UMTRI-2001-34

RESISTANCE OF LED AND INCANDESCENT FRONT TURN SIGNALS TO MASKING EFFECTS FROM ADJACENT HEADLAMPS

Michael Sivak
Brandon Schoettle
Michael J. Flannagan

November 2001

RESISTANCE OF LED AND INCANDESCENT FRONT TURN SIGNALS TO MASKING EFFECTS FROM ADJACENT HEADLAMPS

Michael Sivak
Brandon Schoettle
Michael J. Flannagan

The University of Michigan
Transportation Research Institute
Ann Arbor, Michigan 48109-2150
U.S.A.

Report No. UMTRI-2001-34
November 2001

Technical Report Documentation Page

1. Report No. UMTRI-2001-34	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Resistance of LED and Incandescent Front Turn Signals to Masking Effects from Adjacent Headlamps		5. Report Date November 2001
		6. Performing Organization Code 302753
7. Author(s) Sivak, M., Schoettle, B., and Flannagan, M.J.		8. Performing Organization Report No. UMTRI-2001-34
9. Performing Organization Name and Address The University of Michigan Transportation Research Institute 2901 Baxter Road Ann Arbor, Michigan 48109-2150 U.S.A.		10. Work Unit no. (TRAIS)
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address The University of Michigan Industry Affiliation Program for Human Factors in Transportation Safety		13. Type of Report and Period Covered
		14. Sponsoring Agency Code

15. Supplementary Notes

The Affiliation Program currently includes Adac Plastics, AGC America, Autoliv, Automotive Lighting, Avery Dennison, BMW, Coherix, Corning, DaimlerChrysler, Denso, Donnelly, Federal-Mogul Lighting Products, Fiat, Ford, GE, Gentex, GM NAO Safety Center, Guardian Industries, Guide Corporation, Hella, Ichikoh Industries, Koito Manufacturing, Lang-Mekra North America, LumiLeds, Magna International, North American Lighting, OSRAM Sylvania, Pennzoil-Quaker State, Philips Lighting, PPG Industries, Reflexite, Renault, Schefenacker International, Stanley Electric, TEXTRON Automotive, Valeo, Vidrio Plano, Visteon, Yorka, 3M Personal Safety Products, and 3M Traffic Control Materials.

Information about the Affiliation Program is available at: http://www.umich.edu/~industry

16. Abstract

Previous research has shown that, as expected, fast-rise signals (such as LEDs and neon lamps) lead to shorter reaction time than slower-rise signals (such as incandescent lamps). The present study, in two converging experiments, investigated whether rapid rise time makes turn signals more resistant to masking from an adjacent headlamp. The first experiment used a method of limits to obtain luminous intensity thresholds for LED and incandescent turn signals in the presence of headlamp glare. In the second experiment, subjects judged the relative conspicuity of simultaneously presented LED and incandescent turn signals when they flanked an illuminated headlamp. The results of the two experiments were consistent: There was no difference between the two light sources in either detection threshold or judged conspicuity. These results suggest that faster rise time does not affect the resistance of turn signals to headlamp masking.

17. Key Words turn signals, direction indicators, masking, headlamps, conspicuity, threshold, LEDs, incandescent light sources		18. Distribution Statement Unlimited	
19. Security Classification (of this report) None	20. Security Classification (of this page) None	21. No. of Pages 16	22. Price

Acknowledgments

Appreciation is extended to the members of the University of Michigan Industry Affiliation Program for Human Factors in Transportation Safety for support of this research. The current members of the Program are:

Adac Plastics
AGC America
Autoliv
Automotive Lighting
Avery Dennison
BMW
Coherix
Corning
DaimlerChrysler
Denso
Donnelly
Federal-Mogul Lighting Products
Fiat
Ford
GE
Gentex
GM NAO Safety Center
Guardian Industries
Guide Corporation
Hella
Ichikoh Industries
Koito Manufacturing
Lang-Mekra North America
LumiLeds
Magna International
North American Lighting
OSRAM Sylvania
Pennzoil-Quaker State
Philips Lighting
PPG Industries
Reflexite
Renault
Schefenacker International
Stanley Electric
TEXTRON Automotive
Valeo
Vidrio Plano
Visteon
Yorka
3M Personal Safety Products
3M Traffic Control Materials

We thank Truck-Lite Co. for providing the lamps used in this study, and Carol Flannagan for her assistance with the data analysis.

Contents

Introduction

Turn signals that are near headlamps are required to be more intense than those that are farther away. In the U.S., for example, turn signals spaced less than 100 mm from a low-beam headlamp are required to have at least 2.5 times the intensity of turn signals spaced at least 100 mm from a headlamp (FMVSS, 2000). (The spacing is measured from the optical center of the turn signal to the edge of the light-emitting area of the headlamp.) Such intensity adjustments are intended to overcome the masking effects of headlamp illumination.

The intensity adjustments for headlamp proximity have been developed in the context of incandescent turn signals. However, alternative lights sources (such as LEDs and neon lamps) are beginning to be used for turn signals. An important difference between incandescent and those newer alternative sources is the time course of the rise of illumination. Incandescent signal lamps have a gradual light onset: For larger automotive signal lighting filaments it takes about 250 milliseconds to reach 90% of the eventual asymptotic light level. In contrast, both LED and neon light sources have a virtually instantaneous rise time, measured in nanoseconds (Sivak et al., 1993). The rise-time profile is of potential relevance here because there is evidence that, in some situations, abrupt-onset stimuli are more attention getting than stimuli with rather gradual onsets (e.g., Theeuwes, 1995). If this applies in the context of automotive signaling, then abrupt-onset turn signals might be more resistant to headlamp masking, which, in turn, would suggest that smaller intensity adjustments for abrupt-onset turn signals would be sufficient to compensate for masking illumination from nearby headlamps.

The present two experiments were designed as converging operations to investigate whether abrupt-rise turn signals are, indeed, more resistant to masking. The first study evaluated detection threshold in the near visual periphery, while the second study used judged conspicuity as the dependent measure. Both studies used incandescent and LED turn signals, and both were performed in the presence of masking illumination from a headlamp. However, because the rise-time profiles of LEDs and neon lamps are comparable, the present findings for LEDs are equally applicable to neon lamps.

Experiment 1: Detection threshold in near visual periphery

Experimental setup

This experiment was conducted in a darkened UMTRI laboratory. Figure 1 shows an overhead view of the setup. The subject sat 10 m from a wall where a large mirror (reflectance of 87%) was mounted. The mirror enabled the viewing distance between the subject and the stimuli to be doubled (to 20 m). A small green LED, mounted on the wall (straight ahead and to the right of the mirror), served as a fixation point during each trial.

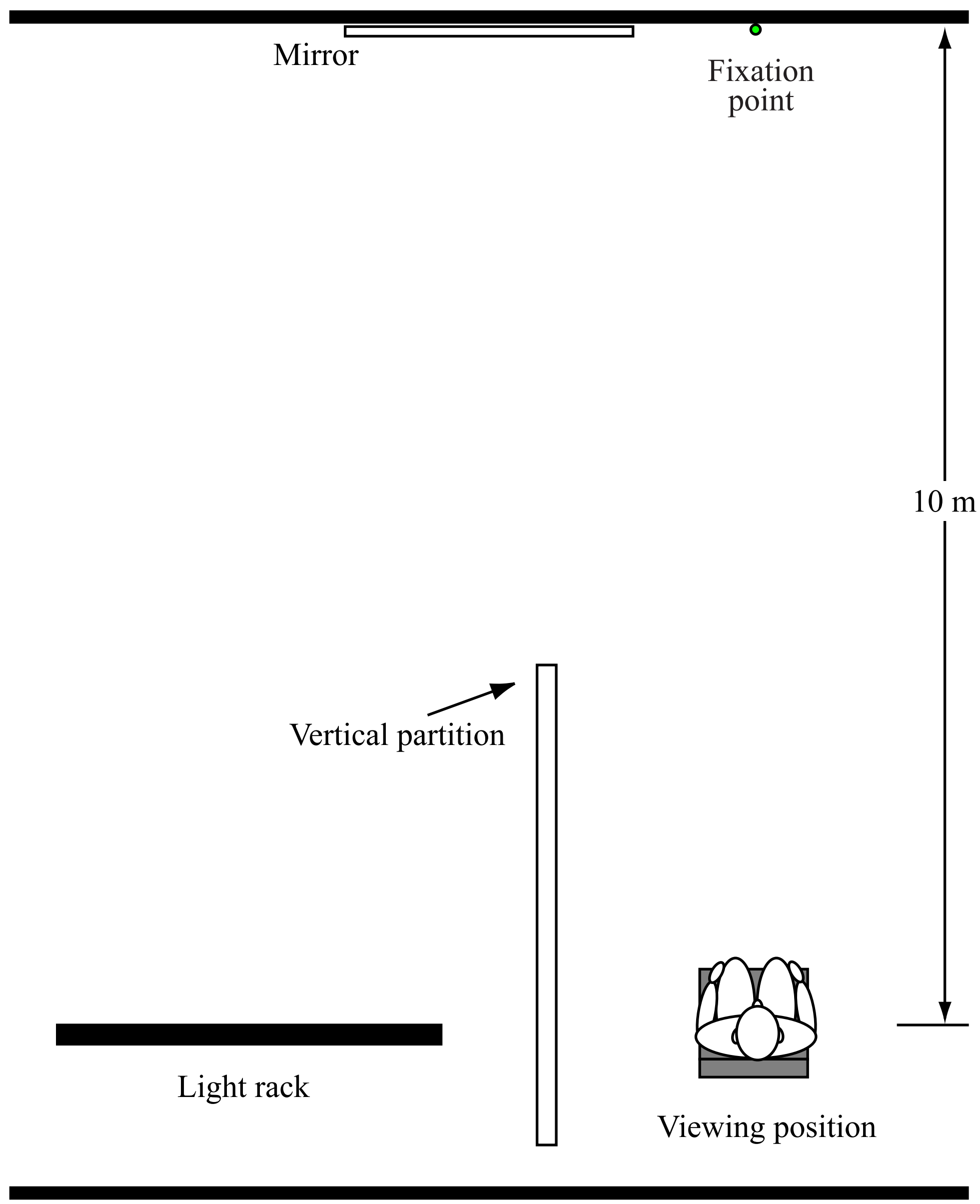

Figure 1. Overhead diagram (not to scale) of the laboratory setup in Experiment 1.

A light rack was positioned directly to the left of the subject, allowing a clear view reflected in the mirror from the subject's position. The angle between the fixation point and the center of the image of the headlamp (as seen in the mirror) was 8°, approximating the angle between straight ahead and the left headlamp of an oncoming vehicle in the left adjacent lane at 20 m (Sivak et al., 1996). The angle between the fixation point and the center of the image of the turn-signal lamp was 7.5°.

The light rack (see Figure 2) included one headlamp (HL) and one turn signal (TS). The headlamp was a round, sealed-beam halogen headlamp with a diameter of 7 in (17.8 cm). Two different lamps were used at the turn-signal position, incandescent and LED. Both were amber, round, and had a diameter of 3 in (7.6 cm). The spacing between the center of the turn signal and the edge of the headlamp was 95 mm. Only one turn signal was used on each trial, and it was always mounted in such a way that it appeared to the right of the headlamp in the mirror-reflected view. The turn signal and headlamp were both mounted with their centers at 0.62 m above the floor. The light-rack assembly and a vertical partition (see Figure 1) allowed for the experimenter to be hidden from the subject.

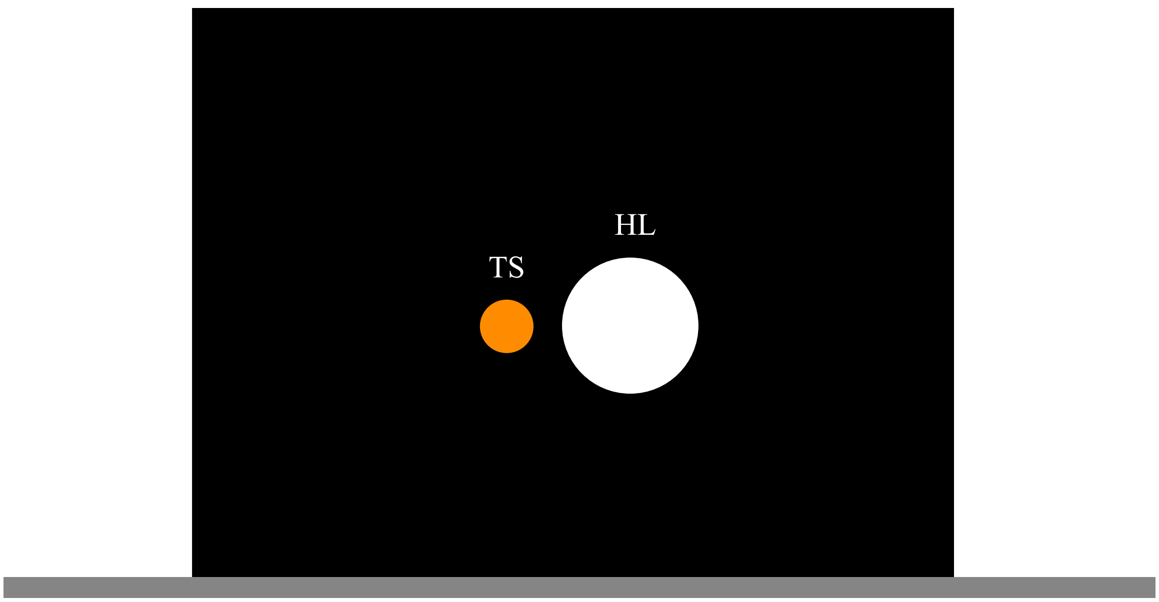

Figure 2. Schematic of the light rack in Experiment 1. Because the subject viewed the lamps in the mirror, the turn signal (TS) appeared to the right of the headlamp (HL).

Task

During each trial, the intensity of the turn signal was either adjusted from low to high (an ascending trial), or vice versa (a descending trial). This was accomplished by removing or adding neutral density filters. The task on each trial was to indicate when the turn signal became visible or when the turn signal became invisible, depending upon the trial type. When the subject stated that the turn signal had just appeared or just disappeared, the experimenter recorded the filter level that yielded the lowest visible intensity for that trial. The specific instructions were as follows:

> The task that we would like you to perform involves detecting a turn signal mounted next to a headlight. We will present several different turn signals with different intensities. As you keep your gaze relatively fixed on the small green light, we would like you to tell us when the turn signal becomes visible as we make it brighter, or when it becomes invisible as we make it dimmer, depending upon the trial we are running. I will let you know which kind of trial we are running before each one begins.

Stimuli

Two variables were manipulated:

- turn-signal light source (LED or incandescent)
- luminous intensity of the turn signal (16 levels, obtained by using 16 sets of neutral density (ND) filters)

To provide for an approximate intensity match between the two turn signals at full power, and to accommodate a reasonable intensity range around the expected threshold, 'permanent' neutral density filters were affixed to both turn-signal assemblies. The LED had a 0.45 ND filter applied and the incandescent had a 0.15 ND filter applied.

Before each experimental session, both turn-signal lamps were photometered using a Minolta T-1 illuminance meter. Table 1 lists, for each filter level, the mean luminous intensity (calculated from the photometered illuminances). The luminous intensities in Table 1, as well as in the rest of the report, are "effective" values because they correspond to the luminous intensities that would have produced the actual illuminances at the subject's eyes *if* the lamps were viewed directly (without the use of the mirror). In other words, the reported luminous intensities are corrected for the reflectance of the mirror.

Table 1
The mean luminous intensities of the turn signals in Experiment 1.

Filter	Nominal neutral density (ND) filter level	Mean luminous intensity (cd)	
		LED	Incandescent
0	—	5.09	5.77
1	0.15	3.73	4.14
2	0.30	2.76	3.11
3	0.45	2.01	2.26
4	0.60	1.30	1.43
5	0.75	0.92	1.02
6	0.90	0.77	0.90
7	1.05	0.55	0.64
8	1.20	0.39	0.41
9	1.35	0.28	0.29
10	1.50	0.23	0.25
11	1.65	0.16	0.17
12	1.80	0.10	0.14
13	1.95	0.09	0.12
14	2.10	0.06	0.09
15	2.25	0.05	0.06
16	2.40	0.03	0.04

The headlamp and turn signal were wired through a switch box, allowing each lamp to be activated and deactivated as necessary. The turn signal was additionally wired through a turn-signal flasher (1.5 Hz, 50% duty cycle). All lamps were powered at 12.8 V.

The headlamp was adjusted before each session to provide an illuminance of 1.88 lux at the eyes of the subject (corresponding to 750 cd emitted in the direction of the subject's eyes), in order to ensure a reasonable amount of masking glare. Beginning with the first trial, the headlamp remained on until the final trial was complete.

Subjects

Twelve paid subjects participated in this experiment. There were 6 younger subjects (ranging from 20 to 33 years old, with a mean of 25.7), and 6 older subjects (ranging from 64 to 79 years old, with a mean of 70.3). The younger group was composed of 4 females and 2 males, while the older group included 3 males and 3 females. All subjects were licensed drivers.

Procedure

Each subject was run individually in a session lasting about one hour. The subject was allowed to dark adapt for 10 minutes prior to testing. There were 4 unique trials, obtained by a full factorial combination of 2 turn-signal light sources (LED and incandescent) and 2 directions (ascending and descending). There were 8 trials in each session, consisting of 2 replications of each of the 4 unique trials. The order of presentation of the light source (LED or incandescent) and direction (ascending or descending) was randomized for each subject.

A special frame used to fasten the filters allowed a continuous transition between filters (i.e., the subject did not see the turn-signal lamp at full power between filters, nor was the lamp turned off). In the ascending trials, the turn signal was initially presented with filter number 16 in place (see Table 1). Filter number 15 was then slid into place (replacing number 16) and so on until the subject indicated that the turn signal had become visible. In the descending trials, an analogous procedure was used, beginning with filter number 1. This filter was replaced with filter number 2 and so on until the subject indicated that the turn signal had become invisible.

Dependent variable

The dependent variable was the intensity of the turn signal at threshold.

Results

The mean luminous intensities at threshold (averaged across both the descending and ascending trials for all subjects) were 0.51 cd for the LED turn signal and 0.50 cd for the incandescent turn signal. A paired *t*-test showed that the difference was not statistically significant, $t(11) = .41$, $p = .69$.

Experiment 2: Judged conspicuity

Experimental setup

This experiment was conducted in the same darkened UMTRI laboratory as Experiment 1. The general setup is illustrated in Figure 3. In contrast to Experiment 1, no fixation point was used.

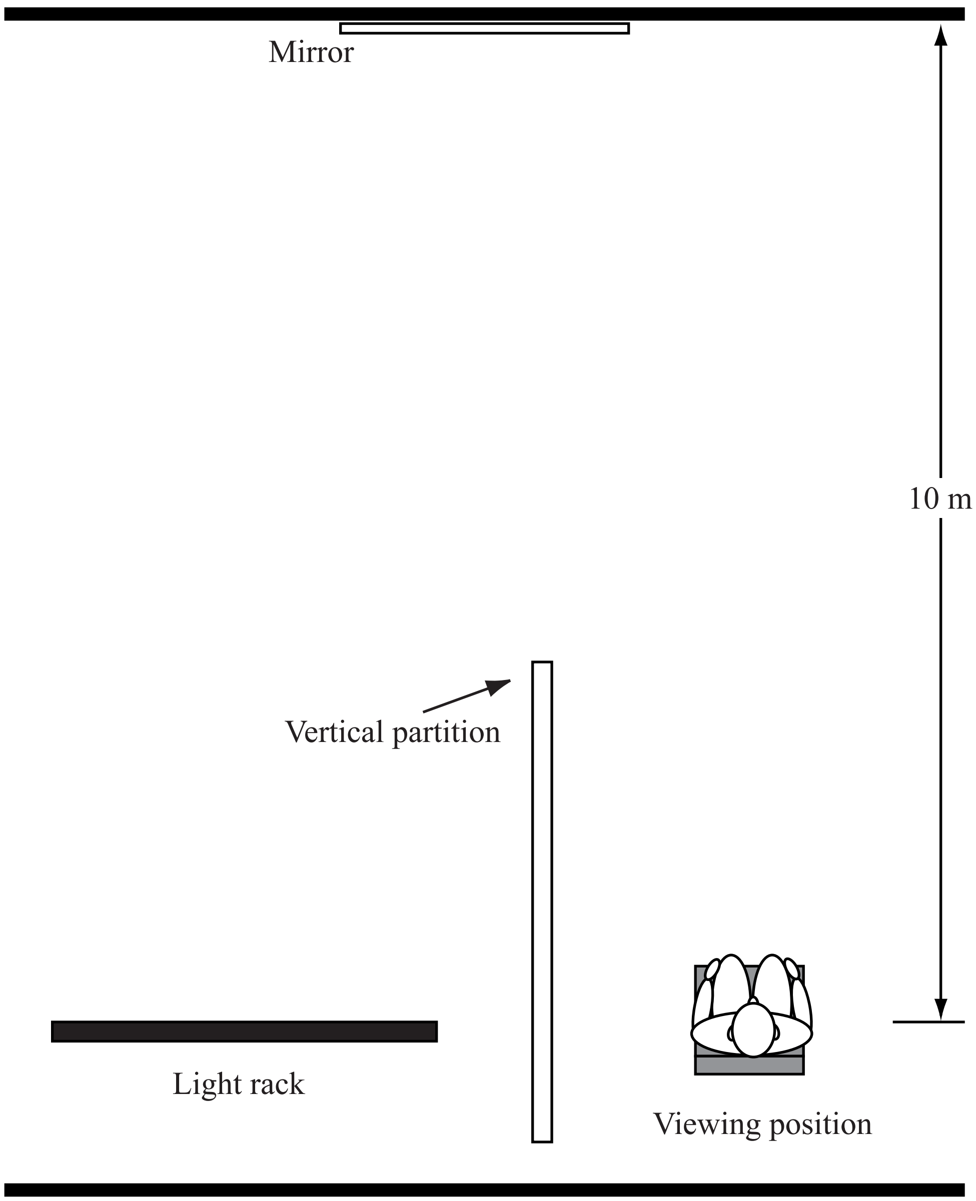

Figure 3. Overhead diagram (not to scale) of the laboratory setup in Experiment 2.

The light rack in this experiment (see Figure 4) included one headlamp (HL) and two turn signals (TS1 and TS2). The headlamp was a round, sealed-beam halogen headlamp with a diameter of 7 in (17.8 cm). The same two lamps as in Experiment 1 were used at the turn-signal positions, incandescent and LED. Both were amber, round, and had a diameter of 3 in (7.6 cm). The spacing between the centers of the turn signals and the edge of the headlamp was 95 mm. The turn signals and headlamp were mounted with their centers at 0.62 m above the floor. The light-rack assembly and a vertical partition (see Figure 3) allowed for the experimenter to be hidden from the subject.

Task

On each trial, both turn signals were simultaneously energized. The turn signals were turned off after six flashes and the subject was asked to indicate which turn signal appeared to be more conspicuous or attention getting. The specific instructions were as follows:

> You will be presented with a headlamp and two turn-signal lamps, one to the left and one to the right of the headlamp. On each trial, we will be adjusting the relative brightness of the two turn signals. Your task will be to indicate which turn signal is more conspicuous or attention getting. Each trial will be limited to six flashes of the turn signals, so please make a decision by the time the turn signals stop flashing. In addition, we would like you to always pick one turn signal as being more conspicuous than the other. In other words, "equally conspicuous" is not an option.

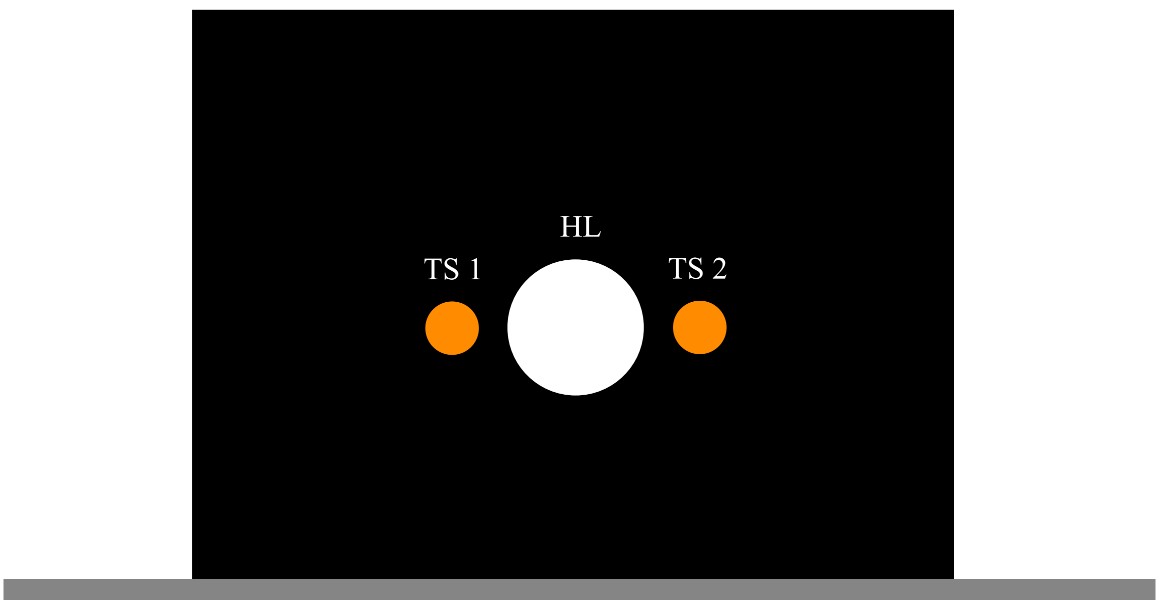

Figure 4. Schematic of the light rack in Experiment 2.

Stimuli

Two variables were manipulated:

- luminous intensity of the LED turn signal (7 levels, obtained by using 7 sets of neutral density filters)
- location of each turn signal in relation to the headlamp (left or right)

As in Experiment 1, ‘permanent’ filters were affixed to both turn-signal assemblies to obtain approximate intensity matches and reasonable intensity ranges across the conditions. Again, the headlamp and turn signals were wired through a switch box, allowing lamps to be activated and deactivated as necessary. For each trial, both turn signals were energized simultaneously at 12.8 V. The turn signals were wired through a single turn-signal flasher, with their flashing synchronized at 1.5 Hz and 50% duty cycle.

The headlamp was adjusted before each session to provide an illuminance of 1.25 lux at the eyes of the subject (corresponding to 500 cd emitted in the direction of the subject’s eyes). Beginning with the first trial, the headlamp remained on until the final trial was complete.

Before each experimental session, both turn-signal lamps were photometered using a Minolta T-1 illuminance meter. Table 2 lists the means of the calculated luminous intensities for each turn signal.

Table 2
The mean luminous intensities of the turn signals in Experiment 2.

Filter	Nominal neutral density (ND) filter level for LED	Mean luminous intensity (cd)	
		LED	Incandescent
0	—	5.45	2.37
1	0.15	3.90	
2	0.30	2.90	
3	0.45	2.10	
4	0.60	1.37	
5	0.75	0.97	
6	0.90	0.82	

Subjects

Twelve paid subjects participated in this experiment. None of them were involved in Experiment 1. There were 6 younger subjects (ranging from 20 to 23 years old, with a mean of 21.7), and 6 older subjects (ranging from 65 to 76 years old, with a mean of 70.5). Each age group included 3 males and 3 females. All subjects were licensed drivers.

Procedure

Each subject was run individually in a session lasting about one hour. The subject was allowed to dark adapt for 10 minutes prior to testing. There were 14 unique trials, obtained by a full factorial combination of 2 locations of the turn signals (the LED to the left and the incandescent to the right of the headlamp, and vice versa), and 7 levels of luminous intensity of the LED turn signal. There were 56 trials in each session, consisting of 4 replications of each of the 14 unique trials. The order of presentation of the location of each turn signal (left or right) and the 7 intensity levels of the LED turn signal was randomized for each subject.

For each trial, one of 6 filters was put in place over the LED turn signal to adjust the intensity to the predetermined level. (The seventh intensity level, labeled as filter no. 0, included no filter in place.) The incandescent turn signal remained at a fixed luminous intensity for all trials (see Table 2).

Dependent variable

On each trial, the subject indicated whether the left or the right turn-signal lamp was more conspicuous. Each subject was presented with 8 trials for each of the 7 luminous intensities of the LED turn signal (4 trials with the LED to the left of the headlamp, and 4 trials with the LED to the right of the headlamp). (As indicated above, the incandescent turn-signal lamp was always presented at the same luminous intensity.)

For each intensity level of the LED turn-signal lamp, we calculated (individually for each subject) the percentage of the times the LED lamp was judged as more conspicuous than the incandescent lamp (out of the 8 trials). Using logistic regression (Hosmer & Lemeshow, 2000), we generated the slope and intercept of the logistic curve that best fitted each subject's data. From this curve, we then calculated the predicted intensity level of the LED lamp that would result in equal conspicuity of the two lamps (i.e., we calculated the intensity at which the LED lamp would have been judged as more conspicuous than the incandescent lamp 50% of the time). The approach is illustrated in Figure 5 using the data from one subject. The calculated luminous intensity for the LED lamp at equal judged conspicuity with the incandescent lamp (individually for each subject) was the dependent variable.

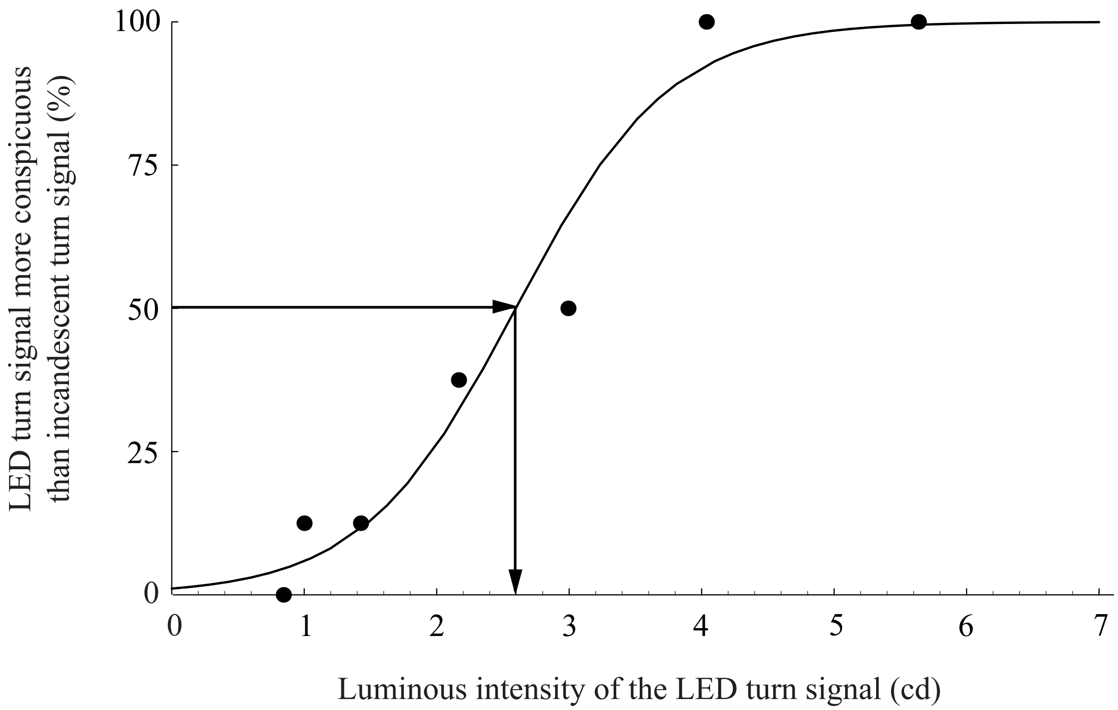

Figure 5. Derivation for one subject of the luminous intensity of the LED turn signal that would lead to it being judged as being more conspicuous than the incandescent turn signal 50% of the time. (The luminous intensity of the incandescent turn signal was always 2.37 cd.)

Results

At equal conspicuity with the incandescent turn signal at 2.37 cd, the mean luminous intensity of the LED turn signal was 3.09 cd. A *t*-test showed that the difference was not statistically significant, $t(11) = 2.19$, $p > .05$.

Summary

An inherent advantage of fast-rise signal lamps, such as LEDs and neon lamps, is that they yield shorter reaction time than standard, incandescent signal lamps. This is the case partly because, for fast-rise lamps, the emitted illumination reaches any given level of light output sooner, and partly because the onset is more abrupt.

The present study, in two converging experiments, investigated whether rapid rise time makes turn signals more resistant to masking from an adjacent headlamp. The first experiment used a method of limits to obtain luminous intensity thresholds for LED and incandescent turn signals in the presence of headlamp glare. In the second experiment, subjects judged the relative conspicuity of simultaneously presented LED and incandescent turn signals when they flanked an illuminated headlamp. The results of the two experiments were consistent: There was no difference between the two light sources in either detection threshold or judged conspicuity. These results suggest that faster rise time does not affect the resistance of turn signals to headlamp masking.

The implication of this study is that the signal conspicuity in masking situations depends primarily on the increment in luminance that the signal provides above the veiling luminance from the masking lamp. Thus, lamps that deliver equal levels of incremental luminance at their asymptotic levels of output (and are thus of equal intensity, provided that they are of equal size) would perform the same. The time profile of the onset appears not to be important.

References

FMVSS (Federal Motor Vehicle Safety Standards). (2000). Standard No. 108: Lamps, reflective devices, and associated equipment. In *Code of Federal Regulations, [Title] 49, Part 571.* Washington, D.C. Office of the Federal Register.

Hosmer, D.W. and Lemeshow, S. (2000). *Applied logistic regression.* New York: Wiley.

Sivak, M., Flannagan, M.J., Budnik, E.A., Flannagan, C.C., and Kojima, S. (1996). *The locations of headlamps and driver eye positions in vehicles sold in the U.S.A* (Technical Report UMTRI-96-36). Ann Arbor: The University of Michigan Transportation Research Institute.

Sivak, M., Flannagan, M.J., Sato, T., Traube, E.C., and Aoki, M. (1993). *Reaction time to neon, LED and fast-incandescent brake lamps* (Technical Report UMTRI-93-37). Ann Arbor: The University of Michigan Transportation Research Institute.

Theeuwes, J. (1995). Abrupt luminance change pops out; abrupt color change does not. *Perception and Psychophysics, 57,* 637-644.