The effect of oncoming headlight glare on peripheral detection under a mesopic light level

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1. Introduction

While driving on a roadway at night, peripheral vision is used to detect potential hazards in adjacent areas such as pedestrians or animals that are about to cross the roadway (Rea, 2001). The peripheral vision can be influenced by many factors such as oncoming headlight glare, fixed street lighting, and forward headlights.

Oncoming headlights sometimes cause disability glare that may obscure driver's vision, both foveal and peripheral. The effects of disability glare on foveal vision have been investigated by many researchers for about 70 years and are generally specified by equivalent veiling luminance (e.g. Stiles and Crawford, 1937). However, few researchers have studied how disability glare impairs peripheral vision. So, it is important to investigate the effect of oncoming headlight glare on peripheral detection in a real roadway setting.

Regarding the influence of spectral power distribution (SPD) on peripheral detection, recent laboratory studies have shown, for example, off-axis detection can be better for metal halide lamps than for high pressure sodium lamps at the same photopically specified light level (He et al., 1997, Lewis, 1998 and 1999, Bullough and Rea, 2000). Glare also might be linked to SPD; light sources with relatively more short-wavelength content are perceived as more glaring at the same photopically specified intensity (Ferguson et al, 1953, de Boer and van Heemskerck Veeckens, 1955). These data suggest that there may be an interaction between headlight glare and fixed lighting when different SPDs are employed.

A field study was carried out to investigate how oncoming glare from halogen headlights impaired driver's detection of peripheral targets under two fixed street lighting sources—high pressure sodium (HPS) and metal halide (MH) lamps.

2. Experiment

2.1. Location and Apparatus

This study used a paved private parking lot at the Rensselaer Technology Park, North Greenbush, NY. All existing luminaires in the parking lot were turned off during the experiment. No other luminaires in the area affected illuminance on the parking lot and no extraneous light sources were visible to subjects while performing the experiment. In the parking lot, traffic cones demarcated a 3m wide, 80m long lane along the north end of the parking lot (Figure 1).

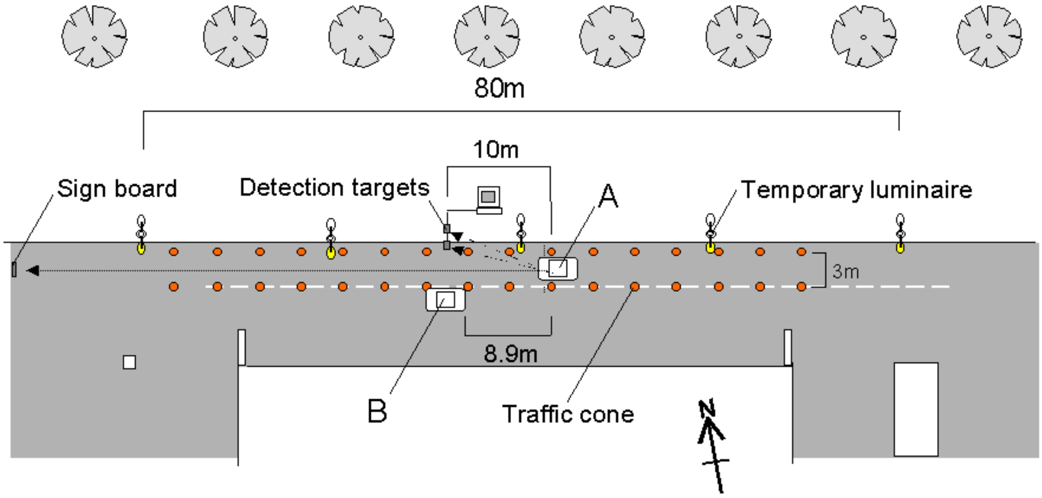


Figure 1: Lane employed in the experiment

The study used five temporary streetlight luminaires. The poles were placed at 20m intervals along the straight portion of the track (Figure 1). Two independent luminaires were mounted on every one of the five 12' high poles; one housed a high-pressure sodium (HPS) lamp and the other contained a metal halide (MH) lamp. A cylinder on the top of each pole held both luminaires, one on each side. By rotating the cylinder the positions of the luminaires could be easily and quickly changed during the study. To meet the IESNA illuminance recommendations (Rea, 2000) and reduce illuminance level to 5.5 lx (average) on the pavement, metal mesh filters were attached to the luminaires. Specification for the luminaires and lamps are given in Table 1. Figure 2 shows the SPDs of the light emitted by the luminaires with and without the mesh filters.

	Quantity	Specification	Product name and number	Manufacturer
Pole	5	3.65m (12’)	RA4-12-D2-NP	Gardco Emco McPhilben
HPS unit	5	150W, 277V	G13-4XL-150HPS-277V-NP	Gardco Emco McPhilben
MH unit	5	175W, 277V	G13-4XL-175MH- 277V-NP	Gardco Emco McPhilben
HPS lamp	5	150W, Ra30, 16,000lm	LU150/55/MED 67508-1	OSRAM SYLVANIA
MH lamp	5	175W, Ra65, 11,700lm	M175/U/MED 64479-0	OSRAM SYLVANIA

Table 1: Luminaire and lamp descriptions

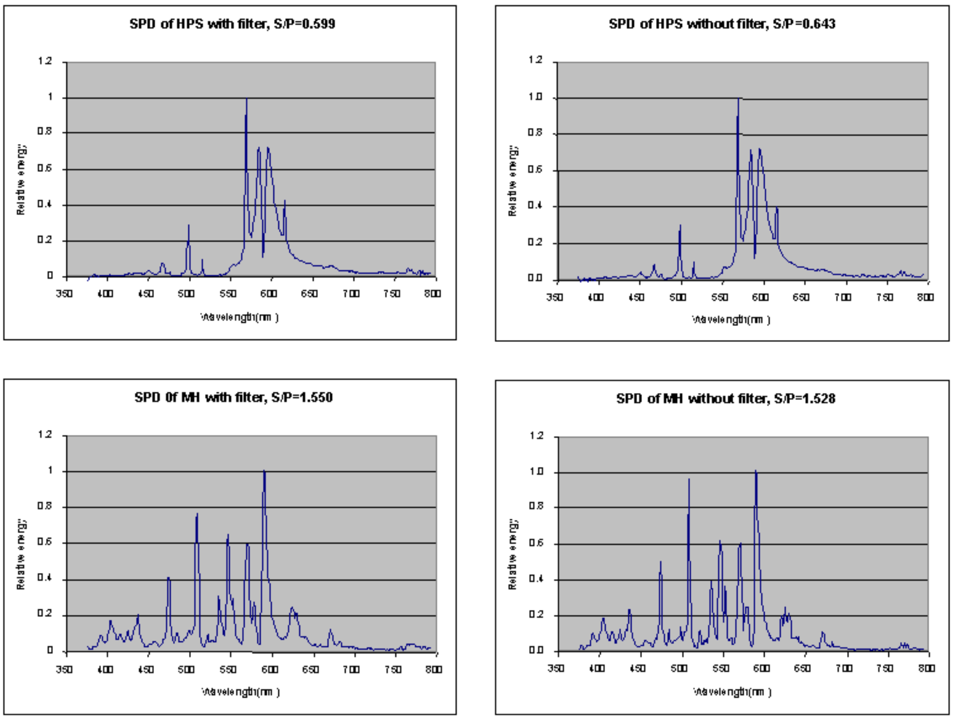


Figure 2: Spectral power distributions of light emitted by luminaires

The study used a white 1999 Ford Taurus SE with halogen headlamps. The car was positioned near the third (central) pole in Figure 1 (A). Subjects rode in the driver’s seat of the car (left side). The vertical illuminance distribution at a distance of 10m from the headlights of the car is shown in Appendix 1. A gold 1995 Volkswagen Jetta GLS with halogen headlamps (B) provided oncoming headlight glare. It was parked facing the opposite lane of the track 8.9 m from the subject in the Taurus. At this position, the headlights of the Jetta provided the maximum vertical illuminance level (2.4lx) to the left eye of the subject.

The subjects' task was to detect a change in reflectance for one of two targets while fixated on a signboard at the end of the track (Figures 1, 3, and 4). Figure 4 diagrams the experimental system employed in this experiment. The experimental system composed of the two detection targets, the signboard, a computer, a micro-controller, a manual switch, a transmitter, and a receiver.

Figure 3: View of parking lot employed in the experiment

The detection targets were located 15° and 23° off-axis to the right when the subjects looked straight ahead. Each detection target was a 25×17cm liquid crystal panel behind an opening of a 60 cm black painted cubic box. The targets subtended 1.38°×0.94° (solid angle 3.97×10^{-4}sr) and 1.32°×0.89° (solid angle 3.60×10^{-4}sr), respectively, for the driver's viewing position shown in Figure 4. The liquid crystal panel was electrically switched from transparent (reflectance 0%) to gray (reflectance 20%) and required approximately 0.25 seconds to reach full transmittance. When it turned transparent, the subject saw the black painted interior in the box.

A resistive force sensor was used as the manual switch for each subject to signal target detection. The sensor, connected to the transmitter, was attached to the dashboard next to the steering wheel of the car. When a subject touched the sensor, the transmitter sent a signal to the receiver. The receiver was connected to the micro-controller of the computer. The micro-controller circuit measured each subject's reaction time from the time one of detection targets was presented until the subject touched the sensor. The micro-controller sent the reaction time value to the computer that then recorded the reaction time, in milliseconds.

The signboard display was placed at the end of the straight track in front of the subject. It was composed of seven red LEDs and was controlled by a separate micro-controller. The signboard displayed a 30×20cm (14×10 min arc) numerical character for one second in a random order. The details of the experimental system are given in Table 2.

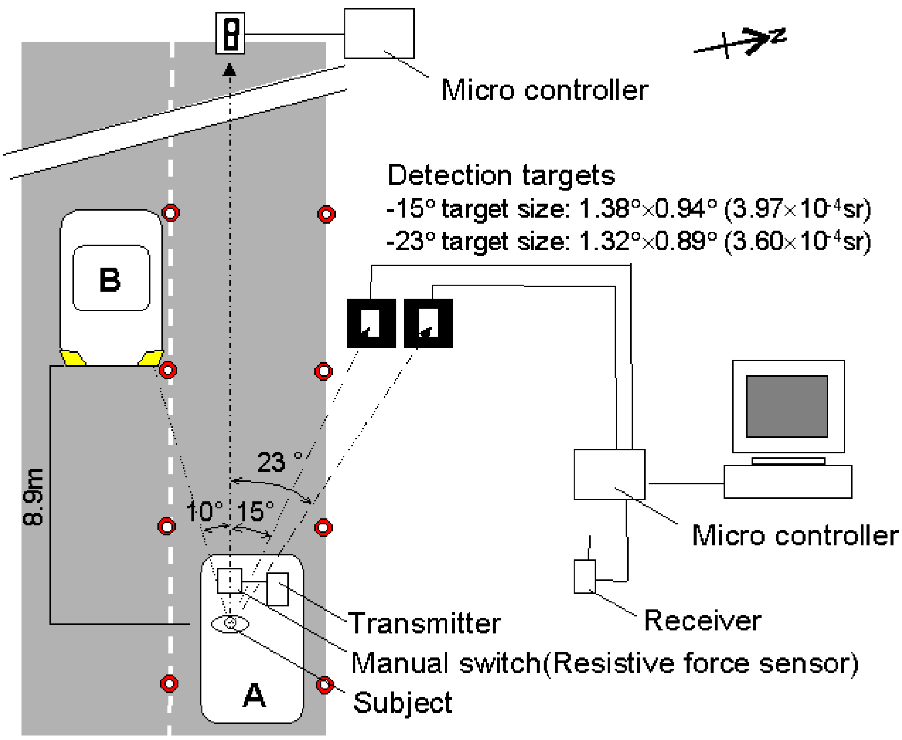


Figure 4: Experimental system

Description	Part name and number	Manufacturer
Liquid crystal panel	Privacy Glazing, Sample	3M
Micro controller	BASIC Stamp II Module, BS2-IC	Parallax
Transmitter	418MHz TRANSMITTER, 27986	Parallax
Receiver	418MHz RECEIVER, 27987	Parallax
Computer	ChemBook 7200E, Intel Pentium III 600MHz	ChemBook
Software	LabView 5.1	National Instruments

Table 2: Experimental system

2.2. Experimental conditions

Table 3 summarizes the experimental conditions. Two spectral power distributions (MH and HPS), two target locations (15° and 23° off-axis), and two oncoming headlight conditions (headlights on and off) were employed (eight experimental conditions in all). Illuminance level and illuminance uniformity on the road surface as well as target luminance and contrast were kept essentially constant during the study.

Although the same type of luminaire head was used for HPS and MH lamps, luminous distributions of HPS and MH luminaires differed slightly because of the different lamp sizes and bulb finishes. Figure 5 shows illuminance distributions on the pavement for the HPS and the MH luminaires around the third (central) pole in Figure 1. Although there were some differences in illuminance distribution for HPS and MH luminaires, the target photopic luminances were maintained at 0.33cd/m^2 by adjusting the location of each target for each condition. The contrast of the target to the background was always 0.54. Contrast was defined as $(L_T - L_B) / L_B$.

Variables	Ranges
Spectral power distribution	MH and HPS
Forward headlight	On and off
Off-axis angle (degrees)	15 and 23
Mean illuminance on road surface (lux)	5.5*
Illuminance uniformity (E_{min}/E_{ave})	0.13**
Luminance of targets (cd/m^2)	0.06***
Contrast of targets with background	0.54

*The mean illuminance levels were 5.4 lx for HPS and 5.6 lx for MH.

**The illuminance uniformity values were 0.15 for HPS and 0.11 for MH.

***When the headlight was turned on, the target luminance was increased to 0.27 cd/m^2 for the 15° off-axis target and 0.13 cd/m^2 for the 23° off-axis target.

Table 3: Experimental conditions employed in the headlight study

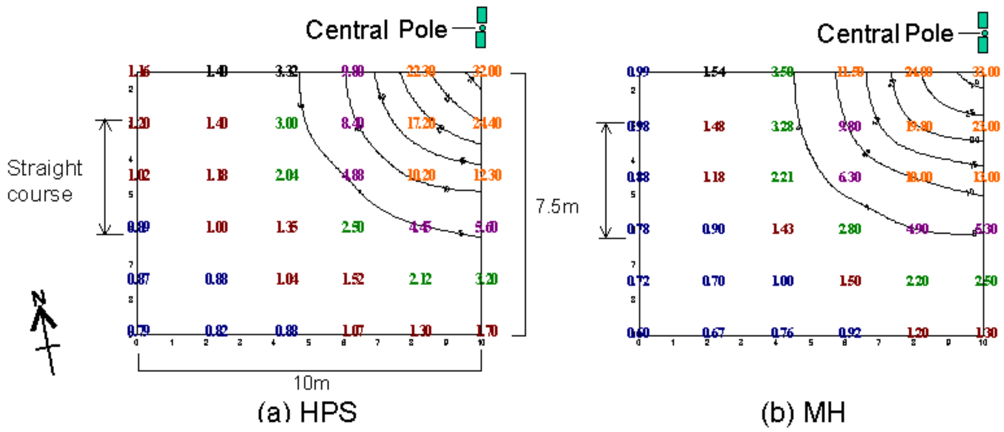


Figure 5: Illuminance distributions on the pavement

2.3. Procedure

Eight subjects (seven males and one female); all licensed drivers between the ages of 22 and 39 years old participated in the study. The subjects reported that they had normal color vision and visual acuity but were not formally screened for these characteristics. Every subject completed 100 trials, 80 trials for the experimental conditions (8 experimental conditions ×10 repetitions) and 20 trials for dummy presentations when no target appeared; no false positive was reported in this experiment. The 100 trials were divided into two parts (50 trials in each part). Half the trials were for HPS lamps and the other half were for the MH lamps. The order of the lamps and oncoming headlight conditions was counterbalanced across subjects. In each half part, the order of the target positions and dummy presentations was randomized.

Prior to the study, an experimenter instructed the subjects on the procedures for the study. Then, the experimenter asked the subject to get into the car, buckle the seatbelt, adjust the position and inclination of the seat, and determine the position of the sensor on the dashboard to touch it as quickly as possible. Then, the experimenter operated the computer-controlled system, issued instructions to the subject, and recorded the subject’s responses and behaviors. Another experimenter rode in the passenger seat with a radio transceiver. The experimenter in the passenger seat took the role of a correspondent between the subject and the other experimenter—letting the subject know instructions received from the outside experimenter and reporting the subject’s response and behavior to the outside experimenter. After at least twenty practice trials, the subject started the first 50 trials.

Every subject was asked to look at the character on the signboard at the end of the straight. As soon as the subject detected one of the off-axis targets, the subject touched the sensor with his or her right hand to signal detection. For each presentation, the off-axis target was presented for a maximum of two seconds, or until the subject signaled detection. After touching the sensor, the subject reported to the experimenter in the passenger seat which target appeared to the subject (15° or 23°). During the trials, the experimenter watched the subject's behavior and reported it to the outside experimenter if he noticed something important.

After the first 50 trials, the subject took a rest for about forty minutes, while the experimenters prepared for the next lamp type. Then, the subject started the second 50 trials.

2.4. Results

Table 4 shows the mean reaction times for the ten trials for each condition and each subject. The means in the last column of Table 4 suggest that there are large individual differences in the subjects' reaction times. Combined with the large standard deviations, shown in the last row of Table 4, it was impossible to make statistical inferences for the raw data. To reduce the effect of the individual differences for the statistical analyses, the individual data were standardized to their own mean reaction time for the MH/15°/OFF condition. This was always the shortest mean reaction time. Thus, statistical analyses were based on the ratios of mean reaction times to the mean reaction times for that condition.

The means of the reaction time ratios for all eight conditions are plotted in Figure 6 (a), (b), (c), and (d). These figures suggest:

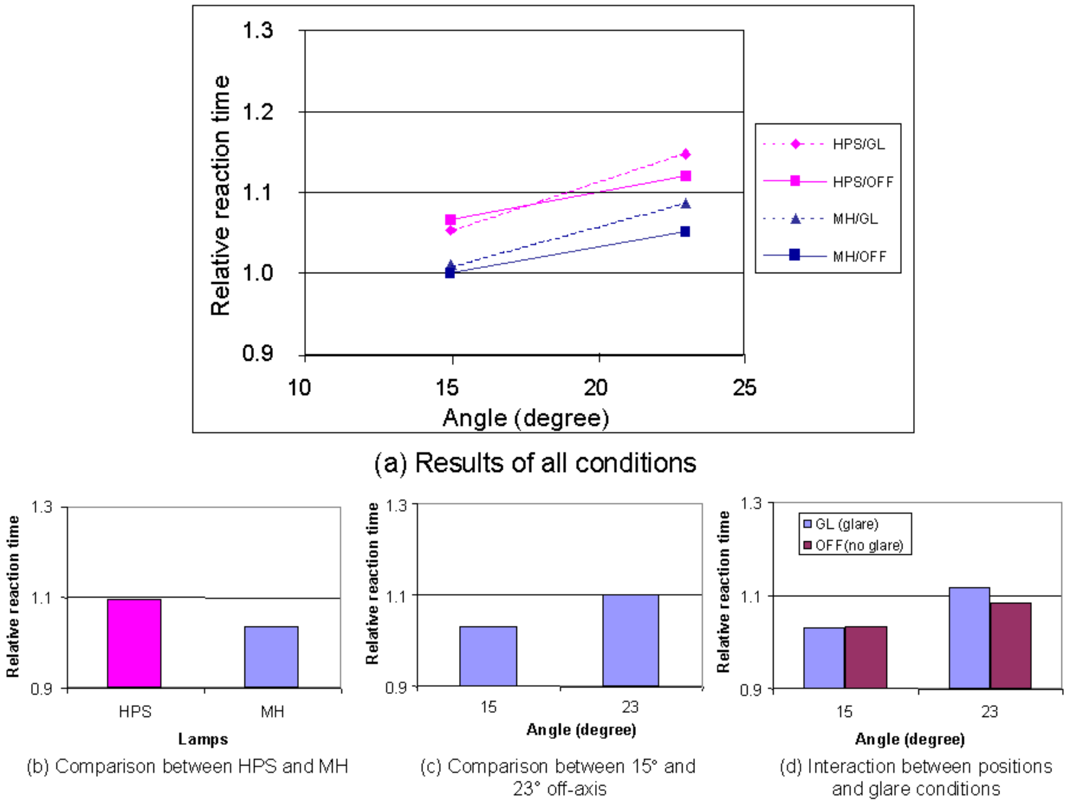
- Reaction times under MH were shorter than under HPS: Figure 6 (a & b).
- Reaction times for the inner target (15º off-axis) were shorter than those for the outer (23º off-axis) targets: Figure 6 (a & c).

- Oncoming headlight glare increased reaction time only for the outer target (23° off-axis): Figure 6 (a & d).

Condition* / Subject	HPS/15/GL	HPS/15/OFF	HPS/23/GL	HPS/23/OFF	MH/15/GL	MH/15/OFF	MH/23/GL	MH/23/OFF	Mean
S1	677	679	736	708	683	655	724	706	696
S2	813	902	1057	1079	828	751	868	855	894
S3	685	700	730	740	606	658	700	701	690
S4	596	605	584	574	600	587	590	594	591
S5	604	632	703	665	617	571	679	592	633
S6	802	769	812	810	751	762	806	754	783
S7	618	597	640	585	505	541	552	568	576
S8	756	731	797	778	739	757	824	784	771
Mean	694	702	757	742	666	660	718	694	704
SD	87	101	142	160	104	89	112	103	108

Conditions*: Lamps (HPS or MH)/target positions (15° or 23° off-axis)/glare conditions (ON or OFF)

Table 4: Results of reaction time measurements in the oncoming glare study



(a) Results of all conditions

(b) Comparison between HPS and MH

(c) Comparison between 15° and 23° off-axis

(d) Interaction between positions and glare conditions

Figure 6: Results

Results of three-way ANOVA, shown in Table 5, support three inferences. The results of the ANOVA show significant differences in reaction time between the HPS and MH lamps and between the inner and outer target positions. Table 5 also presents a significant interaction between the target position and the glare condition. This interaction supports the inference that the oncoming headlight glare affected detection for the outer target more than detection of the inner target. Results of t-test (paired two sample for mean) show that there is a significant difference between reaction times for the 23° off-axis target with oncoming glare and without oncoming glare (Table 6).

Source	df	Mean square	F	p
Lamp	1	5.727×10^{-2}	6.252	0.041*
Position	1	7.658×10^{-2}	10.672	0.014*
Glare	1	3.415×10^{-3}	2.288	0.174
Lamp×Position	1	3.517×10^{-4}	0.119	0.740
Lamp×Glare	1	7.994×10^{-4}	0.258	0.627
Position×Glare	1	4.181×10^{-3}	8.875	0.021*
Lamp×Position×Glare	1	1.365×10^{-4}	0.114	0.746

*Significance criterion: p<0.05

Table 5: Three-way ANOVA

	Oncoming glare	
	ON	OFF
Mean	1.116	1.085
Variance	0.011	0.011
Observations	16	16
Pearson Correlation	0.891	
Hypothesized Mean Difference	0.000	
df	15	
t Stat	2.503	
p (T<=t) one-tail	0.012*	
t Critical one-tail	1.753	
p (T<=t) two-tail	0.024*	
t Critical two-tail	2.131	

*Significance criterion: p<0.05

Table 6: T-test (paired two sample for mean)

3. Discussion

This field study showed that the mean reaction times for the inner target (15º off-axis) were shorter than those for the outer (23º off-axis) targets. This result was expected because a recent laboratory study showed that off-axis detection improves as target eccentricity decreases (Lingard and Rea, 2001). Interestingly, for the inner (15° off-axis) target, the mean reaction times were constant with or without the glare sources, but for the outer (23° off-axis) target, the existence of the glare source significantly raised the mean reaction times. These results seem to suggest that the effects of a glare source on off-axis detection could be larger as the eccentricity angle of the glare source increases. However, in this experiment, the forward headlights increased the luminance of the inner target more than the luminance of the outer target and the target luminance for the inner target was higher than that of the outer target as mentioned in Table 6. Assuming that a veil of light—equivalent veiling luminance caused by the oncoming headlight—uniformly covers the whole visual field, the contrast between the target and the immediate background for the inner target could become much higher than that for the outer target. Therefore, it is impossible to infer from this field study whether the oncoming glare caused a larger influence on an outer target than on an inner target or whether the difference of contrast of target surfaces increase the effect of the oncoming headlight glare.

It may be safe to conclude from this field study only that in a practical roadway setting there was a significant effect of glare from a type of headlights on peripheral detection for the outer (23° off-axis) target but no effect of oncoming headlight glare was found for the inner (15° off-axis) target.

With regard to the effects of SPD of fixed lighting on off-axis detection, this field study verified there is a significant difference between HPS and MH lamps. In general, field studies include uncontrolled visual noise, which sometimes reduces the sensitivity of experiment to measure experimental effects. In the field studies of this report, forward headlights, fluctuation of moonlight illuminance, and illuminance distribution of fixed lighting could be such noise. It is meaningful, nonetheless, that the field studies confirmed the basic findings of previous laboratory studies, namely that drivers performed off-axis detection better under MH lamps than under HPS lamps at mesopic light levels (He et al., 1997, Lewis, 1998 and 1999, Bullough and Rea, 2000). Thus, the results of these field studies emphasize that lighting design based on the mesopic luminous efficiency functions might improve roadway lighting safety or energy efficiency, or both.

The statistical analyses showed no interaction between the lamp type and the existence of oncoming headlight glare. Since, however, several studies suggested that glare caused by a light source might be related to its SPD, further analysis comparing halogen headlights with MH headlights under HPS and MH fixed lighting is needed.

4. Conclusions

This field study suggested that the glare caused by oncoming headlight impaired driver performance for the outer (23° off-axis) target, but not for the inner (15° off-axis) target. The field study also supported the results of the laboratory studies on the spectral effects of fixed roadway lighting. Further study is needed concerning the SPD of oncoming headlight glare when used with fixed lighting of different SPDs.

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Appendix 1

(a) 1999 Ford Taurus

Left ◄———— Center ————► Right

	6.0m	5.0m	4.0m	3.0m	2.0m	1.0m	0.0m	1.0m	2.0m	3.0m	4.0m	5.0m	6.0m
1.0 m	0.89	1.08	1.50	1.80	5.50	12.50	13.00	6.53	3.11	1.68	1.17	0.90	0.80
0.5 m	1.10	3.20	5.89	44.0	69.0	400.0	293.0	111.0	39.0	10.0	4.14	1.99	1.07
Pavement → 0.0 m	1.82	8.00	14.0	29.0	42.0	52.0	46.0	29.0	14.0	8.80	1.45	1.10	1.03

Ranges used: 0.01 for low illuminance (below 10 lx), 0.1 for high illuminance (10 lx and above)

(b) Headlight illuminance distribution

Appendix 1: Car (A in Figure 1) and forward headlight pattern

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