GUIDELINES FOR VEHICLE AND EQUIPMENT COLOR, MARKING AND LIGHTING

NCHRP Project 05-24

Equipment Fleet Management

2024 National Conference and Trade Show

Loveland, CO

August 21, 2024

Need for Study

Some practitioners/field personnel view more markings, lights, light activity as being safer

A risk exists that over-marking and/or over-lighting decreases safety

Manufacturers continue to provide more visually-stimulating products, difficult for practitioners to know if those products provide meaningful safety benefits

Project Objective

Develop guidelines for the selection and application of color, retroreflective markings, and lighting to vehicles and equipment that will effectively identify vehicles and equipment, communicate their activities to the motoring public, and thus enhance safety.

Project Tasks

1. Collect and Review Information Pertinent to Vehicle Color, Retroreflective Markings, and Vehicle Warning Light Design, Selection, and Application
   - Literature review
   - Agency practices
   - Vendor interviews
2. Identify and discuss factors related to vehicle color, retroreflective markings, and warning light design and selection
3. Assess relevance, importance, and priority of factors for study

Project Tasks (cont'd)

4. Prepare an updated work plan and interim report
5. Meet with panel
6. Execute phase II studies
    4. Static closed-course studies
    5. Dynamic closed-course studies
    6. Field evaluations
7. Prepare final report and implementation guidelines

Past Research – Retroreflective Vehicle Markings

Greater visual contrast = more conspicuous and detectable

Wide range of colors in use

Inverted V and checkerboard marking patterns are most common

Some concern exists about effect of highly retroreflective materials upon worker or pedestrian visibility

Past Research – Vehicle and Equipment Warning Lights

Amber and amber-white most common, use of other colors (red, blue, green, etc.) dependent upon state laws and codes

Multi-colored lights perceived as more urgent or hazardous, increases driver response

Detection of lights depends on peak luminous intensity and effective intensity of the warning light array

Faster flash frequencies may be perceived as implying more urgent or hazardous conditions

Past Research – External Factors

Vehicle and equipment detection depends upon size and extent to which color and shape differ from other vehicles in the traffic stream and from the background of the visual scene

Factors other than visibility (such as initial purchase price and salvage value) are often considered when specifying vehicle and equipment color in procurements

Optimum marking and warning light systems may differ significantly between daytime and nighttime viewing conditions

Fundamental Objectives of a Marking and Warning Light System

- Objective 1 – Attract attention and provide adequate warning of vehicle/equipment presence
- Objective 2 – Assist in determining appropriate driving action approaching work activity
- Objective 3 – Not be confused with authorized emergency vehicles
- Objective 4 – Not adversely affect driver abilities to detect and recognize the vehicles or equipment, other traffic control devices in use, workers on foot, or nearby pedestrians

Factors Examined

Retroreflective vehicle markings

- Color combinations
- Marking patterns
- Amount of material

Flashing warning lights

- Number of lights (i.e., peak luminous intensity)
- Flash patterns
- Colors

Ambient lighting

- Daytime
- Nighttime

Task 6 Phase II Studies

- ***Static Closed-Course Studies*** - determine how vehicle marking and warning light factors affect driver recognition of workers on foot and of flashing arrow board displays
- ***Dynamic Closed-Course Studies*** – determine whether different warning light factors affect driver abilities to correctly recognize work vehicle movement and perceptions of hazard risks present
- ***Field Evaluations*** – determine effect of best-performing marking and warning light configurations upon driver speed and lane choice

Daytime Closed-Course Static Studies

- Focused exclusively on vehicle markings (no warning lights included)
- Treatments evaluated
  - Colors: yellow and black versus red and white
  - Patterns: inverted V versus checkboard (Battenburg)
  - Amount of material: 3’ x 6’ panel versus 1’ x 6’ strip
- Used a glance recognition study to evaluate performance
- Marking treatments viewed from 400’ away

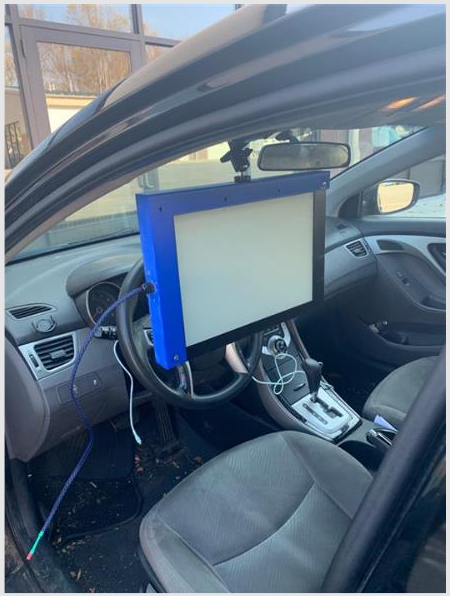






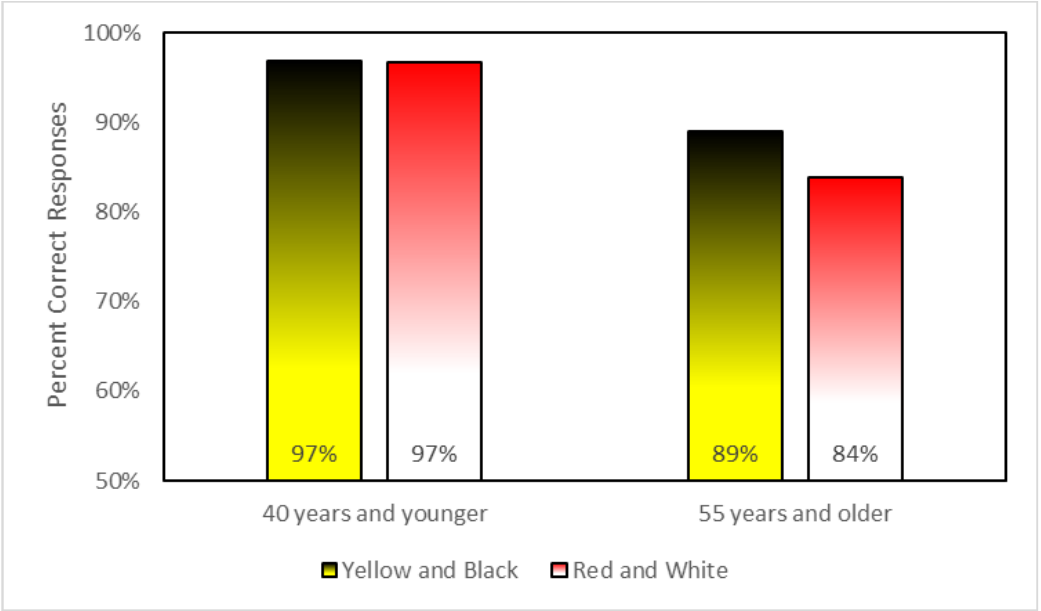

Study participants viewed each treatment for a brief (200 millisecond) period and determined if a worker was present or not

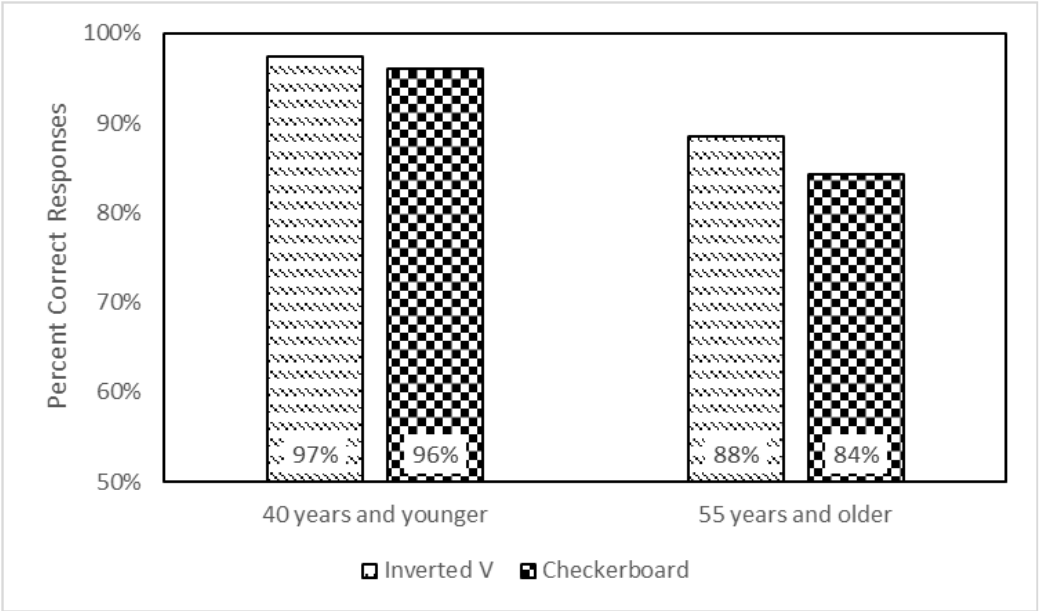

Electronic Occlusion Shutter System



- Screen is opaque until current applied
- Allows for very accurate short display times

Effect of Marking Colors and Patterns on Worker Recognition Accuracy





Nighttime Closed-Course Static Studies

- Focused on effects of warning light factors on worker recognition and arrow board display (with and without vehicle markings present)
- Treatments evaluated
  - Number of warning lights used in array: 2 versus 4 versus 8
  - Warning light colors: amber versus amber and green
  - Warning light flash speed: 1.25 hz versus 2.5 hz
  - Warning light flash pattern: lights flash in an alternating left-right pattern versus asynchronous flashing of the individual lights
- Vehicle markings (when used) was the 3’ x 6’ yellow and black checkerboard pattern

- Number of lights

- Light colors

- Flash speed

- Flash pattern

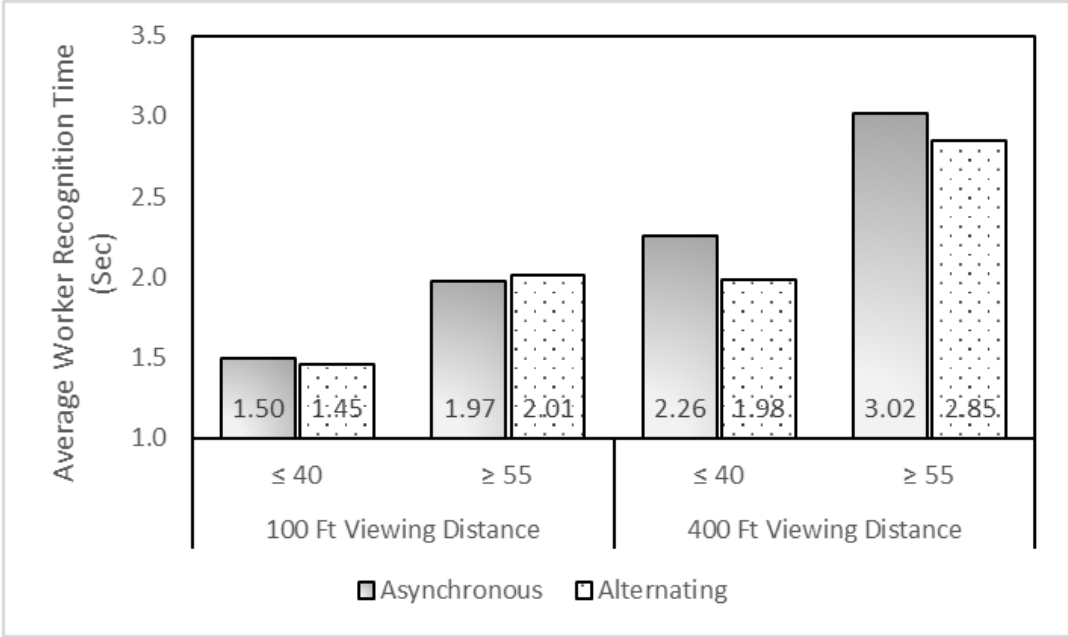
Study Methodology

- Participant vehicle positioned either 100’ or 400’ from work vehicle with marking and warning light treatments
- At one distance, participants identified worker presence; at the other distance, participants identified arrow board display
- Measured time to identify worker or arrow board display, accuracy of identification, and ratings of worker or arrow board visibility, work vehicle visibility, treatment distraction, and discomfort glare created

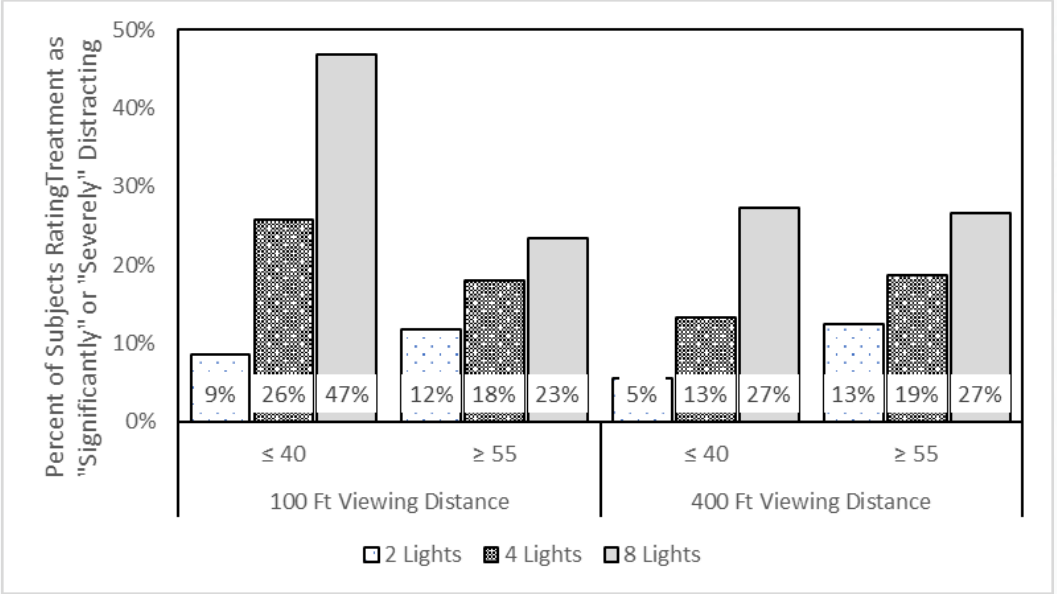
Results – Worker Detection/ Recognition

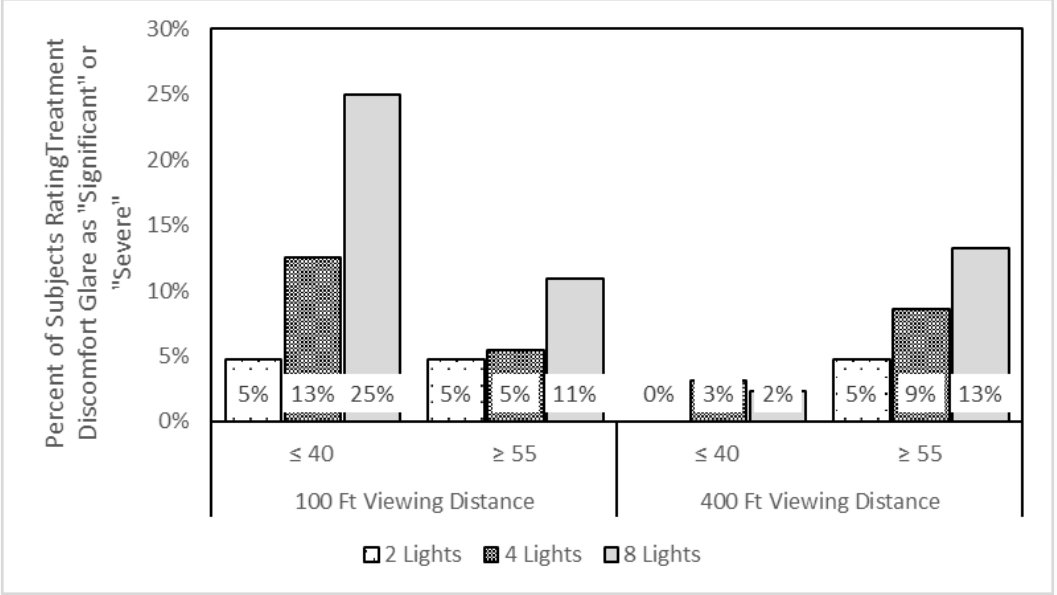
- Participants ≥ 55 years had longer detection/recognition times
- Worker detection/recognition accuracy worse at 400 ft viewing distance
- Presence of vehicle markings improved worker detection/recognition accuracy for participants ≤ 40 years

Asynchronous flashing increased worker recognition time at farther viewing distances

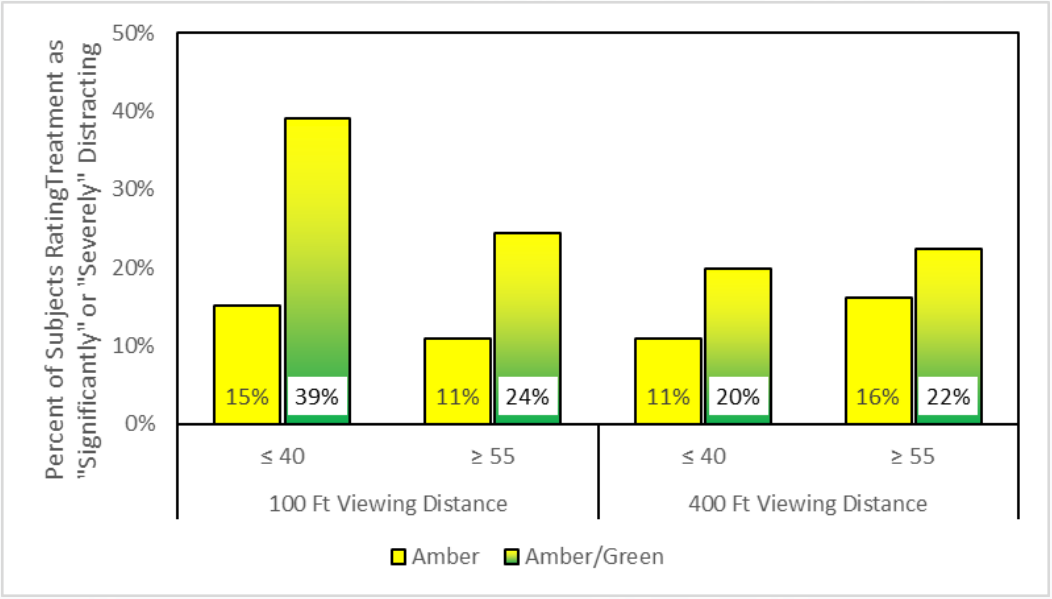


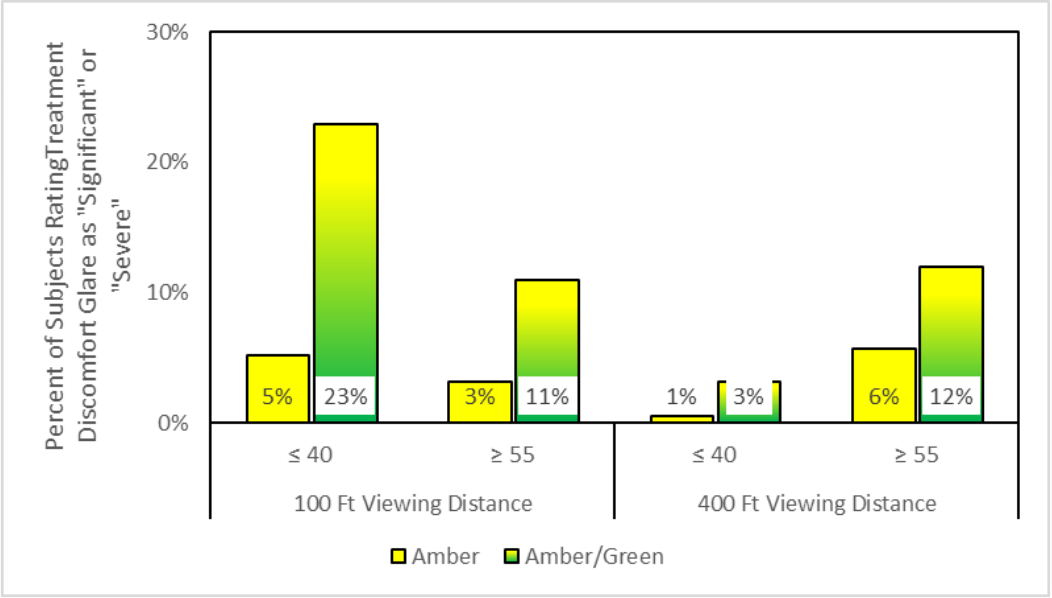
Many participants rated the 8-light display distracting and causing discomfort glare



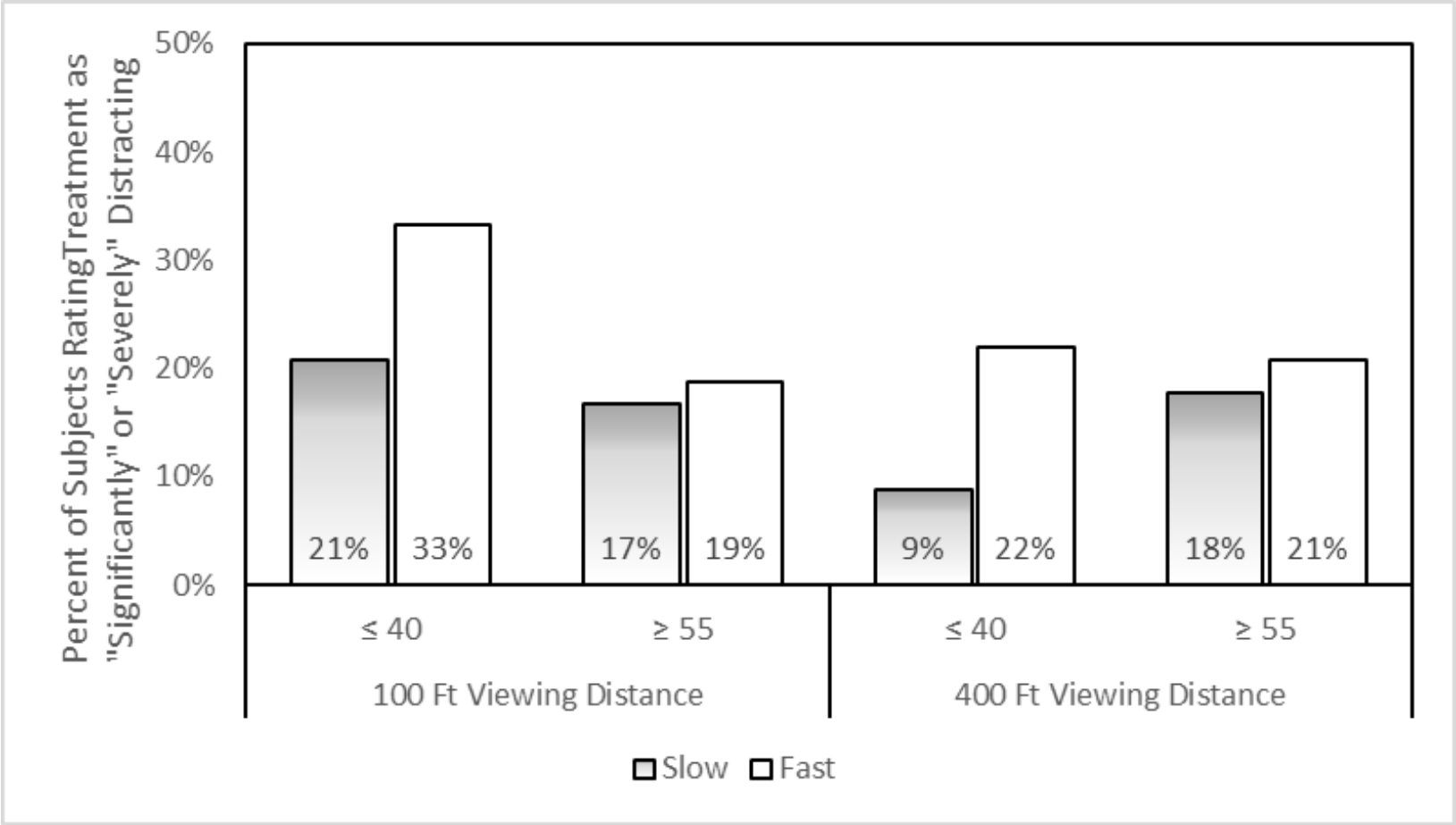


Many participants also rated multi-colored light arrays as more distracting and causing discomfort glare

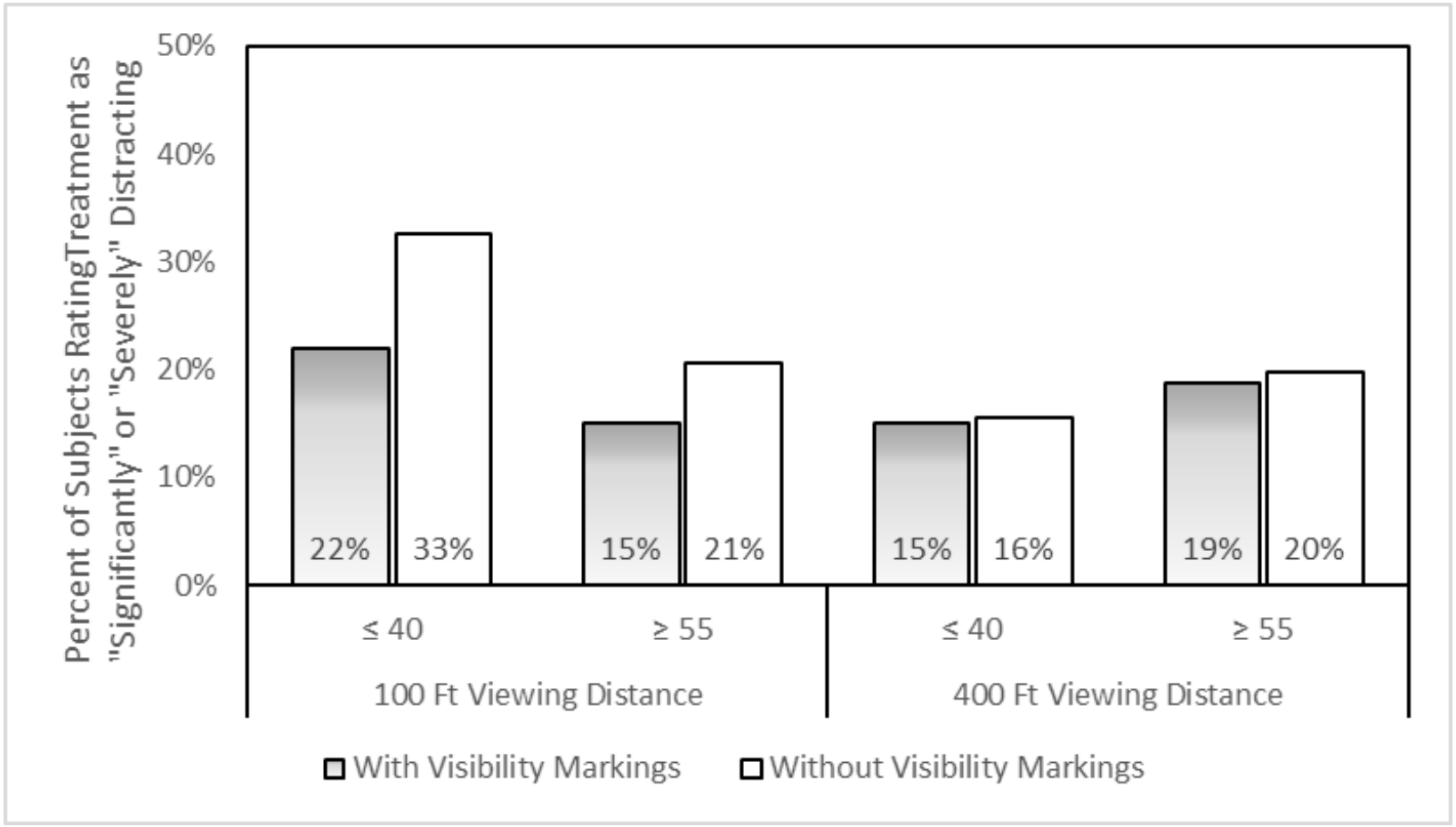




Participants ≤ 40 years rated the fast flash speed as distracting



Presence of markings on the rear of the treatment vehicle reduced distraction ratings when viewed at the 100’ distance



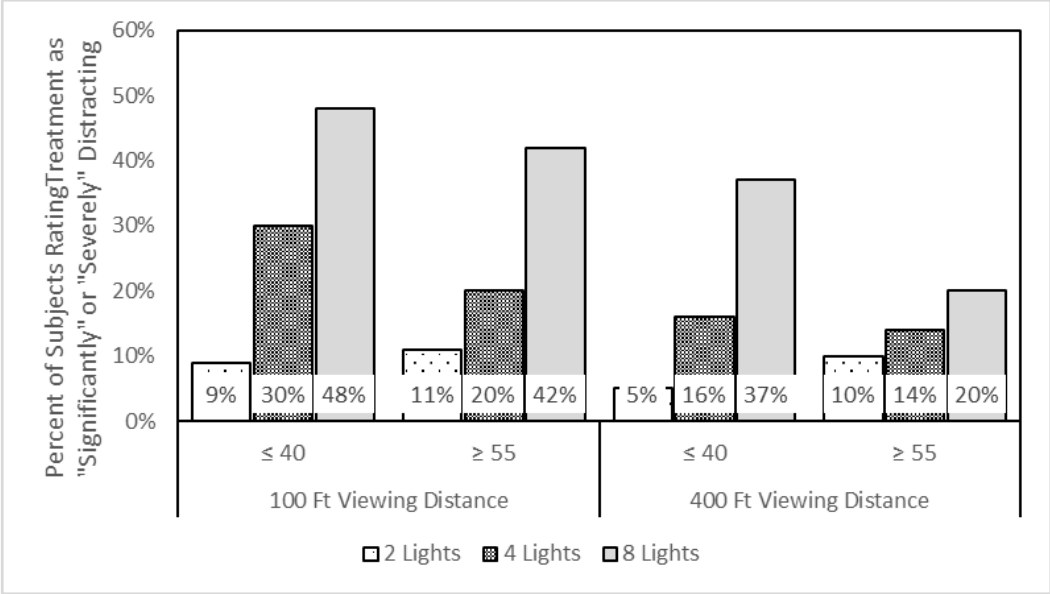
Results – Arrow Board Detection/ Recognition

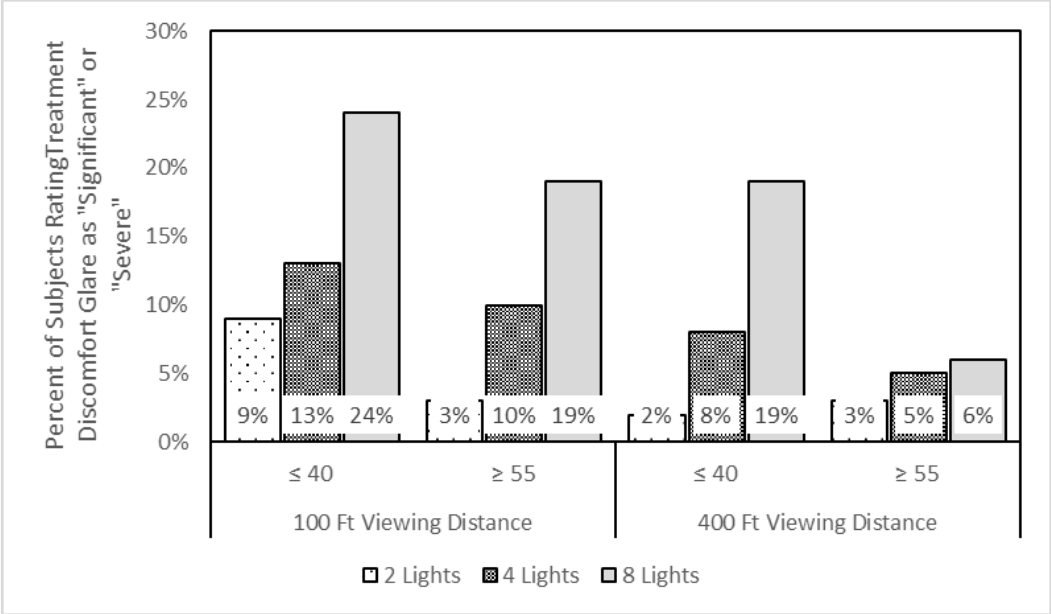
- Participants ≥ 55 years old had longer arrow board detection/recognition times
- Arrow board detection/ recognition times were worse at 100 ft viewing distance

Other Arrow Board Trends

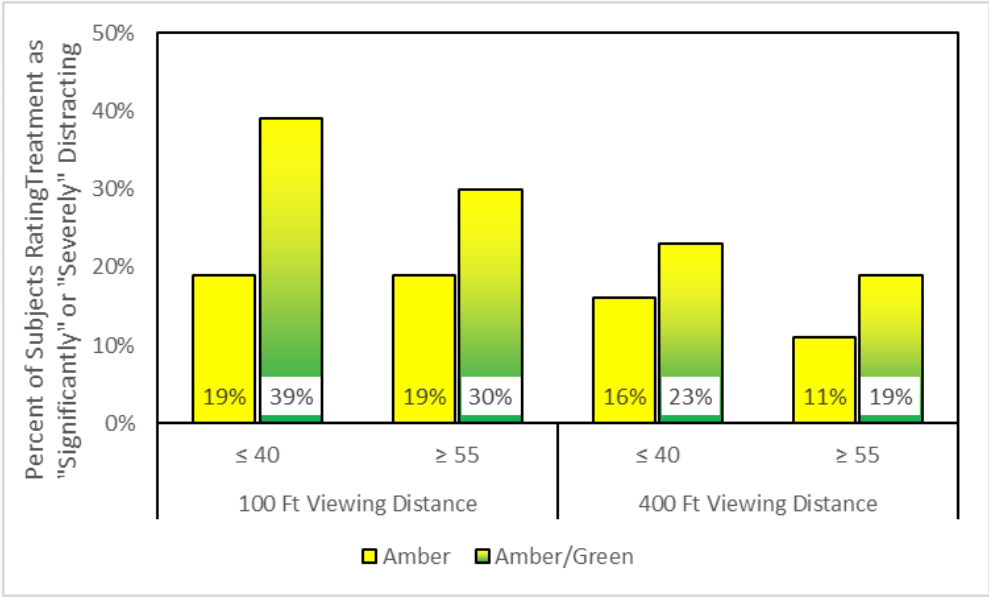
- None of the warning light attributes affected recognition times of the arrow board displays or accuracy of recognition.
- Warning light attributes also did not significantly affect ratings of arrow board visibility.
- Presence of vehicle markings on the rear of the work vehicle increased ratings of work vehicle visibility.
- The fast flash speed resulted in lower ratings of work vehicle visibility.

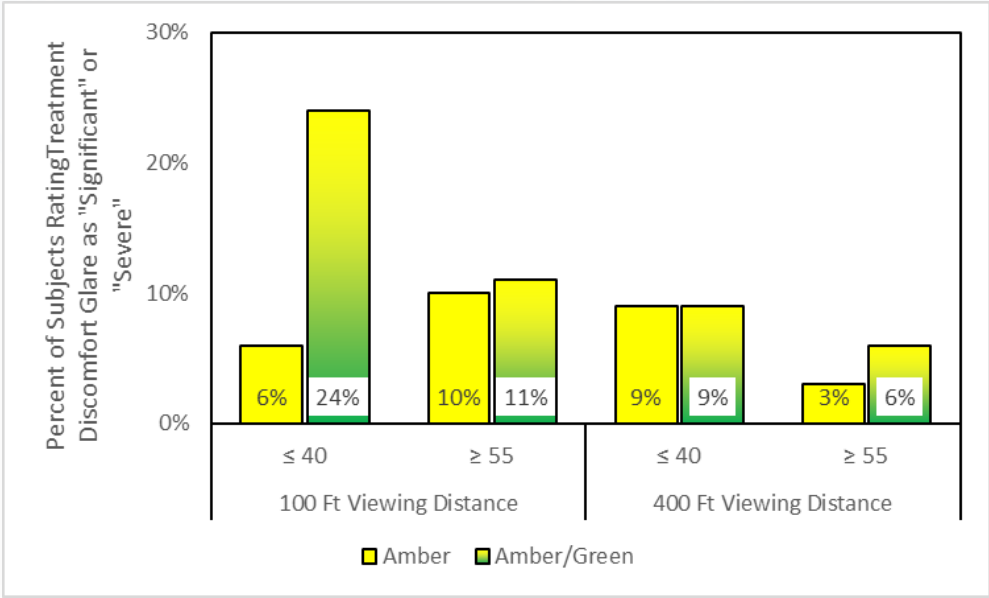
Participants again rated 8-light arrays as more distracting and causing more discomfort glare.



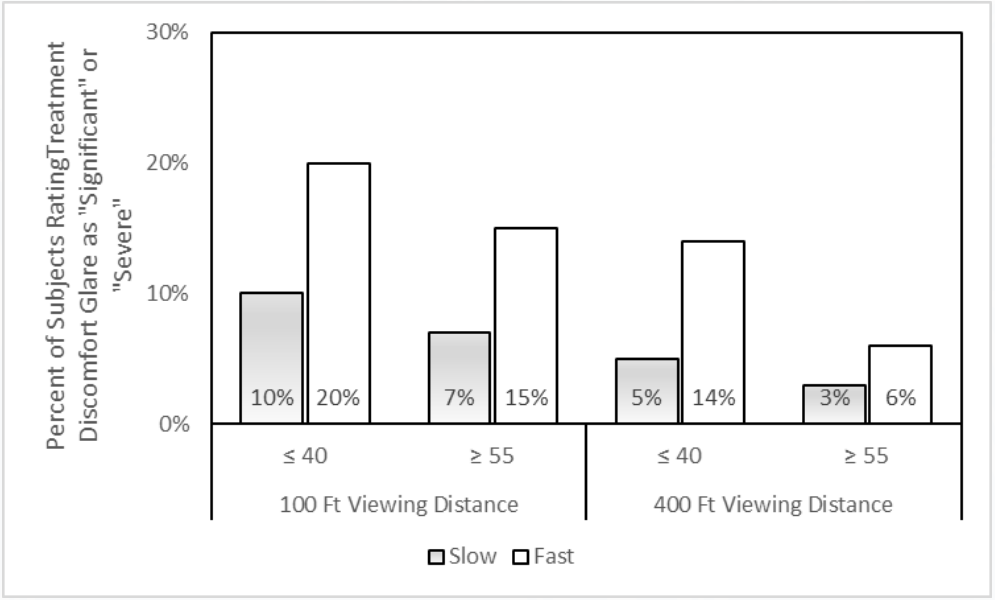


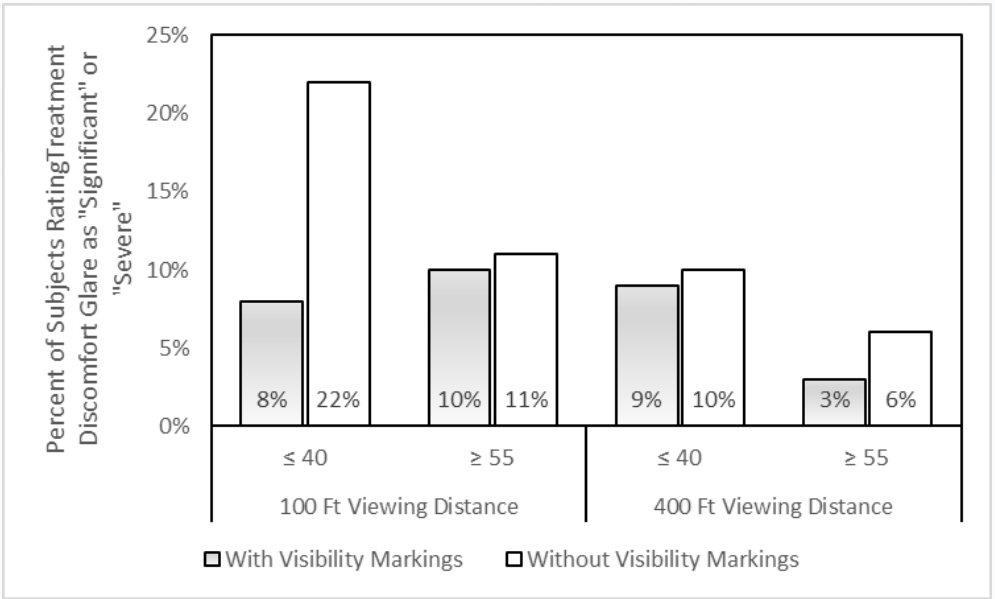
Amber and green warning light arrays resulted in higher ratings of distraction and discomfort glare for participants ≤ 40 years when viewed at 100’ viewing distance



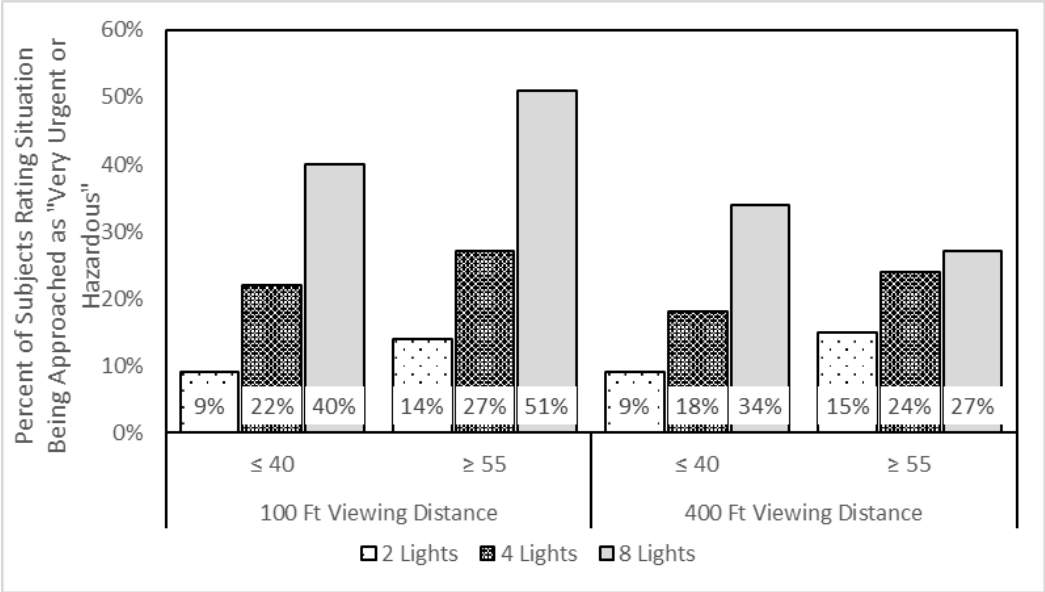


The fast flash speed resulted in higher ratings of discomfort glare, while use of vehicle markings on the rear of the treatment vehicle reduced ratings of discomfort glare.

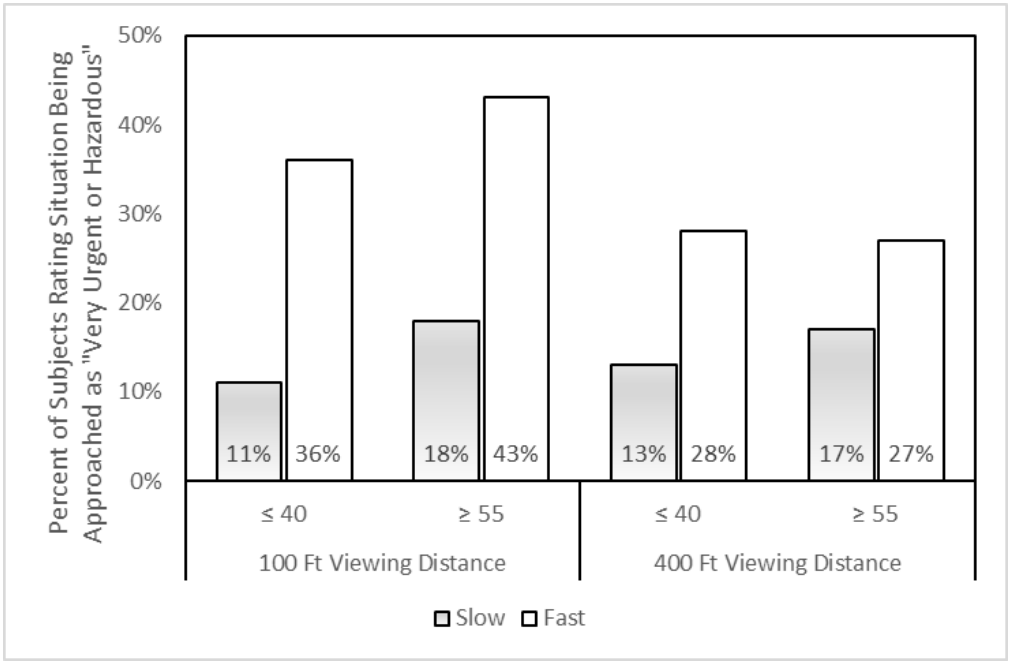


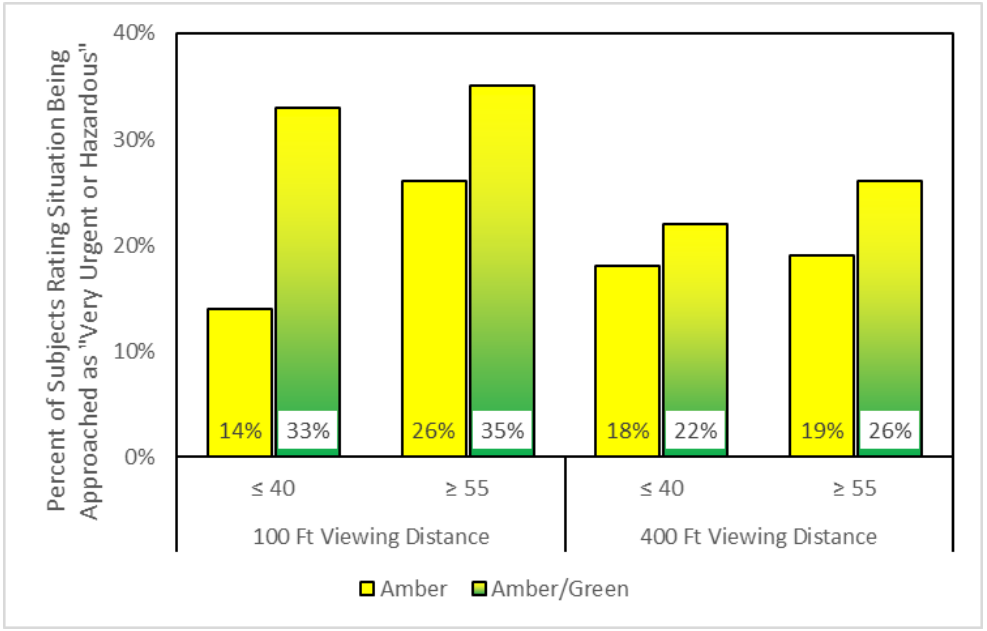


More lights in the warning light array increased participant rating of urgency or hazard risk implied by the lights.



The fast flash speed and the amber and green warning light arrays also increased participant rating of urgency or hazard risk implied by the lights





Daytime and Nighttime Closed-Course Dynamic Studies

- Focused on effects of different flash speeds or flash patterns upon driver ability to judge speed of work vehicles they are approaching while driving.
  - Slow speed (1.25 hz)
  - Fast speed (2.5 hz)
  - An alternating slow and fast speed (1.25 hz, then 2.5 hz, then 1.25 hz, etc.)
  - Alternating flash pattern
  - Asynchronous flash pattern
- Determine whether flash speeds and patterns have different effects of specular glare that may occur when the pavement is wet at night

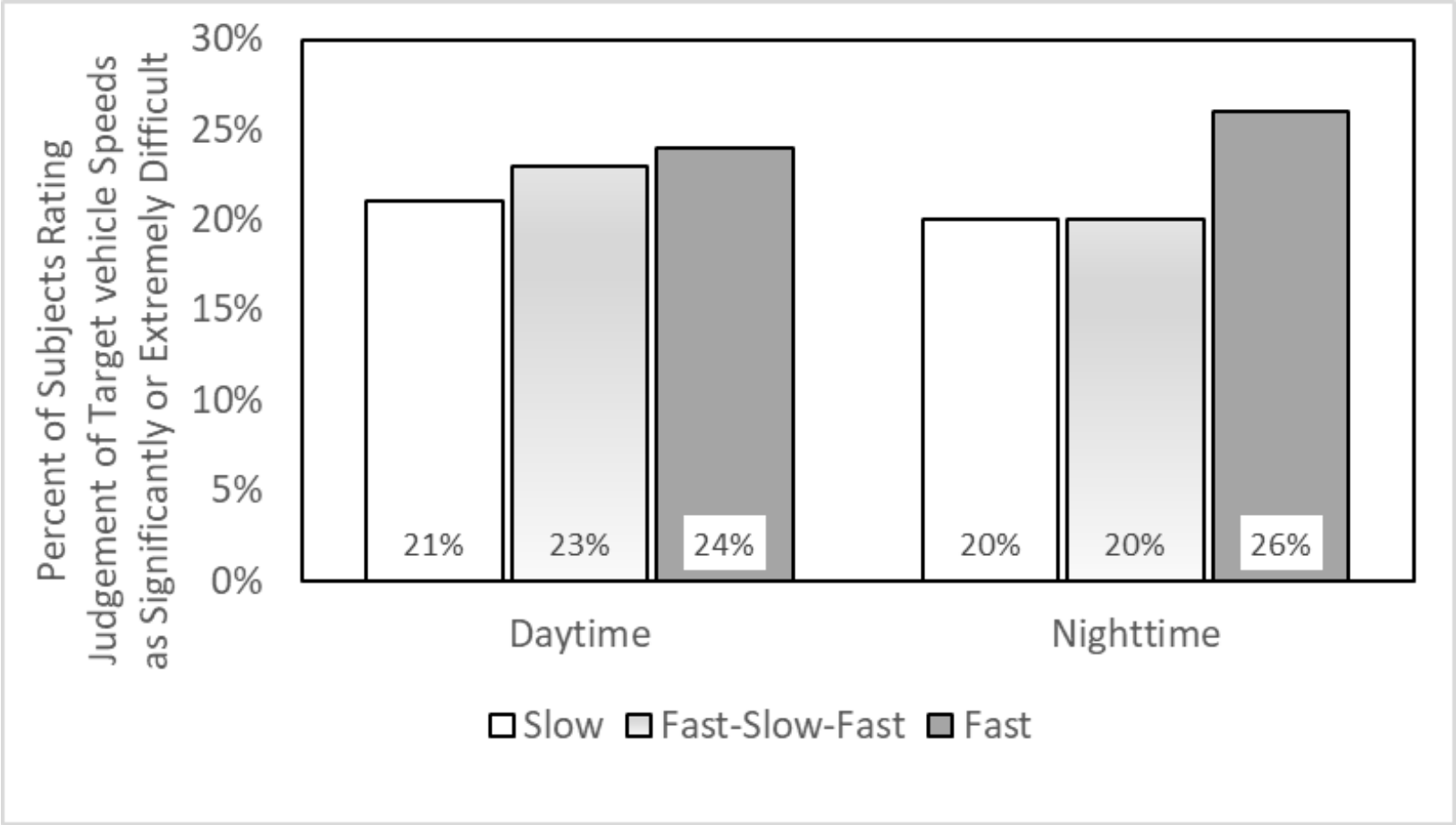
Study Methodology

- Study participants seated in driver seat of data collection vehicle traveled towards work vehicle with warning light treatment at ~ 30 mph.
- Work vehicle either faced the data collection vehicle or away and either remained stationary, moved slowly (3 mph), or moved slightly faster (10 mph)
- Participant identified when they could tell whether the work vehicle was stationary, moving slowly, or moving slightly faster

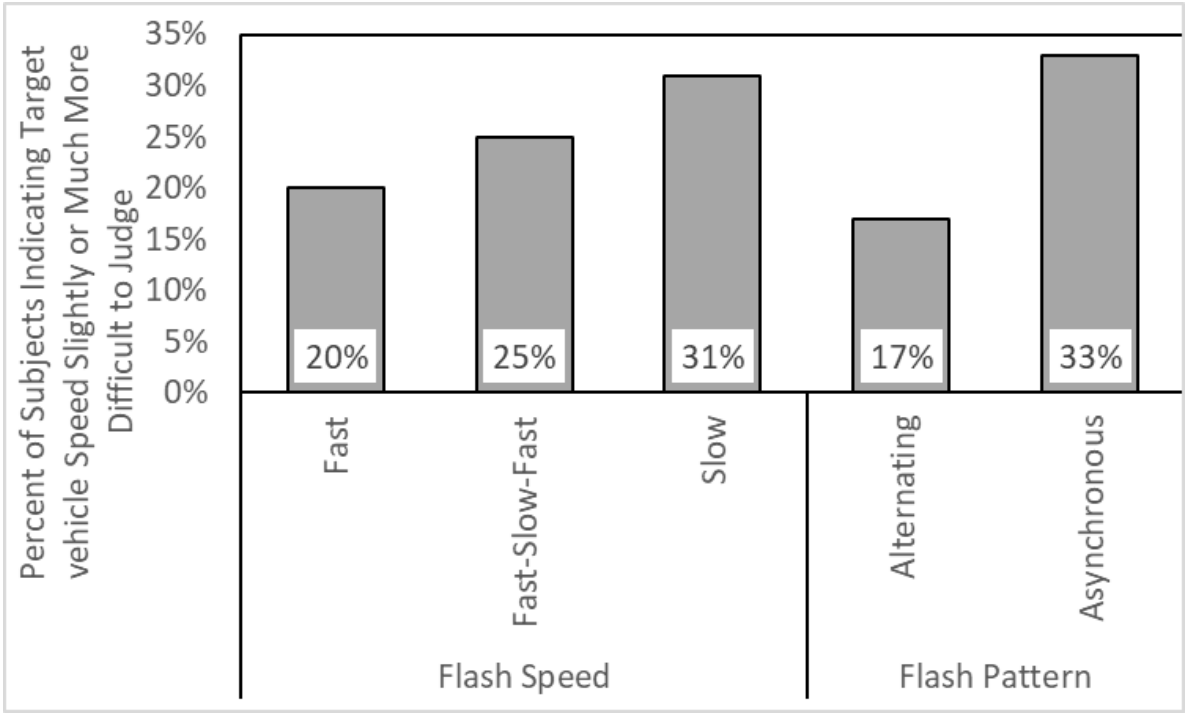
Results of Closed-Course Dynamic Studies

- Participants less likely to accurately identify target vehicle speed when traveling toward the subject than when it was traveling away from (in same direction as) data collection vehicle.
- None of the warning light treatments significantly affected target vehicle speed identification accuracy.

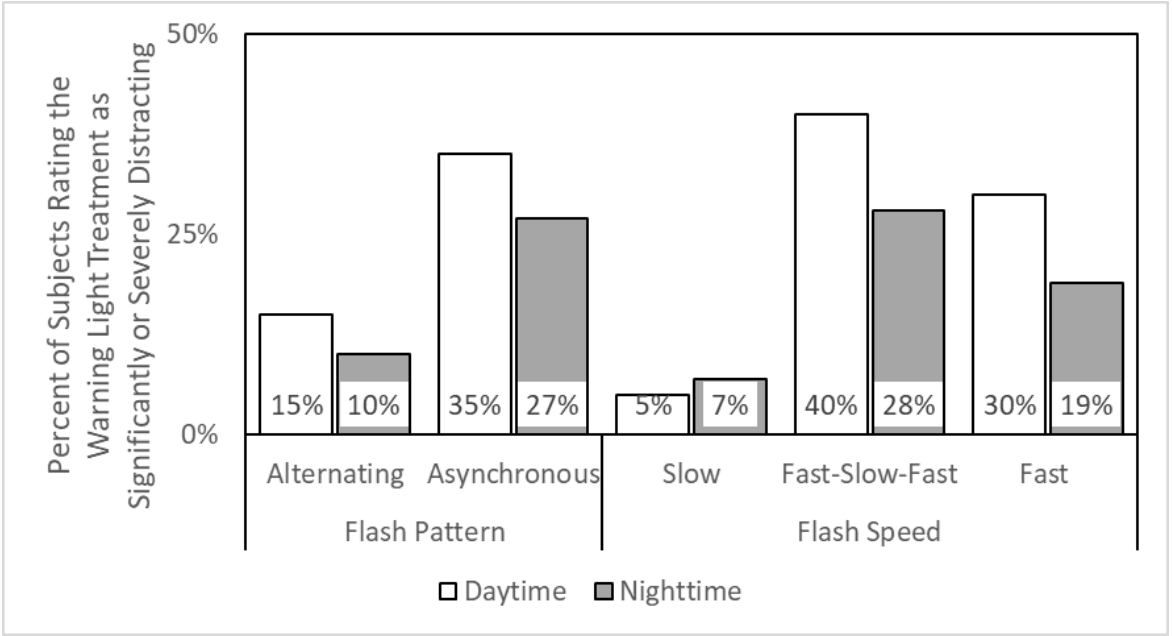
Judgement of work vehicle speed traveling toward the participant was more difficult when the fast flash speed was displayed



Warning light treatments using a slow flash speed was more difficult when pavement was wet



Alternating flash pattern and slow flash speed were rated as less distracting than other treatments



Field Evaluations of Best Warning Light Treatments

- Focused on driver behaviors (speeds, lane choice) approaching and passing by a work vehicle with warning light treatments that
- Warning light treatments evaluated
  - Amber versus amber and green
  - Slow flash speed, fast flash speed, alternating fast-slow-fast flash speed
  - Alternating flash pattern
  - 8-light array evaluated daytime, 4-light array evaluated at night

Study Methodology

- Stationary shoulder closures were evaluated
- Same locations evaluated during daytime and nighttime viewing conditions
- Four study sites selected
  - Two in Texas, two in Connecticut
  - Two on two-lane highways, two on multi-lane highways or interstates
- Used lidar to measure speeds of vehicles passing by the work vehicle
- At multi-lane highway sites, lane distribution adjacent to the work vehicle were also recorded

Speeds past the work vehicle tended to be lower when amber and green lights were displayed

Site	Average Speed, mph			
	Daytime		Nighttime	
	Amber	Amber/ Green	Amber	Amber/ Green
Site 1: Four-lane divided	71.9	71.6	69.9	69.3
Site 2: Two-lane highway	67.3	68.0	66.1	64.7
Site 3: Two-lane highway	48.4	46.4	45.7	43.3
Site 4: four-lane divided	70.2	67.9	67.5	66.5

Amber and green lights also resulted in greater percentages of drivers using lane away from work vehicle

Site	Percent of Traffic in Lane Away from Work Vehicle			
	Daytime		Nighttime	
	Amber	Amber/ Green	Amber	Amber/ Green
Site 1: Four-lane divided	74	80	86	93
Site 4: four-lane divided	51	53	53	52

Conclusions

- Vehicle markings assist driver abilities to detect workers on foot at night, so long as they are not overly unique. Unique markings may increase their attention-attracting abilities, but possibly at the expense of decreased worker detection and recognition.
- Use of more Class 1 warning lights in an array increases ratings of urgency or level of hazard being approached, but also increases distraction and discomfort glare.

Conclusions (Cont'd)

- Use of multi-color (amber and green) lights increases driver perceptions of urgency or level of hazard being approached, but also distraction and discomfort glare. Amber and green lights yielded the greatest response by drivers during the field evaluations
- Fast flash speeds increases driver perceptions of urgency or level of hazard being approached, but also distraction and discomfort glare.
- The alternating fast-slow-fast flash speed did not affect driver abilities to judge work vehicle speeds or influence driver behavior in the field evaluations.

Conclusions (cont'd)

- An asynchronous flash pattern reduces driver abilities to detect and recognize worker presence and causes higher ratings of discomfort glare.
- The asynchronous flash pattern was also rated as indicating a less urgent or hazardous situation than does an alternating flash pattern.

Implementation Recommendations

- Different marking and warning light needs exist depending on type of roadway operations vehicle or equipment of interest
  - Service patrols/incident response
  - Temporary traffic control vehicles
  - Winter weather treatment and response vehicles
  - Project inspector or manager vehicles
  - Construction, maintenance and utility work vehicles
  - Construction, maintenance, and utility work equipmen

Vehicle Marking and Warning Light Recommendations

Service Patrol/Incident Response	– **Marking Colors: red and white (or colors other than yellow and black)** – **Marking Pattern: inverted V or checkerboard** – **Peak Light Intensity: 1200 cd minimum daytime, 1200 cd maximum nighttime** – **Light Color(s): multi-color (amber and green, amber and blue or amber and red if allowed by law)** – **Light Flash Speed(s): fast (2.5-3 Hz) or alternating fast-slow (1-1.25 Hz)-fast**

Vehicle Marking and Warning Light Recommendations (cont'd)

TTC Vehicles (Truck- or Trailer-Mounted Attenuators, Shadow Vehicles, etc.)	– **Marking Colors: yellow and black (if using checkerboard pattern) or red and white (if using an inverted V pattern)** – **Marking Pattern: see marking colors** – **Peak Light Intensity: 1200 cd minimum daytime, 1200 cd maximum nighttime** – **Light Color(s): multi-color (amber and green, amber and blue or amber and red if allowed by law)** – **Light Flash Speed(s): slow or alternating fast - slow -fast**

Vehicle Marking and Warning Light Recommendations (cont'd)

Winter Pre-Treatment Vehicles/ Snowplowing Operations	– **Marking Colors: yellow and black (or other colors that contrast with a white background)** – **Marking Pattern: checkerboard** – **Peak Light Intensity: 1200 cd minimum daytime, 1200 cd maximum nighttime** – **Light Color(s): multi-color (green and amber, blue and amber or red and amber if allowed by law)** – **Light Flash Speed(s): slow or alternating fast-slow-fast**

Vehicle Marking and Warning Light Recommendations (cont'd)

Project Inspector/Project Manager Vehicles	– **Marking Colors: yellow and black** – **Marking Pattern: inverted V** – **Peak Light Intensity: 1200 cd minimum daytime, 1200 maximum nighttime** – **Light Color(s): multi-color (green and amber, blue and amber or red and amber if allowed by law)** – **Light Flash Speed(s): slow or alternating fast-slow-fast**

Vehicle Marking and Warning Light Recommendations (cont'd)

Construction/Maintenance/Utility Work Vehicles	– **Marking Colors: yellow and black** – **Marking Pattern: inverted V** – **Peak Light Intensity: 1200 cd minimum daytime, 1200 maximum nighttime** – **Light Color(s): amber or amber and white** – **Light Flash Speed(s): slow**
Construction Equipment	– **Marking Colors: none required (yellow and black if agencies choose to use them)** – **Marking Pattern: none require (inverted V if used)** – **Peak Light Intensity: minimum 300 cd (single Class 2 warning light)** – **Light Color(s): amber or amber and white** – **Light Flash Speed(s): slow**

Questions?

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