WARNING BEACON CHARACTERISTICS FOR VISIBILITY, GLARE PREVENTION AND CLOSURE DETECTION

Bullough, J.D., Rea, M.S.
Lighting Research Center, Rensselaer Polytechnic Institute, Troy, NY, USA
bulloj@rpi.edu, ream@rpi.edu

Abstract

Front line service workers in the transportation, construction, utility and delivery sectors of the work force are over-represented in terms of work place fatalities. Flashing yellow warning beacons often are the only line of defence between these workers and drivers on the road. Standards for warning beacons include specifications for minimum intensity characteristics to ensure visual detection, for chromaticity to ensure that they can be distinguished from red and blue emergency vehicle flashing lights, and for the flash rate to ensure conspicuity and to prevent seizures among drivers with photosensitive epilepsy. Previous research has suggested that if warning beacons are too bright under nighttime viewing conditions, they could produce glare. Prior studies have also shown that it can be difficult to judge closing distance when lights flash in an on-off pattern compared to temporally modulating lights that do not go completely off. The results of two experiments of visual responses to warning lights are summarized. These findings can enhance the foundations for warning beacon standards.

Keywords: Transportation signals, Flashing lights, Driving safety

1 Introduction

Front line service workers in the transportation, construction, utility and delivery sectors of the work force are over-represented in terms of work place fatalities (NIOSH, 2014). When these individuals are working on or adjacent to active rights-of-way along the roadway, flashing yellow warning beacons often are the only line of defence between them and drivers on the road. Published standards for warning beacons (SAE, 1990, 1997, 1998) include specifications for the minimum intensity characteristics to ensure visual detection, for chromaticity to ensure that they can be distinguished from red and blue emergency vehicle flashing lights, and for the flash rate to ensure conspicuity and to prevent seizures among drivers with photosensitive epilepsy by limiting flash rates to no higher than 4 Hz. Although some experimental evidence (Howard and Finch, 1960) suggests that minimum peak luminous intensity standards for warning beacons are appropriate for daytime viewing conditions, additional published work suggests that warning beacons can be too bright under some nighttime viewing conditions, potentially producing glare (Bullough and Rea, 2015). Prior studies have also shown that it can be difficult to judge closing distance when lights flash on-off compared to temporally modulating lights that do not go completely off (Bullough et al., 2001). Two experiments were conducted to enhance the foundations for warning beacon standards.

2 Methods

Two experiments were conducted, a visibility experiment to assess the role of the warning beacon's peak luminous intensity on observers' ability to detect the warning beacon onset and the visibility of potential roadway hazards, and a closure detection experiment to evaluate the impact of the temporal flashing characteristics of a warning beacon on observers' ability to judge the relative motion of the beacons.

2.1 Warning Beacon Visibility Experiment

In the visibility experiment, 26 subjects, grouped approximately evenly by male and female, younger (<30 years) and older (>50 years), viewed the onset of warning beacons under simulated daytime (background luminance 300 cd/m^2) and nighttime (background luminance 1 cd/m^2) roadway scenes, and with or without visual clutter (other flashing lights). As illustrated in Figure 1, Subjects fixated on a low-contrast Landolt ring target located adjacent to the roadway or 5 degrees to the right of the roadway edge. This location was used because Mourant and Rockwell (1970) found driver gaze locations to vary within 5 degrees from the roadway ahead; thus, the onset of a warning beacon would be likely to occur up to 5 degrees from a driver's line of sight. The peak luminous intensity of the flashing warning beacon (1 Hz flash frequency) could be varied randomly across trials between 80 and 3100 cd. Subjects were instructed to push a button as quickly as they could detect the randomly presented warning beacon located adjacent to the roadway edge, and then to rate its visibility relative to a reference warning beacon with a peak luminous intensity of 850 cd (defined by the experimenter as having a visibility of 10) presented before the session began. Subjects also rated the visibility of the low-contrast fixation target relative to its visibility when no warning beacon was present (this was defined by the experimenter as having a visibility of 10). The latter rating was used as a surrogate measure for disability glare caused by the simulated warning beacon.

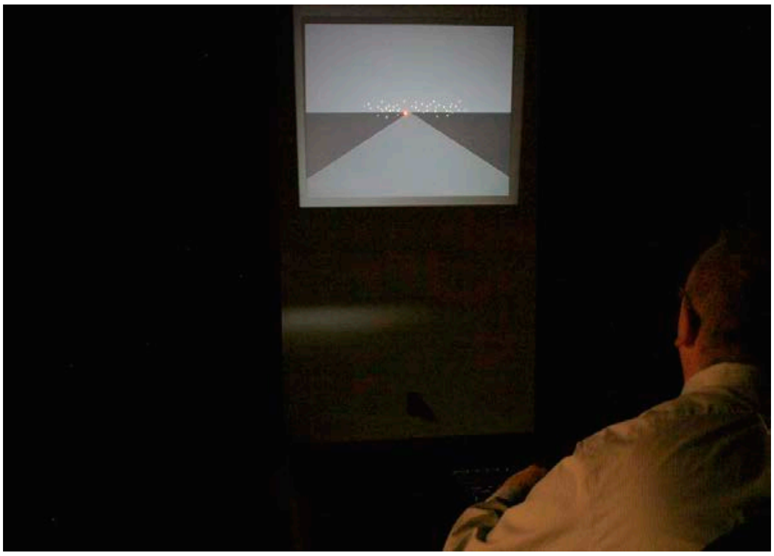

Figure 1 – Photograph of subject performing the visibility experiment.

2.2 Closure Detection Experiment

In the closure detection experiment, the same subjects viewed video animations of warning beacons (1 Hz flash frequency) seen from a simulated distance of 100 m under nighttime viewing conditions (background luminance 1 cd/m^2). For some trials a single beacon was shown while for other trials (see Figure 2), two side-by-side synchronized beacons were separated by a simulated distance of 2.4 m. The modulation of the beacon flashing was also randomized among completely on (100%) and off (0%) flashing, steady-burning (always 100%), and completely on (100%) and dim (10%) flashing. In some sets of trials, subjects fixated directly on the simulated warning beacons and in others they fixated at a location 5 degrees to the left of the warning beacons. After random intervals, the simulated beacons would appear to start to move toward the observer with an apparent velocity of 16 km/h. Subjects were instructed to press a button as soon as they could detect the approach of the warning beacons. The time between initiation of the simulated approach and the button press was recorded.

Figure 2 – Frame from video animation showing a pair of beacons in the closure detection experiment.

3 Results

3.1 Warning Beacon Visibility Experiment

Figure 3 shows the mean response times (RTs) to the onset of warning beacons, as a function of the peak luminous intensity, for warning beacons viewed under daytime and nighttime conditions, and located adjacent to (on-axis), or 5 degrees from (off-axis), the subjects' line of sight.

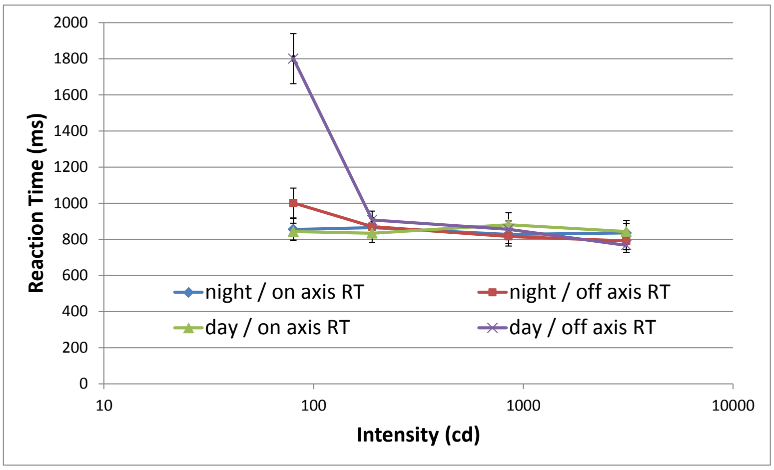

Figure 3 – Mean (±s.e.m.) response times to the onset of warning beacons under daytime and nighttime viewing conditions and when viewed on- or off-axis.

An analysis of variance (ANOVA) using RTs to the onset of the warning beacon as the dependent variable revealed a main effect of the maximum warning beacon intensity, with higher intensities associated with statistically shorter response times. RTs were also longer when the warning beacon was viewed off-axis from the fixation location, and for the female subjects. A statistically reliable interaction between the ambient light level and the maximum warning beacon intensity was found; RTs decreased with maximum intensity during the daytime but changed little as a function of intensity for the nighttime conditions. A reliable two-way interaction between the ambient light level and the presence of clutter was also found; with clutter present, RTs under nighttime conditions became similar to those under daytime conditions. The mean RTs in Figure 3 appear to reach asymptotic values for peak luminous intensities of 200 cd or greater. For some specific experimental conditions (e.g., off-axis viewing under daytime conditions with visual clutter present, and for older subjects), peak luminous intensities approaching 850 cd were needed before asymptotic RT values were achieved. This is consistent with previous findings (Howard and Finch, 1960; Rea and Bullough, 2015) showing a peak luminous intensity between 500 and 600 cd provided consistent daytime visibility. Flannagan et al. (2008) reported that RTs to flashing yellow lights continued to decrease above peak intensities of 1000 cd when the lights were viewed 45 degrees off-axis in that study, whereas in the present study they were viewed within 5 degrees from the line of sight.

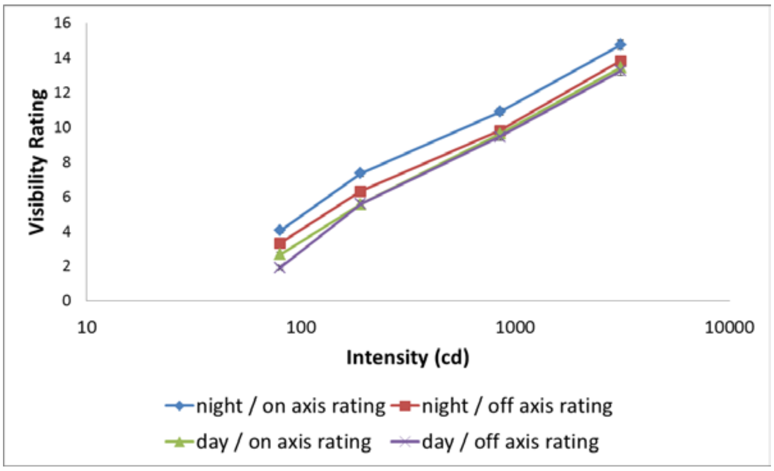

Figure 4 – Mean (±s.e.m.) warning beacon visibility ratings under daytime and nighttime viewing conditions and when viewed on- or off-axis.

Figure 4 shows the mean visibility ratings for the warning beacons as a function of peak luminous intensity, for daytime and nighttime conditions and for on- and off-axis viewing. An ANOVA using visibility ratings of the warning beacons as the dependent variable showed that visibility statistically increased with higher warning beacon intensities, with nighttime viewing conditions, and for uncluttered roadway scenes. The visibility rating data do not exhibit asymptotic behaviour as the RT data do; higher peak intensities (up to about 3000 cd) yield higher ratings of warning beacon visibility under all viewing conditions.

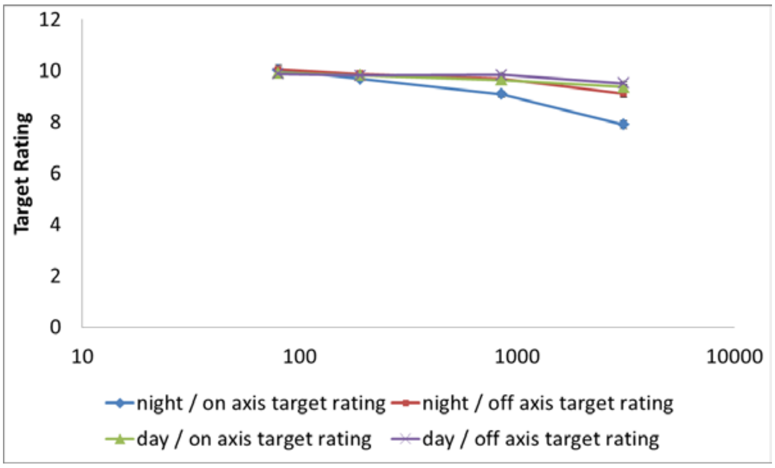

Figure 5 – Mean (±s.e.m.) target visibility ratings under daytime and nighttime viewing conditions and when the warning beacon was located on- or off-axis.

Figure 5 shows the mean target visibility ratings, plotted as a function the peak luminous intensity of the beacon, for daytime and nighttime conditions and when the beacon was located on- or off-axis from the subjects' line of sight. An ANOVA using visibility ratings of the low-contrast fixation target statistically decreased as the beacon intensity increased, and there was a reliable interaction between the ambient light level and the warning beacon intensity so that the decrease in rated target visibility only occurred under nighttime ambient conditions, and especially for on-axis viewing conditions, when disability glare would be most problematic (Rea, 2000).

3.2 Closure Detection Experiment

Figure 6 shows the mean closure detection times in the closure detection experiment for the three temporal flashing profiles used. An ANOVA using closure detection time as the dependent variable revealed reliable main effects of the number of warning beacons, the flashing configuration, and the location of the warning beacons in the field of view. Two warning beacons yielded shorter closure detection times than a single beacon. On-off flashing yielded longer closure detection times than either steady-burning lights or the on-dim flashing lights. Closure detection times were also shorter when viewed on-axis than 5 degrees off-axis.

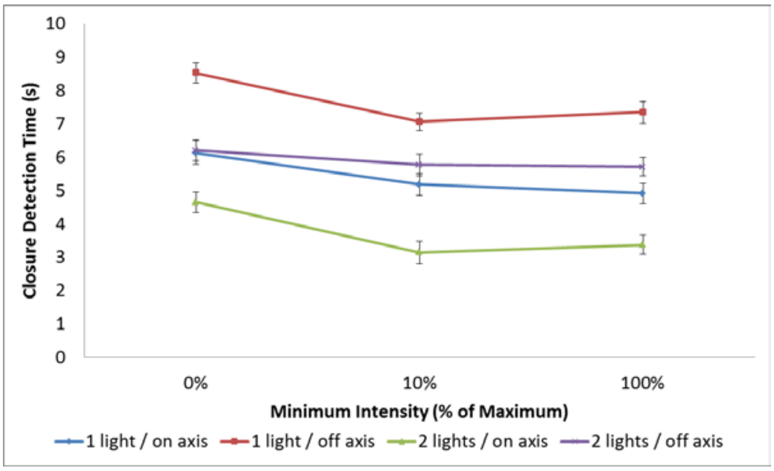

Figure 6 – Mean (±s.e.m.) closure detection times to single warning beacons or pairs of beacons viewed on- or off-axis, as a function of the relative minimum intensity.

4 Discussion

These data can contribute to the development of better performance specifications for warning beacons to help ensure that they can be detected rapidly by drivers under both daytime and nighttime conditions, without producing excessive glare, especially under nighttime conditions. The data also indicate that a minimum intensity value of 10% relative to the maximum for flashing warning beacons will assist in supporting judgments of the relative speed of service vehicles equipped with these lights. Preliminary specifications derived from these results (Table 1) will be field-tested in full-scale test track evaluations to validate and, as necessary, refine them. Subsequent work will focus on the use of different chromaticities and flash rates, and on the coordination of flashing characteristics among multiple warning beacons to provide visual information to drivers about the nature of activities in the work site.

Table 1 – Preliminary Warning Beacon Performance Specifications

Performance Characteristic	Preliminary Recommendation	Rationale
Peak luminous intensity	530 cd minimum (daytime) 180 cd minimum (nighttime)	Minimum levels observed to yield asymptotic reaction times Higher nighttime levels would impair visibility of low contrast objects
Temporal modulation	10:1 maximum:minimum intensity ratio	Steady-burning lights outperform on-off flashing for closure detection

5 Acknowledgements

The present study was supported by the U.S. National Institute of Occupational Safety and Health (NIOSH) under grant R01 OH0 10165 to Mark Rea. Dennis Guyon, Nicholas Skinner and Timothy Plummer from the Lighting Research Center, and Philip Garvey, Eric Donnell and

Martin Pietrucha from Pennsylvania State University provided valuable technical assistance in preparing this paper.

References

BULLOUGH, J. D., M. S. REA, R. M. PYSAR, H. K. NAKHLA, D. E. AMSLER. 2001. Rear lighting configurations for winter maintenance vehicles. *Proceedings of the Illuminating Engineering Society Annual Conference*, Ottawa, August 5-8, Illuminating Engineering Society.

BULLOUGH, J. D., M. S. REA. 2015. Luminous intensity requirements for service vehicle warning beacons. *Transportation Research Board 94th Annual Meeting*, Washington, January 11-15, Transportation Research Board.

FLANNAGAN, M. J., D. F. BLOWER, J. F. DEVONSHIRE. 2008. *Effects of Warning Lamp Color and Intensity on Driver Vision.* Warrendale: Society of Automotive Engineers.

HOWARD J., D. M. FINCH. 1960. Visual characteristics of flashing roadway hazard warning devices. *Highway Research Board Bulletin*, 255, 146-157.

MOURANT, R. R., T. H. ROCKWELL. 1970. Mapping eye-movement patterns to the visual scene in driving: an exploratory study. *Human Factors*, 12, 81-87.

NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH. 2014. *National Occupational Research Agenda*. Washington: National Institute for Occupational Safety and Health.

REA, M. S. (Editor). 2000. *IESNA Lighting Handbook: Reference and Application*, 9th Edition. New York: Illuminating Engineering Society.

SOCIETY OF AUTOMOTIVE ENGINEERS. 1990. *Flashing Warning Lamps for Authorized Emergency, Maintenance and Service Vehicles, J595.* Warrendale: Society of Automotive Engineers.

SOCIETY OF AUTOMOTIVE ENGINEERS. 1997. *Optical Warning Devices for Authorized Emergency, Maintenance and Service Vehicles, J845.* Warrendale: Society of Automotive Engineers.

SOCIETY OF AUTOMOTIVE ENGINEERS. 1998. *Gaseous Discharge Warning Lamp for Authorized Emergency, Maintenance and Service Vehicles, J1318.* Warrendale: Society of Automotive Engineers.