Mark.Rea@mountsinai.org	<b>Recipient Organization:</b> ICAHN SCHOOL OF MEDICINE AT MOUNT SINAI ICAHN SCHOOL OF MEDICINE AT MOUNT SINAI 1 GUSTAVE L. LEVY PL NEW YORK, NY 100296574  <b>DUNS:</b> 078861598 <b>UEI:</b> C8H9CNG1VBD9 <b>EIN:</b> 1136171197A1  <b>RECIPIENT ID:</b>
<b>Change of Contact PD/PI:</b> NA	
<b>Administrative Official:</b> AMANDA AMESCUA One Gustave L. Levy Place, Box 1075 New York, NY 100296574  <b>Phone number:</b> 646-605-8659 <b>Email:</b> amanda.amescua@mssm.edu	<b>Signing Official:</b> AMANDA AMESCUA One Gustave L. Levy Place, Box 1075 New York, NY 100296574  <b>Phone number:</b> 646-605-8659 <b>Email:</b> amanda.amescua@mssm.edu
<b>Human Subjects:</b> NA	<b>Vertebrate Animals:</b> NA
<b>hESC:</b> No	<b>Inventions/Patents:</b> No

## B. ACCOMPLISHMENTS

### B.1 WHAT ARE THE MAJOR GOALS OF THE PROJECT?

1: We examined the main effects and interactions among warning light color and intensity, and the color of vehicles and their retroreflective markings on driver response and decision-making accuracy. The goal was to determine the importance of having perceptually grouped color schemes for warning lights, vehicles and markings on service vehicles.

2: We examined the main effects and interactions among color-consistent and color-inconsistent warning lights with groups of vehicles on driver response. The goal was to determine if the ability of approaching drivers to anticipate an emergency or non-emergency situation was influenced by enhancing or reinforcing the flashing of warning lights by increasing the flash frequency and overall intensity of emergency lights (e.g., red lights) and decreasing them for non-emergency lights (e.g., yellow lights).

3: The final goal was to confirm our conclusions about perceptual grouping from the previous laboratory studies. The findings of previous laboratory-based tasks in this project were validated in a full-scale field study at a closed test track.

#### B.1.a Have the major goals changed since the initial competing award or previous report?

No

### B.2 WHAT WAS ACCOMPLISHED UNDER THESE GOALS?

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### B.3 COMPETITIVE REVISIONS/ADMINISTRATIVE SUPPLEMENTS

**For this reporting period, is there one or more Revision/Supplement associated with this award for which reporting is required?**

No

### B.4 WHAT OPPORTUNITIES FOR TRAINING AND PROFESSIONAL DEVELOPMENT HAS THE PROJECT PROVIDED?

NOTHING TO REPORT

### B.5 HOW HAVE THE RESULTS BEEN DISSEMINATED TO COMMUNITIES OF INTEREST?

Research team members made the following outreach presentations based on project findings to groups that would not typically be aware of our research:

"Warning lights and vehicle markings: AIMing for improved safety" for Transportation Research Board 103rd Annual Meeting, Washington, DC, January 9, 2024.

"Blinded by the lights? Impacts of emergency vehicle lighting on first responder safety" for the New York State Traffic Incident Management Symposium, Oriskany, NY, July 23, 2023.

"Impacts of emergency vehicle lighting and markings on responder safety" for the Transportation Research Board Emergency Responder Transportation Safety Research Summit, Piscataway, NJ, November 1, 2023.

"Recent research on emergency vehicle lighting and safety" for Road Insights: Trends in Emergency Lighting - CARFAX for Police, Centreville, VA, May 16, 2023.

"Effects of emergency vehicle lighting characteristics on driver perception and behavior" for the Texas Department of

Transportation Bi-Monthly Statewide Traffic Incident Management Webinar, Austin, TX, April 20, 2022.  
"Impacts of emergency vehicle lighting on first responder safety" for the Annual Thomas F. With Fire Police Training and Education Seminar, Mountour Falls, NY, March 19, 2022.

Videos featuring project results have also been disseminated via Youtube:

"Safety First, Making Driving Less Lethal" - <https://www.youtube.com/watch?v=h4-KCFjceHs>

"Proceed with Caution: Lighting for Emergency Vehicle Responder Safety" - <https://www.youtube.com/watch?v=5L-Pz-B4KcM>

**B.6 WHAT DO YOU PLAN TO DO DURING THE NEXT REPORTING PERIOD TO ACCOMPLISH THE GOALS?**

Not Applicable

### Accomplishments Summary Report

NIOSH R21 OH01245 - Coordination of Vehicle Lighting and Markings for Improved Worker Safety

PI: Mark Rea, Icahn School of Medicine at Mount Sinai

January 23, 2024

#### Specific Objectives

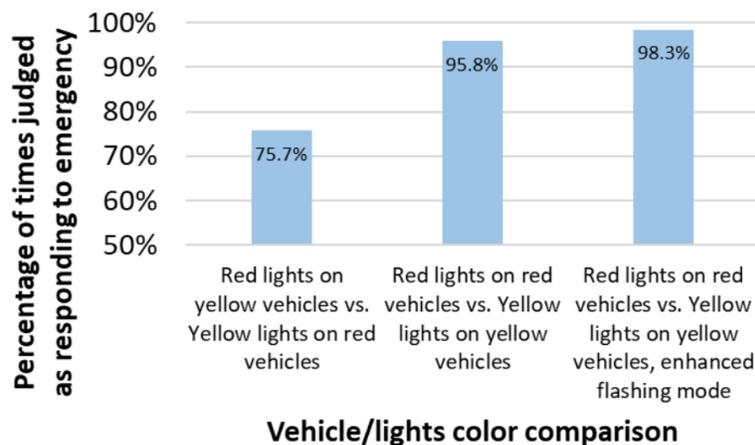
The overall objective of this project is to understand how flashing warning lights, vehicle colors, and vehicle marking colors can be deployed in such a way that drivers approaching service vehicles will be quickly and consistently informed about the type and nature of roadside scenarios. Armed with this information they will be able to execute driving maneuvers that reduce the chances of workers and their vehicles being struck by approaching traffic.

1. We examined the effects of warning light colors, and the colors of vehicles and their markings, on driver response and decision-making accuracy. The goal was to determine if coordinating these colors would assist drivers in identifying emergency versus non-emergency situations along the roadway.
2. We examined the effects of reinforcing warning light and vehicle/marking colors with changes in flash rates and intensity on driver response. The goal was to determine if such reinforcing would result in drivers being more willing to slow down or stop when approaching a service vehicle and nearby workers.
3. The findings from the previous objectives, investigated in laboratory studies, were verified in a full-scale field study at a closed test track. The goal was to validate findings about perceptual grouping under more realistic driving conditions.

#### Major Activities

In an initial scale model laboratory pilot study with a limited number of subjects (n=10), red- (representing emergency) and yellow- (representing non-emergency) colored/marked vehicles were fitted with red and yellow flashing lights and viewed along a simulated roadway scene. Colors of vehicles/markings and their lights sometimes matched, and sometimes did not. Many subjects identified the use of red flashing lights as an emergency scenario, and some were more likely to identify red vehicles as an emergency. Coordinating the colors of vehicles and lights, and further, reinforcing the coordination by flashing red lights brighter and faster than yellow lights, increased unanimity among the responses.

This study was followed by an online survey in which a larger number of participants (n=118) viewed video clips of the scale model roadway scenes and responded whether scenes identified an emergency or non-emergency scenario. The color of flashing lights was the primary cue for participants' judgments, followed by the vehicle and marking colors and with only a very small incremental effect of reinforcing the flashing of red lights by making them flash brighter and faster (see Figure below).



To understand the impacts on vehicle/marking and flashing light colors on driver behavior, a third laboratory experiment was conducted to assess the responses of participants (n=25) on whether they would be more likely to proceed or to slow down and prepare to stop in response to red or yellow vehicles equipped with red or yellow flashing lights, with similar intensity and flash rate or with the flash rate and intensity of red lights increased relative to yellow to reinforce emergency perceptions. The presence of flashing red lights was again the primary cue for participants to slow down and prepare to stop, with vehicle color and the brightness/speed of flashing having decreased importance.

Finally, the results of these laboratory investigations were carried out in cooperation with team members from Pennsylvania State University to validate the findings under realistic driving conditions, using a full-scale outdoor field study along a closed test track. Red flashing lights again were the primary cue for drivers to judge whether a vehicle was part of an emergency scenario; red vehicles/markings were a secondary cue.

### Significant Results

The results have important implications for the safety of workers along the roadway near service vehicles. The colors of flashing lights should be coordinated with those of vehicles and their markings in order to inform drivers about the nature and type of situations they are approaching, so that they can begin to make appropriate driving maneuvers that will help them avoid collisions with workers and their vehicles. Such coordination increases the likelihood that drivers will make consistent decisions when driving near service vehicles equipped with flashing lights. These results further suggest that novel colors for lights and vehicles (e.g., lime-green for fire engines) is not necessarily beneficial, because of the strong association of certain colors (e.g., red) with emergency situations.

### Key Outcomes and Achievements

The project led to several peer-reviewed technical publications which have been published, or have been approved for publication and are in press, or have been submitted for publication:

- “Impacts of coordinating the colors of flashing warning lights and vehicle markings on driver perception,” *SAE Technical Paper* 2023-01-0839. Warrendale, PA: Society of Automotive Engineers, 2023. (<https://doi.org/10.4271/2023-01-0839>)
- “Lights, colors, action! The importance of consistent perceptual information on service vehicles for safe driving,” *Transportation Research Board 103rd Annual Meeting*, Washington, DC, January 7-11. Washington, DC: Transportation Research Board, 2024. (<https://annualmeeting.mytrb.org/OnlineProgram/Details/21278>)
- “Responses to flashing warning lights and colors of service vehicles,” *SAE Technical Paper* 2024-01-2229. Warrendale, PA: Society of Automotive Engineers, 2024. (<https://doi.org/10.4271/2024-01-2229>)
- “Consistency in subjective judgments of service vehicle type based upon vehicle and flashing light colors,” submitted to *Transportation Research Record*, 2024.

Project results were shared in several presentations and online videos as follows:

- “Safety first: Making lighting less lethal,” National Lighting Bureau, 2022. (<https://www.youtube.com/watch?v=h4-KCFjceHs>)
- “Proceed with caution: Lighting for emergency vehicle responder safety,” National Lighting Bureau, 2023. (<https://www.youtube.com/watch?v=5L-Pz-B4KcM>)
- “Effects of emergency vehicle lighting characteristics on driver perception and behavior,” Texas Department of Transportation Bi-Monthly Statewide Traffic Incident Management Webinar, 2022.
- “Recent vehicle lighting research,” Society of Automotive Engineers Lighting Discussion Forum, 2023.
- “Recent research on emergency vehicle lighting and safety,” Road Insights: Trends in Emergency Lighting, CARFAX for Police, 2023.
- “Impacts of emergency vehicle lighting and markings on responder safety,” Transportation Research Board Emergency Responder Transportation Safety Research Summit, 2023.
- “Warning lights and vehicle markings: AIMing for improved safety,” Transportation Research Board 103rd Annual Meeting, 2024.

### C. PRODUCTS

#### C.1 PUBLICATIONS

Are there publications or manuscripts accepted for publication in a journal or other publication (e.g., book, one-time publication, monograph) during the reporting period resulting directly from this award?

Yes

##### Publications Reported for this Reporting Period

Public Access Compliance	Citation
N/A: Not NIH Funded	Bullough JD, Skinner NP, Rea MS. Impacts of coordinating the colors of flashing warning lights and vehicle markings on driver perception. SAE Technical Papers. 2023. DOI: 10.4271/2023-01-0839.
N/A: Not NIH Funded	Bullough JD, Rea MS. Lights, colors, action! The importance of consistent perceptual information on service vehicles for safe driving. Proceedings of the Transportation Research Board Annual Meeting. 2024.

#### C.2 WEBSITE(S) OR OTHER INTERNET SITE(S)

Category	Explanation
Audio or video	<a href="https://www.youtube.com/watch?v=5L-Pz-B4KcM">https://www.youtube.com/watch?v=5L-Pz-B4KcM</a>
Audio or video	<a href="https://www.youtube.com/watch?v=h4-KCFjceHs">https://www.youtube.com/watch?v=h4-KCFjceHs</a>
Research Material	<a href="https://www.light-health.org/transportation/road-user-safety">https://www.light-health.org/transportation/road-user-safety</a>

#### C.3 TECHNOLOGIES OR TECHNIQUES

NOTHING TO REPORT

#### C.4 INVENTIONS, PATENT APPLICATIONS, AND/OR LICENSES

Have inventions, patent applications and/or licenses resulted from the award during the reporting period? No

If yes, has this information been previously provided to the PHS or to the official responsible for patent matters at the grantee organization? No

#### C.5 OTHER PRODUCTS AND RESOURCE SHARING

Category	Explanation
Research Material	<a href="https://annualmeeting.mytrb.org/OnlineProgram/Details/20989">https://annualmeeting.mytrb.org/OnlineProgram/Details/20989</a>
Research Material	<a href="https://annualmeeting.mytrb.org/OnlineProgram/Details/21278">https://annualmeeting.mytrb.org/OnlineProgram/Details/21278</a>
Research Material	<a href="https://doi.org/10.4271/2023-01-0839">https://doi.org/10.4271/2023-01-0839</a>

## D. PARTICIPANTS

### D.1 WHAT INDIVIDUALS HAVE WORKED ON THE PROJECT?

Commons ID	S/K	Name	Degree(s)	Role	Cal	Aca	Sum	Foreign Org	Country	SS
MARKREA	Y	REA, MARK S	PHD	PD/PI	1.0	0.0	0.0			NA
	N	Ohlhaus, Howard		Associate Researcher	1.0	0.0	0.0			NA
	N	Overington, Martin		Program Manager	1.5	0.0	0.0			NA
	N	Bullough, John	Ph.D.	Co-Investigator	4.0	0.0	0.0			NA
	N	Skinner, Nicholas		Senior Clinical Research Coordinator	3.5	0.0	0.0			NA

<p><b>Glossary of acronyms:</b>                  S/K - Senior/Key                  Cal - Person Months (Calendar)                  Aca - Person Months (Academic)                  Sum - Person Months (Summer)</p>	<p>Foreign Org - Foreign Organization Affiliation                  SS - Supplement Support                  RS - Reentry Supplement                  DS - Diversity Supplement                  OT - Other                  NA - Not Applicable</p>
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### D.2 PERSONNEL UPDATES

**D.2.a Level of Effort**  
 Not Applicable

**D.2.b New Senior/Key Personnel**  
 Not Applicable

**D.2.c Changes in Other Support**  
 Not Applicable

**D.2.d New Other Significant Contributors**  
 Not Applicable

**D.2.e Multi-PI (MPI) Leadership Plan**  
 Not Applicable

**E. IMPACT****E.1 WHAT IS THE IMPACT ON THE DEVELOPMENT OF HUMAN RESOURCES?**

Not Applicable

**E.2 WHAT IS THE IMPACT ON PHYSICAL, INSTITUTIONAL, OR INFORMATION RESOURCES THAT FORM INFRASTRUCTURE?**

The project resulted in laboratory apparatus consisting of a scale model roadway scene and emergency vehicles varying in color with colored flashing LED lights. This apparatus can be used to investigate future questions beyond the scope of the current R21 grant.

Project findings were shared with technical societies such as the Society of Automotive Engineers (SAE), which develops standards for emergency flashing lights, and with organizations such as the Emergency Responder Safety Institute (ERSI), which advocates for improved safety among first responders. The information from the project will support SAE standards-making activities, and ERSI educational activities.

**E.3 WHAT IS THE IMPACT ON TECHNOLOGY TRANSFER?**

Not Applicable

**E.4 WHAT DOLLAR AMOUNT OF THE AWARD'S BUDGET IS BEING SPENT IN FOREIGN COUNTRY(IES)?**

NOTHING TO REPORT

## G. SPECIAL REPORTING REQUIREMENTS SPECIAL REPORTING REQUIREMENTS

### G.1 SPECIAL NOTICE OF AWARD TERMS AND FUNDING OPPORTUNITIES ANNOUNCEMENT REPORTING REQUIREMENTS

NOTHING TO REPORT

### G.2 RESPONSIBLE CONDUCT OF RESEARCH

Not Applicable

### G.3 MENTOR'S REPORT OR SPONSOR COMMENTS

Not Applicable

### G.4 HUMAN SUBJECTS

#### G.4.a Does the project involve human subjects?

Not Applicable

#### G.4.b Inclusion Enrollment Data

File(s) uploaded:  
NIOSH CumulativeInclusionEnrollmentReport.pdf

#### G.4.c ClinicalTrials.gov

Does this project include one or more applicable clinical trials that must be registered in ClinicalTrials.gov under FDAAA?

### G.5 HUMAN SUBJECTS EDUCATION REQUIREMENT

NOT APPLICABLE

### G.6 HUMAN EMBRYONIC STEM CELLS (HESCS)

Does this project involve human embryonic stem cells (only hESC lines listed as approved in the NIH Registry may be used in NIH funded research)?

No

### G.7 VERTEBRATE ANIMALS

Not Applicable

### G.8 PROJECT/PERFORMANCE SITES

Not Applicable

**G.9 FOREIGN COMPONENT**

No foreign component

**G.10 ESTIMATED UNOBLIGATED BALANCE**

Not Applicable

**G.11 PROGRAM INCOME**

Not Applicable

**G.12 F&A COSTS**

Not Applicable

## Cumulative Inclusion Enrollment Report

This report format should NOT be used for collecting data from study participants.

**Study Title:**

**Comments:**

Racial Categories	Ethnic Categories									Total
	Not Hispanic or Latino			Hispanic or Latino			Unknown/Not Reported Ethnicity			
	Female	Male	Unknown/ Not Reported	Female	Male	Unknown/ Not Reported	Female	Male	Unknown/ Not Reported	
American Indian/ Alaska Native										
Asian										
Native Hawaiian or Other Pacific Islander										
Black or African American										
White										
More Than One Race										
Unknown or Not Reported										
<b>Total</b>										

## I. OUTCOMES

### I.1 What were the outcomes of the award?

Project: "Coordination of Vehicle Lighting and Markings for Improved Worker Safety"

Contact PI: Mark S. Rea

Organization: Light and Health Research Center, Icahn School of Medicine at Mount Sinai

Emergency responders, highway maintenance personnel, utility workers and others who work along the roadway are at increased risk for being injured or killed by vehicle traffic. The vehicles used by these workers are equipped with flashing emergency lights, special paint colors, and reflective markings to help drivers detect and identify them, and hopefully to approach these workers more safely in order to avoid collisions. This project investigated how the colors of flashing lights and of emergency and service vehicles and their markings impact drivers' ability to identify whether a roadside incident scene is an emergency or non-emergency situation.

Through a series of laboratory studies, we determined that the colors of flashing lights were more important than the colors of vehicles and markings at distinguishing an emergency situation from a non-emergency situation. People reported that they would be more likely to stop or slow down when approaching flashing red lights, for example, which they associated with an emergency situation, compared to flashing yellow lights, which they associated with a non-emergency situation. When the colors of vehicles and their markings were coordinated with the colors of flashing lights, the peoples' responses were more consistent. This demonstrates that rapid and confident judgments of whether a scene is an emergency (or not) can be reinforced by coordinated vehicle colors. When emergency lights were brighter and flashed more rapidly than non-emergency lights, peoples' judgments became even more consistent, although this effect was smaller than the color of the flashing lights or vehicle and marking color.

To learn whether our results from the laboratory studies would carry over to real-world conditions, we conducted a field study in which people drove along a course approaching vehicles varying in paint and marking colors, and in the colors, brightness and flash rate of the lights, during the daytime and the nighttime. Just as in the laboratory studies, drivers found the colors of the flashing lights (such as red versus yellow) were most important in judging whether a roadside scene was an emergency or not. Coordinating the vehicle/marking colors with the flashing light colors reinforced the consistency of the drivers' judgments, just as they did for the laboratory study participants. Increasing the brightness and speed of flashing lights made little difference in the field study, at least over the ranges employed in the field study.

Overall, the project provided important results that can be used by emergency response agencies, departments of transportation, utilities, and other organizations to provide guidelines for the selection of vehicle and marking colors and the colors of flashing lights to inform drivers of the type of situation they are approaching. Providing this information to drivers will help them approach service vehicles and workers more safely, reducing risks to those workers.