Impacts of Emergency Vehicle Marking Color, Patterns and Retroreflectivity on Safety-Related Driver Responses

Study Report

Emergency Responder Safety Institute

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Acknowledgments

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Summary

In addition to flashing lights, retroreflective markings provide important visual information to drivers about emergency vehicles and the incidents at which they are working. Based on a review of literature and a discussion among responder safety stakeholders, a field experiment to investigate the impacts of emergency vehicle marking color, retroreflectivity level and spatial patterns on drivers' ability to see emergency responders working near their vehicles was carried out. The study also examined the impacts of a wearable flashing LED light. Agencies should use materials with higher levels of retroreflectivity carefully, especially when they will be covering large areas of the surface of a vehicle. Limiting the maximum retroreflectivity level to no greater than ASTM Type III may help lessen the negative impact of bright reflective materials on drivers' ability to see emergency responders working near their vehicles. As long as the average reflectivity of different color combinations is similar to that of red and yellow reflective markings, chevron patterns with those color combinations will not make emergency responders less visible. They may, however, make a fire response vehicle less likely to be identified as a fire vehicle. Outline patterns of reflective markings on vehicles seem to perform similarly at night to full patterns covering most of the vehicle surface. The effectiveness of using high retroreflectivity materials in an outline pattern in combination with lower (or non-) retroreflectivity materials on the rest of the surface should be studied. The use of wearable flashing LED lights may make emergency responders easier to see at night, without increasing glare to approaching drivers. The ideal properties of these lights should be investigated further.

Introduction

Emergency responders are at greater risk of injury or death while working than other members of the U.S. workforce (National Occupational Research Agenda, 2019). Approximately 44% of all fatal work-related injuries among emergency responders involve motor vehicle crashes, and 25% of these incidents occur when the responder is working outside their vehicle as a pedestrian. Emergency vehicles are marked and lighted to capture the attention of drivers so that they will be aware of the emergency situation, and of the potential presence of emergency responders working near the vehicles when they are parked along the road at an emergency incident.

Standards for the performance of flashing emergency vehicle lights (Society of Automotive Engineers, 2021a, 2021b; National Fire Protection Association, 2022) specify the minimum intensity levels that lights must produce. Only fire apparatus have required specifications for the performance of vehicle markings (National Fire Protection Association, 2022). Specifically, at least 50% of the rear of fire apparatus vehicles is required to be covered with retroreflective striping, which must be either alternating red and yellow (or fluorescent yellow or fluorescent yellow-green) or alternating "different and high-contrasting colors." The stripes must be 6 inches wide and set at a slope 45º downward from the center of the vehicle rear, so that they produce an "upside-down V" pattern. Finally, the material used to create the retroreflective stripes must, at a minimum, conform to specifications published by the American Society for Testing and Materials (ASTM, 2019) for Type I materials, commonly referred to as "engineer grade" materials. These specifications stipulate the amount of light that must be reflected from the materials of a given color for different geometric viewing conditions.

While the standards for the performance of flashing emergency vehicle lights (Society of Automotive Engineers, 2021a, 2021b; National Fire Protection Association, 2022) and of retroreflective marking materials (National Fire Protection Association, 2022) specify minimum performance levels for the brightness of these elements, neither flashing lights nor reflective markings have upper limits for the maximum intensity levels they should not exceed in order to prevent glare to approaching drivers.

This is important because lights and markings should not only be able to alert drivers about the presence of an emergency vehicle, but they should also contribute to informing and managing the expectations and actions of drivers as they navigate past an incident with an emergency vehicle present. In a previous study carried out by the Emergency Responder Safety Institute (ERSI; Bullough et al., 2021), the impact of lights varying in intensity level and color on driver visibility was assessed by measuring the distance at which a simulated firefighter could be seen at night. It was found that lights meeting the minimum performance requirements resulted in slightly shorter detection distances and increased discomfort glare than when the lights were operated at a lower intensity level, although the lights were rated as nearly equally visible by the drivers.

In a different study of flashing lights on police vehicles, drivers were asked to identify the location of a simulated police officer among several vehicles with flashing lights operating either at a higher intensity level, meeting the minimum requirements for Society of Automotive Engineers (2021a, 2021b) emergency flashing lights, or a reduced level producing 60% of the higher intensity level. The response times of drivers to identify the officer's location at night was shorter when the intensity level was reduced (Bullough et al., 2022). These results are consistent with findings from previous laboratory and field studies (Rea and Bullough, 2016; Kersavage et al., 2018) showing that objects and pedestrians are more difficult to see at night when the intensity of flashing lights increases.

Of course, the minimum intensity levels for flashing lights required by the standards (Society of Automotive Engineers, 2021a, 2021b; National Fire Protection Association, 2022) help ensure that the lights will be seen during bright ambient conditions such as on a sunny day, and it is important that the lights produce these intensities during bright daytime conditions. However, the results of the studies mentioned above suggest that agencies should consider using lower intensity levels at night to avoid glare that makes responders harder to see when they are working outside their vehicles.

In the ERSI study (Bullough et al., 2021), retroreflective panels consisting of red and yellow reflective chevron markings meeting ASTM Type V (commonly referred to as "super high intensity" material) specifications (American Society for Testing and Materials, 2019) were sometimes positioned directly behind the flashing lights. When the markings were present, the detection distances to the simulated firefighter were shorter than when they were not. Although there was not a statistically significant main effect of the retroreflective markings, there was a significant interaction between the presence of the markings and the intensity level of the flashing lights (Figure 1), so that the difference in detection distances with and without the retroreflective markings was greatest when the intensity level from the lights was highest.

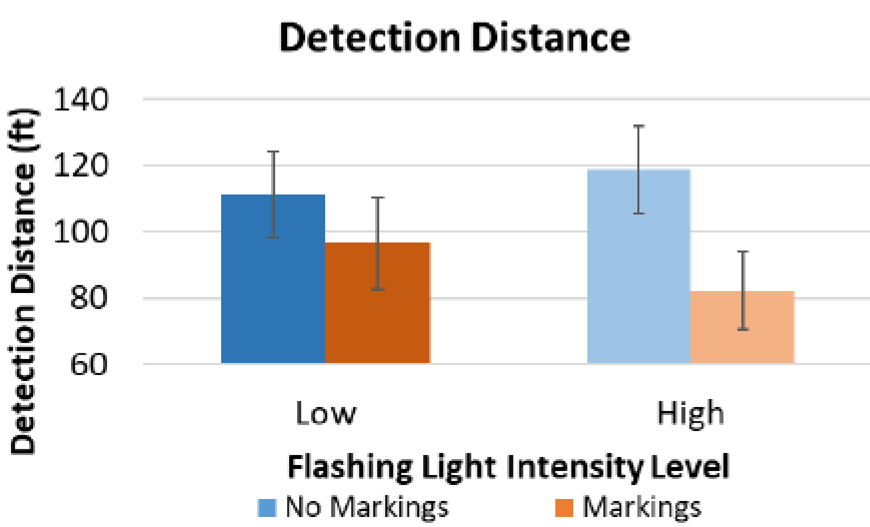

Figure 1. Average (+/- standard error of the mean) detection distances for low and high flashing light intensity levels, and with and without the presence of retroreflective markings (Bullough et al., 2021).

The result shown in Figure 1 offers a hint that the presence of reflective markings with a retroreflectivity level exceeding the minimum (ASTM Type I) requirements specified by NFPA (National Fire Protection Association, 2022) might hamper drivers' ability to see emergency responders around their vehicles. This finding is consistent with previous research showing that highway signs constructed with higher ASTM Types (and tending to have higher apparent brightness when viewed by drivers) resulted in shorter detection distances to objects along the roadway than signs with lower ASTM Types (Carlson et al., 2014), and was one of the reasons the present study was conducted.

An additional reason for the present study comes from a recent change in guidance provided by the National Fire Protection Association (2022). As mentioned above, chevron markings on the rear of fire apparatus may consist of alternating red and yellow/fluorescent-yellow/fluorescent-yellow-green stripes or stripes of "different and high-contrasting colors." There is little published evidence supporting the use of any particular color combination for chevron-style markings on vehicles, or even for the specific pattern or coverage area that should be used with retroreflective vehicle markings on emergency vehicles. Harrison (2004) used photographs and video footage of vehicles with marking schemes developed from principles in published literature to demonstrate that they were judged as conspicuous by members of U.K. police agencies and by members of the driving public in that country. It was concluded that a Battenberg (checkerboard) pattern provided a unique and conspicuous visual cue. Importantly, though, the study by Harrison (2004) did not involve any comparisons of different colors or patterns, so the pattern that was recommended for police vehicles in the U.K. is not necessarily the optimal one for driver visibility and comprehension.

In June 2022, a stakeholder meeting was held via Zoom teleconferencing to discuss previous research as well as possible factors that could be addressed in the present experimental study. Thirteen individuals from academia, responder safety organizations, standards-making organizations, and lighting and marking material manufacturers participated in the discussion. Following a brief overview of the scope of the present study and summaries of previously published research (see Appendix A), participants shared thoughts on factors that could be investigated experimentally:

- Headlight illumination is transitioning from halogen to light-emitting diode (LED) technology and many LED headlights produce a "bluer" or "whiter" illumination color than the "yellowish-white" light from halogen headlights. While this may lead to noticeable differences in sign material color in side-by-side evaluations, the ability of people to identify colors is not impacted (McColgan et al., 2002; Sivak et al., 2003).
- The type of pattern(s) to be studied could impact visibility. The conventional chevron pattern used on fire apparatus (National Fire Protection Association, 2022) should be included as a baseline. The Federal Emergency Management Agency (FEMA) Emergency Vehicle Visibility and Conspicuity Study reported that "outlining vehicle boundaries with 'contour' or 'edge' markings, using retroreflective material, is expected to help enhance emergency vehicle visibility/conspicuity" (Federal Emergency Management Agency, 2009).

- Emergency responders usually wear reflective clothing or gear, and these should be included in the study. Some previous research studies used silhouettes to represent pedestrians or emergency responders within a scene and those might not be representative of the appearance of responders working around their vehicles.

Based on the previous research findings, the results from the literature, and the discussion among stakeholders, a field experiment to investigate the impacts of the retroreflectivity level, vehicle marking color, and marking pattern was designed and carried out.

Methodology

A stationary field experiment was carried out to assess the impacts of different vehicle marking colors, retroreflectivity levels and spatial patterns on driver perceptions and on their ability to identify the location of a firefighter located near the rear of a simulated fire engine.

The simulated fire engine was created by mounting red corrugated plastic panels (3 × 6 feet) covered in different configurations of retroreflective markings into a frame to create the appearance of the rear of a vehicle. Two color combinations of reflective materials were used: red and yellow, or blue and white. Two spatial patterns were created: a "full" pattern consisting of alternating-color chevron striping (6-inch stripes) oriented 45° downward from the center of the frame and covering the entire panels, and an "outline" pattern consisting of 6 × 12 inch alternating color segments around the outer edges of each panel. Figure 2 shows an example of a red and yellow, full pattern, and Figure 3 shows an example of a blue and white, outline pattern.

Figure 2. Photograph of the test frame with the red and yellow, full pattern of retroreflective markings.

Figure 3. Photograph of the test frame with the blue and white, outline pattern of retroreflective markings.

For the full spatial patterns of each color combination, the retroreflectivity level met either the ASTM Type I specifications, denoted as the low retroreflectivity level, or met ASTM Type III specifications, denoted as the high retroreflectivity level. The minimum coefficients of retroreflection specified by the manufacturers of each retroreflective material are listed in Tables 1 and 2 for the low and high retroreflectivity level. (The high-retroreflectivity material actually exceeded the minimum requirements for Type III materials, but did not meet the minima for Type IV so it is classified in the present study as a Type III material.)

Table 1. Minimum coefficients of retroreflection (in cd/m²/lx) for the low retroreflectivity material, as specified by the manufacturer, for each color used in the study. The angles in the leftmost column represent the observation and entrance angles, respectively.

Angles	White	Yellow	Red	Blue
0.2^{o},-4^{o}	70	50	14	4
0.2^{o},30^{o}	30	22	6	1.7
0.5^{o},-4^{o}	30	25	7.5	2
0.5^{o},30^{o}	15	13	3	0.8

Table 2. Minimum coefficients of retroreflection (in cd/m²/lx) for the high retroreflectivity material, as specified by the manufacturer, for each color used in the study. The angles in the leftmost column represent the observation and entrance angles, respectively.

Angles	White	Yellow	Red	Blue
0.2^{o},-4^{o}	460	310	75	35
0.2^{o},30^{o}	250	165	60	20
0.5^{o},-4^{o}	100	70	25	10
0.5^{o},30^{o}	65	45	15	5

The observation angles listed first in Tables 1 and 2 represent the angle that is created by drawing an imaginary line between the light source (such as a headlight) illuminating the retroreflective material (indicated by “Sign” in Figure 4), and between the driver’s eyes and the same location on the retroreflective material (Hawkins et al., 2003). This angle will increase as the driver approaches closer to a retroreflective material. The entrance angle is defined as the angle between the light source and the material, and a line extended exactly perpendicularly out from the material surface. This angle may also change as the driver approaches closer to the material, but it could increase, decrease or even stay constant, depending upon the specific geometry among the light source, the location of the retroreflective material, and the path of the approaching vehicle. The entrance angle is also affected by the tilt or orientation of the material surface, while the observation angle is not.

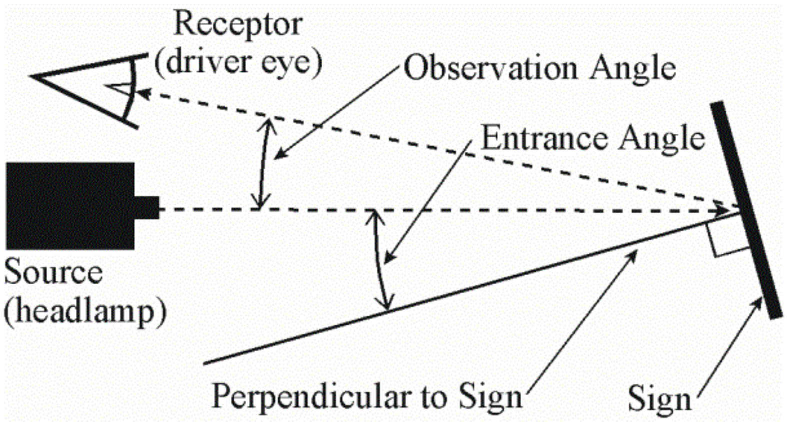

Figure 4. Illustration of observation and entrance angles used to define the performance of retroreflective materials (Hawkins et al., 2003).

Located above the panels in the frame containing the panels was a flashing light bar producing a typical flash pattern with red LED sources. The intensity level from the light bar met Society of Automotive Engineers (2021a, 2021b) standards for emergency flashing lights.

A simulated firefighter was also included in the scene by mounting tan turnout gear and a black helmet onto a rack to create the appearance of a firefighter in the scene. The simulated firefighter could be positioned between the two panels containing the retroreflective markings (as shown in Figure 5), or to the left of the leftmost panel. In some of the trials, the turnout gear was also fitted with a small wearable flashing light containing yellow LEDs and when activated, produced a slow flashing pattern. The wearable light (Figure 6) had multiple intensity level settings; the lowest intensity setting was used in the experiment. From a distance the yellow light appeared to increase in intensity gradually over a duration of just under a second and then switched off immediately, remaining dark for a fraction of a second before repeating the cycle.


Figure 5. Photograph of the simulated firefighter located between the two panels containing retroreflective material.

Figure 6. Photograph of the simulated firefighter with the shoulder-worn yellow flashing LED light on.

At a distance of 150 feet from the simulated fire apparatus vehicle, a rack containing a pair of halogen low beam headlights was located, simulating the location of a passenger vehicle approaching the fire emergency vehicle. Study participants (average age 40 years, standard deviation 15, 8 females/5 males) sat behind the headlights in chairs in a staggered formation providing a view of the simulated fire engine (Figure 7) and looked downward at laptop computers in their laps while blocking a view of the forward scene.

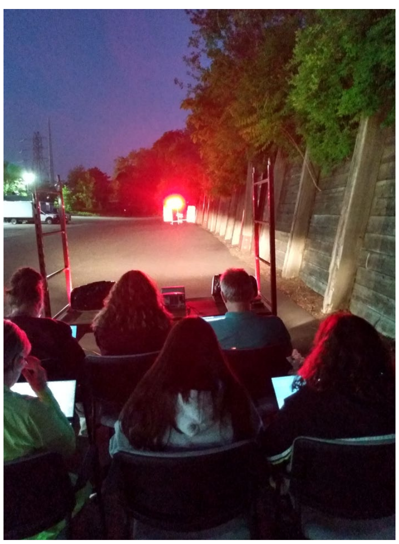

Figure 7. Photograph of study participants in their seating locations behind the headlights and facing the direction of the simulated fire response vehicle.

After subjects completed the informed consent process, they were instructed about the procedures of the experiment. While the experimental conditions for each trial were being set up, they would look toward their screens until an experimenter notified them to begin.

At this point, the screen displayed a five-second countdown, after which the subjects were instructed to look up at the forward scene, and then as quickly as possible, to identify the location of the firefighter within the scene, either between the panels or to the left of the panels, by pressing the appropriate button on the keypad. The computer recorded the response and the response times, and then participants provided subjective responses to the following questions on a scale of 1 to 4:

- How visually uncomfortable was the scene? (1=not at all uncomfortable, 2=slightly uncomfortable, 3=somewhat uncomfortable, 4=very uncomfortable)
- How difficult/easy was it to see the firefighter? (1=very difficult, 2=somewhat difficult, 3=somewhat easy, 4=very easy)
- How bright were the vehicle markings? (1=not at all bright, 2=slightly bright, 3=somewhat bright, 4=very bright)

After entering their responses, participants were instructed to wait to initiate the next trial. After all trials were completed, the computer saved all response data to a text file and participants received a $25 Amazon gift card. Overall, the experiment took about 30-40 minutes to complete. The experiment was run during clear weather starting 30 minutes after sunset (after the end of civil twilight).

There was a total of six experimental conditions representing each combination of color, marking retroreflectivity level and spatial pattern that was used in the study as shown in Table 3. The top four cells of Table 3 represent a 2 × 2 experimental design with color and retroreflectivity level as the independent variables. The bottom four cells of Table 3 represent another 2 × 2 experimental design with color and spatial pattern as the independent variables. The middle two cells in Table 3 are included in both 2 × 2 experimental designs. Finally, a seventh condition consisting of the presence of the wearable LED flashing yellow light was included with red and yellow, high reflectivity markings in the full spatial pattern. This condition would be compared to the same red and yellow, high reflectivity markings with the full pattern but without the wearable flashing light. The order of presentation for all conditions and the location of the simulated firefighter were randomized in a balanced manner during each session.

Table 3. Combinations of marking color, spatial pattern and retroreflectivity level used in the experiment. The top four and bottom four cells in the table represent 2 × 2 experimental designs used to analyze the data.

Color: Red/Yellow Pattern: Full Retroreflectivity: Low	Color: Blue/White Pattern: Full Retroreflectivity: Low
Color: Red/Yellow Pattern: Full Retroreflectivity: High	Color: Blue/White Pattern: Full Retroreflectivity: High
Color: Red/Yellow Pattern: Outline Retroreflectivity: High	Color: Blue/White Pattern: Outline Retroreflectivity: High

Results

In all trials for all participants, the correct location of the firefighter was identified 100% of the time, indicating that subjects were not simply pressing a random key in order to produce a short response time. Dependent measure data for the response times, and the ratings of visual discomfort, ease/difficulty of seeing the firefighter, and brightness of the vehicle markings were subjected to two-way, repeated-measured analyses of variance (ANOVA) according to the 2 × 2 experimental designs described in the Methodology section, and the dependent measure data for the condition including the presence of the wearable flashing light was compared to the corresponding condition with the same marking color, retroreflectivity level, and spatial pattern using a one-way, repeated-measures ANOVA.

For the color × retroreflectivity experimental block, there was a statistically significant main effect of the retroreflectivity level ($F_{1,12}=7.29$; $p=0.014$) on the response time to identify the location of the firefighter (Figure 8). Neither the main effect of color nor the interaction between color and retroreflectivity level were statistically significant ($p>0.05$). The average response time was approximately 0.5 seconds longer when the retroreflectivity was high than when it was low. At a driving speed of 50 mph, this corresponds to a decreased available stopping distance of 37 feet.

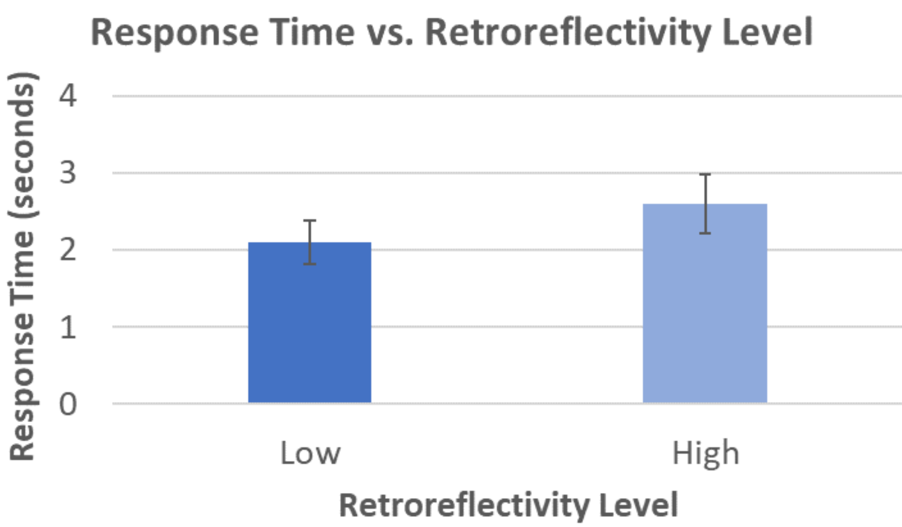

Figure 8. Average response time (+/- standard error of the mean) for each retroreflectivity level in the color × retroreflectivity experimental block.

In the same experimental block, there was a statistically significant main effect of the retroreflectivity level ($F_{1,12}=11.1$, $p=0.006$) on the rating of how easy/difficult it was to see the firefighter (Figure 9). The average rating of ease decreased for the higher retroreflectivity level relative to the low retroreflectivity level. There were no other statistically significant main effects or interactions ($p>0.05$) in this experimental block.

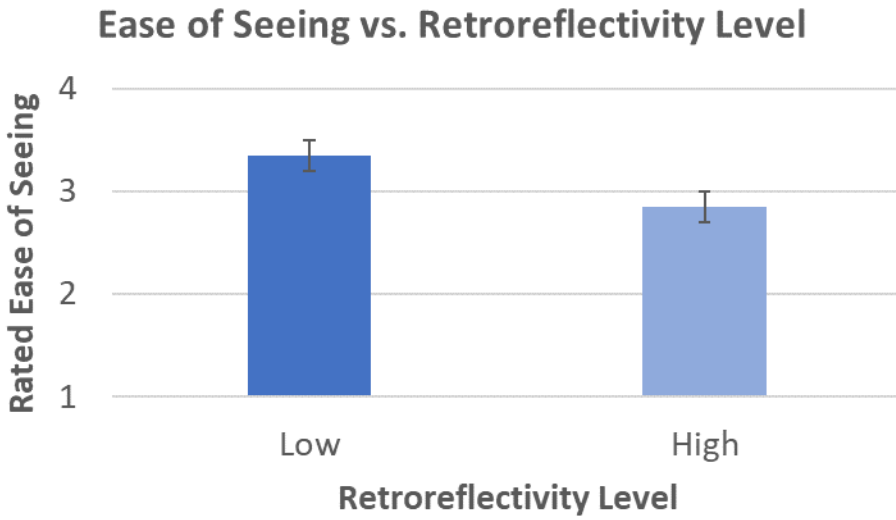

Figure 9. Average rating of how easy it was to see the firefighter (+/- standard error of the mean) for each retroreflectivity level in the color × retroreflectivity experimental block.

In the color × pattern experimental block, there was a statistically significant main effect ($F_{1,12}$=11.1, p=0.006) of vehicle marking color on the ratings of how bright the vehicle markings appeared (Figure 10). The markings were judged as brighter when they were blue and white than when they were red and yellow. There was also a statistically significant main effect ($F_{1,12}$=12.6, p=0.004) of the spatial pattern on the ratings of vehicle marking brightness (Figure 11), whereby the markings were judged as brighter for the full pattern than for the outline pattern. The interaction between color and pattern on this outcome was not statistically significant (p>0.05), nor were there any other significant main effects or interactions in this experimental block.

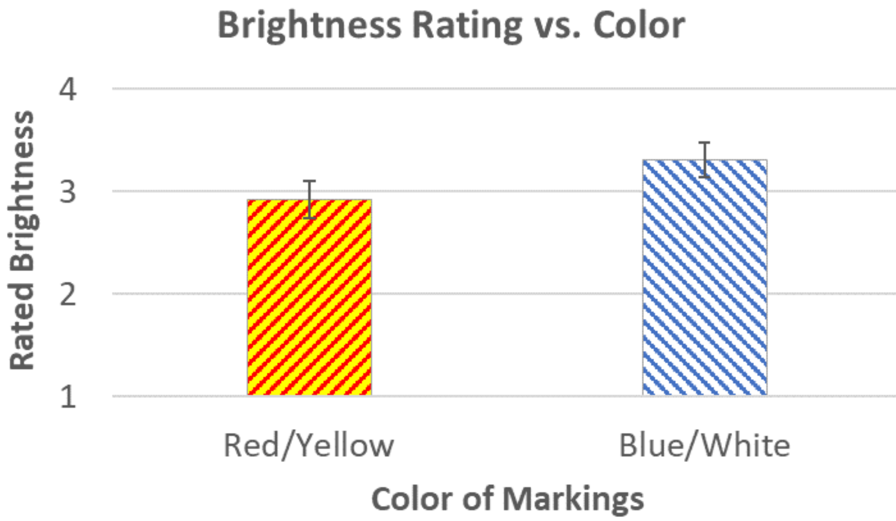

Figure 10. Average rating of how bright the vehicle markings appeared (+/- standard error of the mean) for each color combination in the color × pattern experimental block.

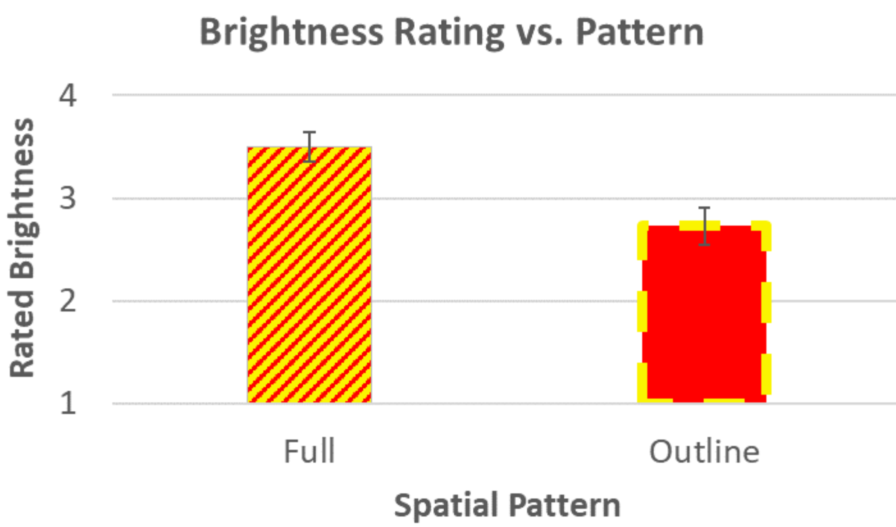

Figure 11. Average rating of how bright the vehicle markings appeared (+/- standard error of the mean) for each spatial pattern in the color × pattern experimental block.

For the comparison of the presence of the wearable flashing yellow LED light or not, the main effect of the presence of the light on the response times approached, but did not reach, statistical significance ($F_{1,12}$=4.01, p=0.068). The average time was approximately 0.65 seconds shorter to identify the location of the simulated firefighter when the flashing light was present compared to when it was not (Figure 12). No other main effects reached or approached statistical significance (p>0.05).

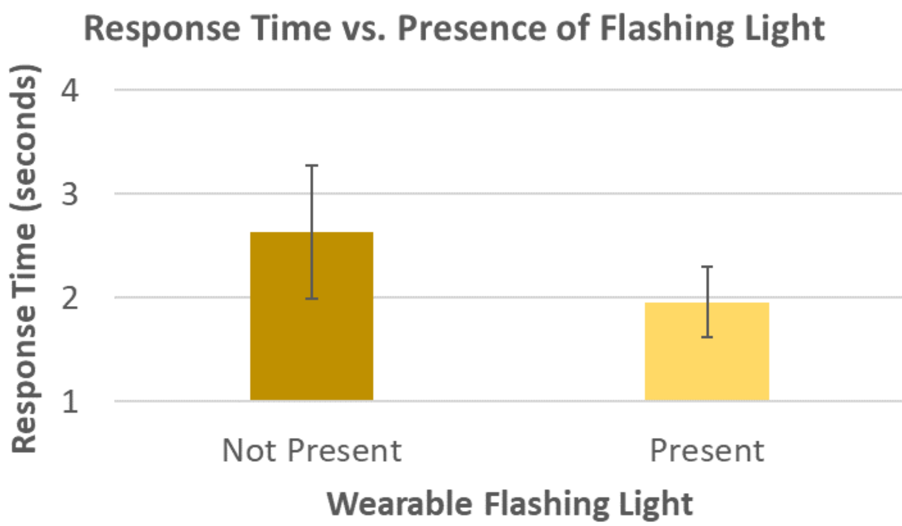

Figure 12. Average response time (+/- standard error of the mean) for the corresponding conditions when the wearable flashing yellow LED light was present and when it was not present.

Discussion

The results of the present study offer some interesting findings related to the use of retroreflective marking materials on emergency vehicles when they are parked at roadside incidents, which is the situation that was simulated in this experiment. The situation used in the experiment focused on the rear markings of a fire apparatus, but the results can be applied to the use of such markings on other vehicles.

Perhaps the most important result from the current study is the finding that response times to identify the location of a emergency responder within the scene was longer when the retroreflectivity level was higher. Based on the minimum coefficients of retroreflectivity for different observation and entrance angles specified by ASTM for Type I (the low-retroreflectivity material used in the present study) and for Type III materials (American Society for Testing and Materials, 2019) and upon the manufacturer's specification for the high-retroreflectivity material used in the present study, Figure 13 shows the minimum luminance that a yellow material would be expected to produce for different distances when approaching an emergency vehicle fitted with different retroreflective materials. For the distance of 150 feet used in the present study, there is not a minimum expected luminance, because the observation angle at this distance (approximately 0.6º) is larger than 0.5º, the largest observation angle for which the minimum performance of these materials is defined. It is unlikely, however, that the luminance would drop off to zero at this distance.

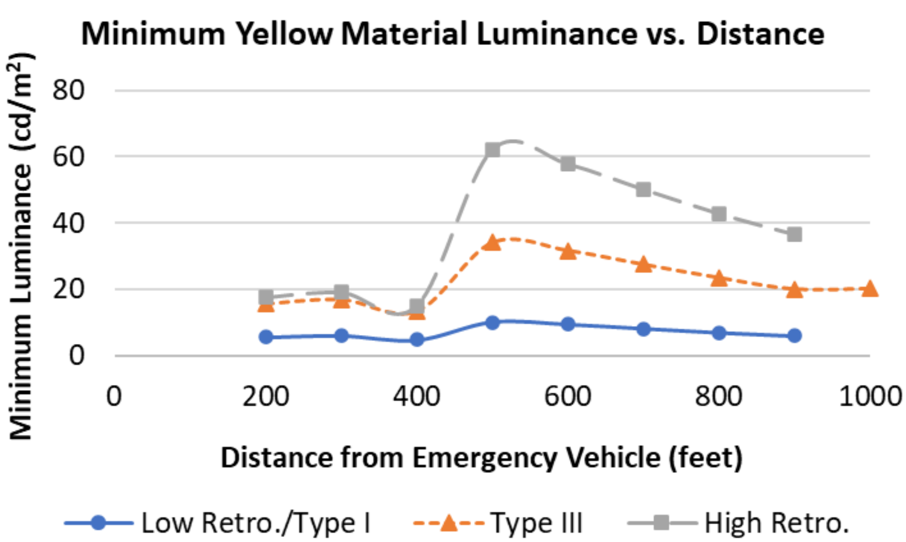

Figure 13. Expected minimum luminances of different retroreflective materials located ahead of a passenger vehicle with low beam headlights at different distances, based on the minimum performance specifications of ASTM Type I materials (used as the low-retroreflectivity material), ASTM Type III materials, and the specifications published by the manufacturer of the high-retroreflectivity material used in the present study. Not all materials have defined performance for the observation and entrance angles corresponding to all of the same distances (e.g., 1000 feet for the Type I and high-retroreflectivity materials).

As shown in Figure 8, the average response time for the high-retroreflectivity materials was just over 2.6 seconds and was 2.1 seconds for the low-retroreflectivity materials, indicating that disability glare from the higher-retroreflectivity material resulted in participants in this study taking 0.5 seconds longer to see the location of the simulated firefighter in the scene. Of note, the 2.6-second response time for the higher-retroreflectivity material is longer than 2.5 seconds often used to estimate a perception-response time for an unexpected event while driving (American Association of State Highway and Transportation Officials, 2011). In the present experiment, participants were not driving a moving vehicle, were instructed as to the stimulus they were attempting to detect in each scene and which of two possible locations it could be in, and they were performing repeated trials with the same overall procedure, so that it was not an unexpected event. Thus, a response time longer than 2.5 seconds in the present experiment could suggest that using the higher retroreflectivity level material at night could impact emergency responder safety.

The orientation of the simulated fire response vehicle in the present study was with the rear of the simulated vehicle more or less directly facing the participants. In actuality, emergency vehicles are often intentionally parked at an angle (Sullivan, 2016) so that approaching drivers can see more easily whether the emergency vehicle is moving, and to deflect any vehicles that might collide with the emergency vehicle away from the incident itself. As the angle of the parked emergency vehicle changes, the entrance angle between the headlights, the retroreflective material and the line perpendicular to the material will increase. According to analyses of the luminances of the materials like those illustrated in Figure 13, even at entrance angles as large as 30º, the minimum luminances of the materials will be between 70% and 80% of the values for the smallest entrance angle at distances less than 400 feet away from the emergency vehicle. This suggests that the results of the present experiment are applicable to situations where the emergency vehicle is parked at an angle.

The present study investigated only one color combination other than red and yellow for the retroreflective markings, namely blue and white. White materials have higher coefficients of retroreflection than yellow materials of the same type, while blue materials have lower coefficients of retroreflection than red materials of the same type, so that each combination of colors had a similar average (differing by only about 12%). The present NFPA standard for chevron marking colors (National Fire Protection Association, 2022) simply requires “high-contrasting” colors but offers no quantitative guidance about how they should contrast.

From a purely psychophysical perspective, if the average coefficients of reflection of the selected colors are similar to the average of red and yellow markings, retroreflective color combinations of different pairs of colors should not produce more disability glare than red and yellow markings. This, of course, does not mean that different color combinations are equally likely to be recognized or identified as the same type of emergency vehicle. It has been demonstrated that drivers use the colors of flashing lights and of vehicles and their markings to identify the type of incident they are approaching; consistent use of colors more likely to be familiar would reinforce drivers' ability to make these identifications. It should also be noted that drivers' judgments of how bright the markings appeared seemed to be more related to the relative luminance of the brightest color in the color combination than to the average luminance of the pair of colors. Thus, to the extent that discomfort glare is related to excess brightness perception and associated with the maximum luminance of a stimulus (Bullough, 2019, 2022), color combinations containing white might be expected to be somewhat more uncomfortable than those containing colors of lower reflectance. In the present study, however, this was not the case.

There were also few differences between the full spatial pattern of retroreflective markings (Figure 2) and the outline pattern that was used in the present study (Figure 3). For fire vehicles, the NFPA (National Fire Protection Association, 2022) requires at least 50% of the rear vehicle surface to be covered with a full chevron pattern. Based on the present results, using marking materials with the higher retroreflectivity level in a full pattern can result in making emergency responders more difficult to see. Higher retroreflectivity levels should perhaps be used only when the spatial pattern is an outline pattern, which was suggested by FEMA to be beneficial for making emergency vehicles more visible. Of course, the use of a full chevron pattern on the rear of a fire vehicle could have benefits for daytime detection and identification of the vehicle. If this is the case, the use of an outline pattern with a higher retroreflectivity level could perhaps be used in conjunction with a full pattern for the remainder of the vehicle surface using materials with a lower retroreflectivity level, possibly even with non-retroreflective materials. While not tested in the present study, such a configuration could offer the benefits of using materials with higher retroreflectivity and with a full spatial pattern, while avoiding the potential drawbacks of disability glare at night.

Finally, the presence of the shoulder-worn flashing yellow LED light did not create any negative impacts in terms of discomfort glare or making the firefighter in the present study more difficult to see. In fact, the average time it took participants in this study to identify the firefighter's location was shorter when the light was deployed, albeit not in a statistically significant manner. Nor is it clear that the specific intensity level, color and flash pattern that was used for this light was optimized for detection of emergency responders. Nonetheless, the use of these lights may be beneficial and should be investigated in future research.

Implications and Preliminary Recommendations

The results of the present study, in combination with previous research, lead to the following preliminary recommendations:

Agencies should use materials with higher levels of retroreflectivity carefully, especially when they will be covering large areas of the surface of a vehicle. Limiting the maximum retroreflectivity level to no greater than ASTM Type III may help lessen the negative impact of bright reflective materials on drivers' ability to see emergency responders working near their vehicles.

As long as the average reflectivity of different color combinations is similar to that of red and yellow reflective markings, chevron patterns with those color combinations will not make emergency responders less visible. They may, however, make a fire response vehicle less likely to be identified as a fire vehicle.

Outline patterns of reflective markings on vehicles seem to perform similarly at night to full patterns covering most of the vehicle surface. The effectiveness of using high retroreflectivity materials in an outline pattern in combination with lower (or non-) retroreflectivity materials on the rest of the surface should be studied.

The use of wearable flashing LED lights may make emergency responders easier to see at night, without increasing glare to approaching drivers. The ideal properties of these lights should be investigated further.

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Appendix A: Stakeholder Meeting Notes

Individuals from the following organizations participated in a stakeholder meeting held on June 30th, 2022 via Zoom teleconferencing, to discuss project objectives and potential investigations:

- 3M
- Association for the Advancement of Automotive Medicine
- Cyberkar Systems
- Embry-Riddle Aeronautical University
- Emergency Responder Safety Institute
- Light and Health Research Center, Icahn School of Medicine at Mount Sinai’
- National Fire Protection Association
- Orafol Americas
- SoundOff Signal
- Towing and Recovery Association of America
- Whelen Engineering

The following pages include a copy of the slides prepared for the meeting in order to facilitate the discussion.

Evaluation of Reflective Sheeting Materials for Stationary Vehicle Demarcation

John D. Bullough, Ph.D.
Light and Health Research Center
Icahn School of Medicine at Mount Sinai

Stakeholder Meeting
June 30, 2022

Project Sponsor: U.S. Fire Administration (through ERSI)

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Acknowledgments

- Scott Parr, Embry-Riddle Aeronautical University
- Steve Austin and Jack Sullivan, Emergency Responder Safety Institute
- Bill Troup, U.S. Fire Administration

2

Purpose and Scope of Present Project

- Markings on vehicles and other equipment (barricades, barrels, cones) may be used to help "harden" a roadside emergency scene
- Most standards and recommendations focus on minimum requirements to ensure adequate visibility during daytime
- The Emergency Responder Safety Institute (ERSI) with support from the U.S. Fire Administration is investigating configurations of high-visibility markings for first responder safety, especially during nighttime

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Background

- Emergency vehicles use flashing lights and high-visibility markings to attract attention
- NFPA 1901 (2016) requires retroreflective chevrons on rear of fire apparatus
  - Minimum requirement: ASTM Type I
  - Higher retroreflectivity "types" are often used
- Does brightness of markings affect perception at night?

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Recent Research Results

- Growing interest in potential for flashing lights to be glaring or distracting at night
  - Standards for flashing lights are minimum requirements
  - Reflective markings might be expected to reduce discomfort glare by increasing brightness of the background
- Recent ERSI research investigated impacts of reducing intensity below minimum levels required by NFPA 1901
  - The study also evaluated light source color, modulation depth (on/off vs. high/low), flash pattern and presence of reflective marking panels (Type V)

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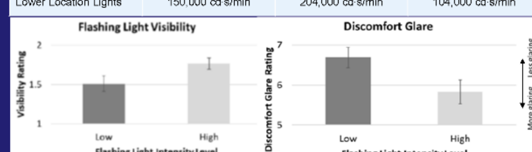
Overview of Study Findings

Flashing Light Location	NFPA 1901 Minimum	High Intensity Level	Low Intensity Level
Upper Location Lights	800,000 cd·s/min	1,065,000 cd·s/min	304,000 cd·s/min
Lower Location Lights	150,000 cd·s/min	204,000 cd·s/min	104,000 cd·s/min



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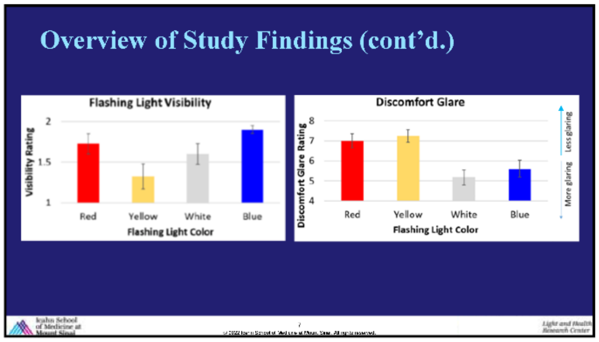
Overview of Study Findings (cont'd.)
Flashing Light Visibility
Visibility Rating
Red
Yellow
White
Blue
Flashing Light Color
Discomfort Glare
Discomfort Glare Rating
Less glaring
More glaring
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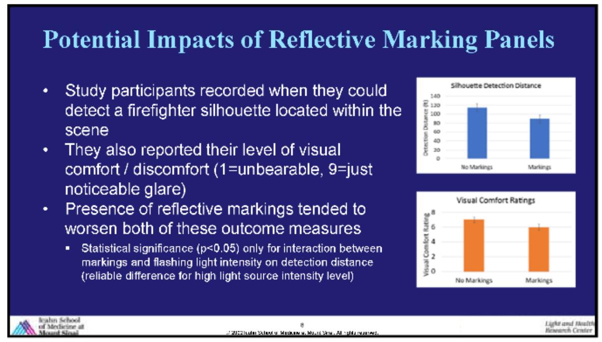
Potential Impacts of Reflective Marking Panels
• Study participants recorded when they could detect a firefighter silhouette located within the scene
• They also reported their level of visual comfort / discomfort (1=unbearable, 9=just noticeable glare)
• Presence of reflective markings tended to worsen both of these outcome measures
▪ Statistical significance (p<0.05) only for interaction between markings and flashing light intensity on detection distance (reliable difference for high light source intensity level)
Silhouette Detection Distance
Visual Comfort Ratings
No Markings
Markings
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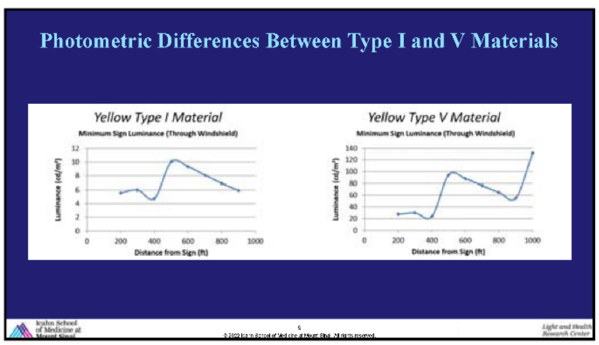
Photometric Differences Between Type I and V Materials
Yellow Type I Material
Minimum Sign Luminance (Through Windshield)
Luminance (cd/m²)
Distance from Sign (ft)
Yellow Type V Material
Minimum Sign Luminance (Through Windshield)
Luminance (cd/m²)
Distance from Sign (ft)
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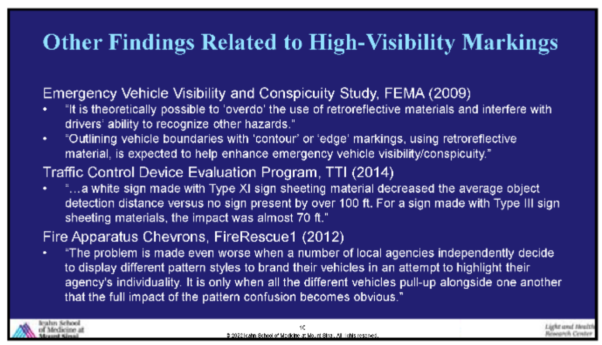
Other Findings Related to High-Visibility Markings
Emergency Vehicle Visibility and Conspicuity Study, FEMA (2009)
• "It is theoretically possible to 'overdo' the use of retroreflective materials and interfere with drivers' ability to recognize other hazards."
• "Outlining vehicle boundaries with 'contour' or 'edge' markings, using retroreflective material, is expected to help enhance emergency vehicle visibility/conspicuity."
Traffic Control Device Evaluation Program, TTI (2014)
• "…a white sign made with Type XI sign sheeting material decreased the average object detection distance versus no sign present by over 100 ft. For a sign made with Type III sign sheeting materials, the impact was almost 70 ft."
Fire Apparatus Chevrons, FireRescue1 (2012)
• "The problem is made even worse when a number of local agencies independently decide to display different pattern styles to brand their vehicles in an attempt to highlight their agency's individuality. It is only when all the different vehicles pull-up alongside one another that the full impact of the pattern confusion becomes obvious."
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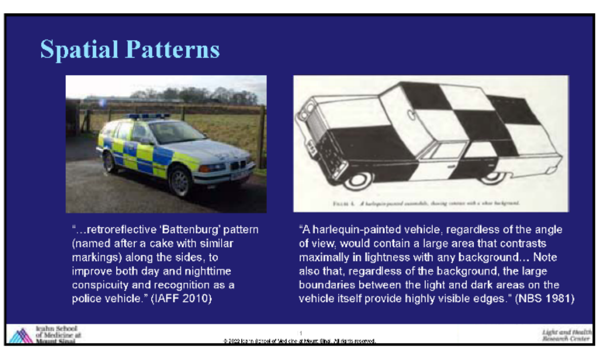
Spatial Patterns
"…retroreflective 'Battenburg' pattern (named after a cake with similar markings) along the sides, to improve both day and nighttime conspicuity and recognition as a police vehicle." (IAFF 2010)
"A harlequin-painted vehicle, regardless of the angle of view, would contain a large area that contrasts maximally in lightness with any background… Note also that, regardless of the background, the large boundaries between the light and dark areas on the vehicle itself provide highly visible edges." (NBS 1981)
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Standards vs. Best Practices
• Forthcoming standards (e.g., NFPA 1900) appear to be relaxing some requirements for reflective markings
▪ Red / yellow (or fluorescent yellow/yellow-green) color combination not required?
• What guidance can be given to agencies selecting high-visibility marking brightness, color, patterns that can support first responder safety while providing for "individuality?"
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Pause for Questions/Comments

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What Factors Could Be Investigated?
• Vehicle marking brightness
• Vehicle marking colors
• Color combinations

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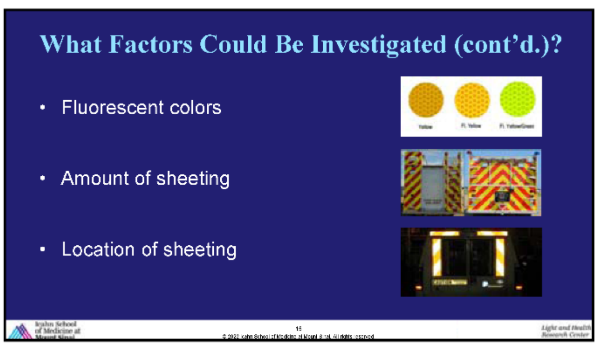
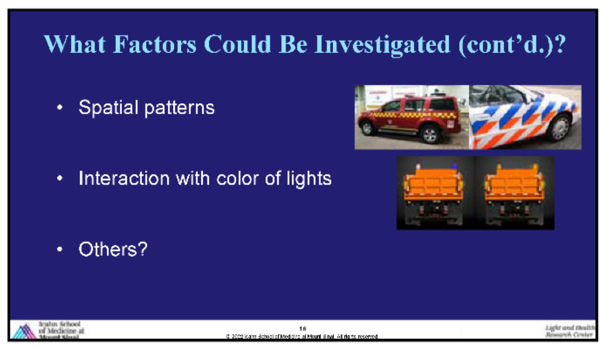

What Factors Could Be Investigated (cont'd.)?
• Fluorescent colors
• Amount of sheeting
• Location of sheeting

15


What Factors Could Be Investigated (cont'd.)?
• Spatial patterns
• Interaction with color of lights
• Others?

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Thank you!
Discussion

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