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**SIMULTANEOUS MASKING
OF FRONT TURN SIGNALS
BY HEADLAMPS AND
OTHER FRONT LAMPS**

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16. Abstract Previous studies have shown that the visibility of a front turn signal is decreased if a headlamp is located near the turn signal. Consequently, both the U.S. and ECE regulations require the turn signals to be more intense in such situations. However, it is unclear how adjacent light sources affect suprathreshold aspects, such as conspicuity. The present field study was designed to examine the effects of several factors on the nighttime conspicuity of front turn signals. Specifically of interest were the effects of the number, luminous intensity, and spatial arrangement (including spacing) of the masking lamps. The following are the main findings: (1) The conspicuity of a turn signal was significantly lower when it was separated from a 1000-cd low-beam headlamp by 50 mm rather than 100 mm (center-to-edge). A 200-cd turn signal at 100 mm was equal in conspicuity to a 288-cd turn signal at 50 mm. This effect is smaller than the effects obtained in previous studies using threshold-visibility paradigms. (2) Adding a second masking light source, at the same 50-mm spacing as the first masking light source, significantly influenced the conspicuity of the turn signal. The effect of the second masking source can be compensated for by an increase in the turn signal intensity corresponding to 8.5% of the intensity of the second masking source. (3) The conspicuity of the turn signal was unaffected by the spatial arrangement of two masking light sources.					
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BACKGROUND

A visual signal is more difficult to detect when it is spatially adjacent to a light source. This phenomenon is known in the basic literature as lateral visual masking (e.g., Kahneman, 1968). Below some minimum proximity (which depends on factors such as the relative intensities and sizes), the nearer the masking light source is, the more difficult it is to detect the subject signal, as measured, for example, by threshold intensity.

In the automotive domain, lateral visual masking has been studied primarily in the context of the ease of detecting front turn signals in the presence of other lamps on the front of the vehicle. Prior studies have dealt with masking of turn signals by low- and high-beam headlamps at night (e.g., Mortimer and Olson, 1966; SAE, 1978; Alferdinck and Varkevisser, 1991; Palmer and Kantowitz, 1994), as well as by daytime running lamps during the day and at dusk/dawn (e.g., Kirkpatrick, Baker, and Heasley, 1997; Palmer and Kantowitz, 1994).

The results of these applied studies are consistent with those of the basic studies. Specifically, detection threshold is elevated when a headlamp or daytime running lamp is relatively near. These findings were obtained by using a variety of dependent variables, such as threshold detection distance (SAE, 1978; Kirkpatrick et al., 1997), maximum peripheral angle for detection (Alferdinck and Varkevisser, 1991), and reaction time (Mortimer and Olson, 1966; Palmer and Kantowitz, 1994).

The most influential study for rulemaking in the U.S. (see below) was performed by SAE (1978). The observers in this study viewed approaching vehicles with different combinations of turn-signal intensity and spacing from a low-beam headlamp. Their task was to determine the distance from which “turn signal operation can be identified.” Based on the findings of this study, SAE (1978) recommended that turn signals spaced less than 50 mm from a low-beam headlamp should have a minimum of 2.5 the intensity of turn signals spaced at least 100 mm from a headlamp. (The spacing was measured from the optical center of the turn signal to the edge of the light-emitting area of the headlamp.)

The results of Palmer and Kantowitz (1994), using a reaction-time paradigm, are generally consistent with those of SAE (1978). Specifically, Palmer and Kantowitz found that at a 50-mm spacing from a headlamp, a turn signal had to be 3.4 times as intense to yield the same reaction time as a turn signal at a 100-mm spacing.

An important contribution of Alferdinck and Varkevisser (1991) was that they varied not only the spacing but also the relative intensities of turn signals and headlamps. When the headlamp intensity in the direction of the observer was substantially greater than the intensity of the turn signal (a ratio of 36 to 1), Alferdinck and Varkevisser found a

strong effect of spacing on maximum peripheral angle for detection of turn signals. However, the effect was weak when the headlamp intensity was only moderately greater than that of the turn signal (a ratio of 3.2 to 1), and it was virtually absent when the headlamp intensity was weaker than that of the turn signal (a ratio of 1 to 3.4).

Consistent with the general findings that an adjacent headlamp will have a negative effect on the visibility of a turn signal, the U.S. and ECE vehicle regulations specify higher intensity requirements for turn signals that are relatively near headlamps (see Tables 1 and 2). Interestingly, these two sets of requirements use different definitions of lamp spacing. In the U.S. requirements, the spacing refers to the distance between the optical center of the turn signal lamp and the edge of the light-emitting area of the headlamp. On the other hand, in the ECE requirements, the spacing refers to the distance between the edges of the (apparent) light emitting areas of the two lamps. Consequently, the area of the turn signal lamp is implicitly taken into account in the U.S., but not in the ECE. For example, a 2-cm edge-to-edge spacing corresponds to a 7-cm center-to-edge spacing if the turn signal lamp is round with a radius of 5 cm, but to a 5-cm center-to-edge spacing if the radius is 3 cm.

Table 1

The current U.S. minimum requirements for a single-compartment front turn signal lamp at H-V (NHTSA, 1999). The spacing is center-to-edge (from the optical axis of the turn signal lamp to the lighted edge of the low-beam headlamp).

Spacing (center-to-edge)	Minimum luminous intensity (cd)
≥ 10 cm	200
< 10 cm	500

Table 2

The current ECE minimum requirements for a front turn signal lamp at H-V (ECE, 1993). The spacing is edge-to-edge (from the edge of the apparent surface of the turn signal lamp to the edge of the apparent surface of the low-beam headlamp and/or the fog lamp).

Spacing (edge-to-edge)	Minimum luminous intensity (cd)
≥ 4 cm	175
> 2 cm, < 4 cm	250
≤ 2 cm	400

Disregarding the differences in the definitions of spacing, the U.S. and ECE regulations are relatively consistent in the required compensatory factors: The U.S. regulations, consistent with the recommendations in SAE (1978), call for a factor of 2.5 between the most proximal and least proximal positions (see Table 1), while the corresponding factor in the ECE regulations is 2.3 (see Table 2).

It is important to emphasize two aspects of the experimental evidence cited above in support of increased intensity requirements for turn signal lamps that are located near headlamps. First, the evidence dealt with threshold phenomena. None of those studies dealt with the effects of adjacent light sources on conspicuity—a suprathreshold, attention-getting property. In other words, there are situations in which a turn signal is clearly above threshold, but its conspicuity is quite low. Consequently, it is quite likely that in many relevant situations, a turn signal is missed, not because adjacent lamps make it below threshold, but because they make it less conspicuous.

Second, the above-mentioned studies considered only one masking light stimulus—namely a headlamp. On the other hand, frequently there are other light sources adjacent to a front turn signal, such as fog lamps or auxiliary low-beam lamps that could be on at the same time as headlamps. The masking effects of multiple light sources have not yet been examined in the applied literature.

To extend previous research, this study was designed to examine the possible masking effects of two light sources on the conspicuity of front turn signals. In addition to manipulating the number of masking lamps, this study also varied the spacing between the lamps, luminous intensity of the masking lamp, and the spatial arrangement of the lamps when two masking lamps were present.

METHOD

Experimental setup

The experimental setup simulated a situation involving two cars facing each other across an intersection. Figure 1 shows a schematic diagram of the setup. The subjects were in the driver's seat of a stationary sedan, 30 m from a light rack. The light rack was positioned directly in front of the subject vehicle and aligned with the vertical centerline of the vehicle. The setup was located in an UMTRI parking area that contained no distracting light sources.

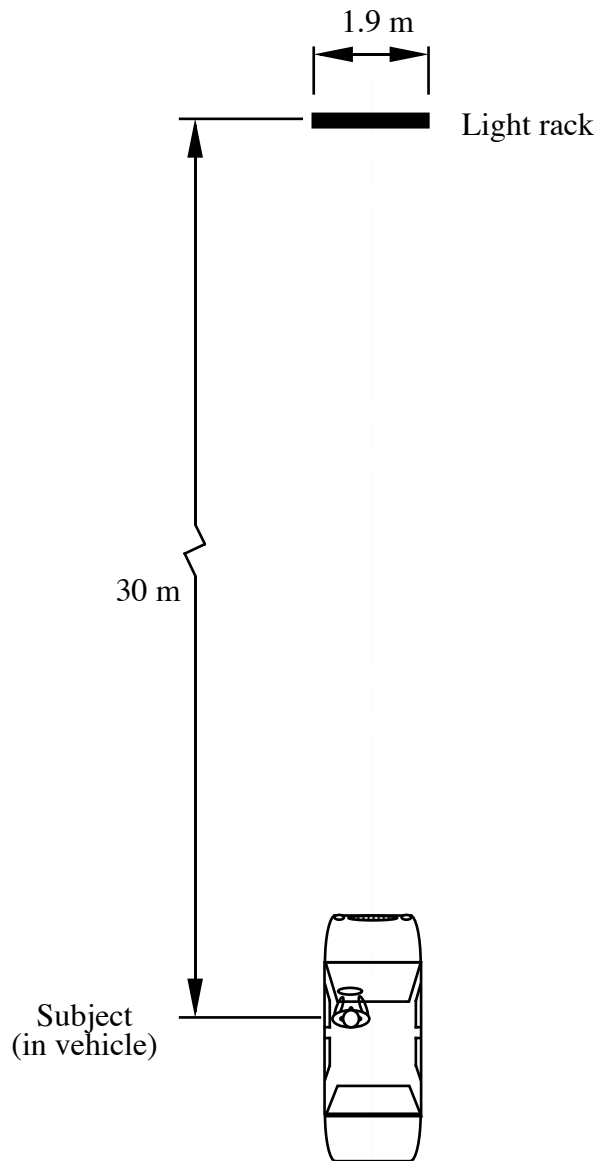


Figure 1. A schematic diagram of the experimental setup.

The light rack (see Figure 2) consisted of two groups of lamps, the control group (left side) and the experimental group (right side). The control group consisted of one headlamp and one turn signal lamp. The experimental group consisted of one headlamp, one turn signal lamp, and two auxiliary lamps.

The labeling of the lamps as “headlamps” and “auxiliary lamps” is arbitrary, because all of these lamps were of identical construction: H6024, round, sealed-beam halogen headlamps, with a diameter of 17.8 cm. All headlamps and auxiliary lamps were individually aimed to produce 1000 cd (at 12.8 V) at the subject’s eyes using the low-beam filament.

The two headlamps and two turn signal lamps were installed with their centers at 0.62 m above the ground, matching the mean headlamp mounting height on current U.S. cars (Sivak et al., 1996). Auxiliary lamp 1 (A1) was also installed with its center at the same height as the headlamps and turn signal lamps. Auxiliary lamp 2 (A2) was installed directly below turn signal lamp 2 (T2), with its center vertically aligned with the center of T2. The headlamp spacing, center to center, was 1.12 m, corresponding to the mean headlamp spacing on current U.S. cars (Sivak et al., 1996).

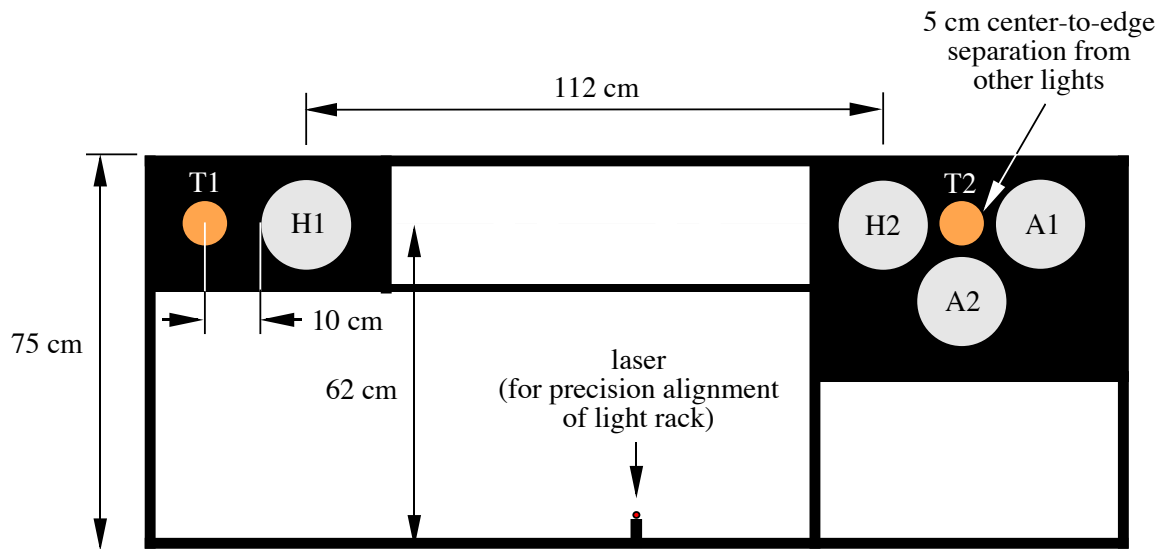


Figure 2. A schematic diagram of the light rack. Both H and A lamps were sealed-beam halogen headlamps with a diameter of 17.8 cm. Both T lamps were turn signal lamps with a diameter of 9 cm. (See text for additional details.)

Both turn signal lamps were round, with a diameter of 9 cm. These lamps had amber lenses and used clear 3457 bulbs. For the control group, the center-to-edge spacing between the turn signal lamp and the headlamp was 100 mm. For the experimental group, the turn signal lamp had a center-to-edge spacing of 50 mm from the headlamp and from each auxiliary lamp. (The 100 mm and 50 mm center-to-edge spacings correspond to 55 mm and 5 mm edge-to-edge spacings, respectively.) Both turn signal lamps were aimed to direct 800 cd (at 14.0 V) toward the subject's eyes. Turn signal 1 (T1) was then filtered down to direct 200 cd toward the subject's eyes. This was achieved by using four neutral density (ND) filters (.15 ND; 71% transmittance each). Luminous intensity of 200 cd corresponds to the U.S. minimum requirement for a one-compartment front turn signal with at least a 100 mm (center-to-edge) spacing from the low-beam headlamps (NHTSA, 1999). T2 had removable filters installed, allowing for a range of one to eight 0.15 ND filters in front of the lamp. This provided a range of 800 to 50 cd, with the maximum surpassing the 500-cd minimum requirement for a one-compartment front turn signal with spacing of less than 100 mm from the low-beam headlamps (NHTSA, 1999).

Task

The task was to judge the relative conspicuity of two flashing turn signals (T1 and T2). The subject was asked to indicate whether T2 was more conspicuous, less conspicuous, or equal in conspicuity to T1. During each trial, the intensity of T2 was adjusted by adding or removing neutral density filters, until the subject indicated the filter level that best provided for equal conspicuity between the two turn signals. An experimenter recorded the number of filters in place over T2 when equal conspicuity was determined.

Stimuli

The following variables were manipulated:

- number of adjacent lamps (1 or 2)
- distances between the lamps (100 or 50 mm, center-to-edge)
- luminous intensity of the second adjacent lamp (250, 500, or 1000 cd)
- spatial arrangement of the lamps when two adjacent lamps were present (one to the left and one to the right of the turn signal, or one to the left and one below the turn signal)

Table 3 lists the seven experimental conditions that were used in this study. (Only one of the two auxiliary lamps was energized on any trial.) The intensities of the auxiliary lamps were varied by applying neutral density filters, with the base intensity for each lamp being 1000 cd. For the 500 cd condition, one 0.3 ND filter was applied (50% transmittance), while for the 250 cd condition, two 0.3 ND filters were used (25% transmittance).

All lamps were wired through a switch box, allowing each lamp to be activated and deactivated as necessary. Both turn signals were additionally wired through a single turn signal flasher. This insured that the flashing of both turn signals would be synchronized at 1.5 Hz and 50% duty cycle. All lamps required for each condition were energized simultaneously.

Table 3
Intensity (in cd) of all lamps in the seven experimental conditions. (See Figure 2 for lamp designations.)

Condition	Control lamps		Experimental lamps			
	H1	T1	H2	A1	A2	T2
1	1000	200	1000	0	0	Determined by the subject through application of neutral density filters
2				250	0	
3				500	0	
4				1000	0	
5				0	250	
6				0	500	
7				0	1000	

Subjects

Twelve paid subjects participated in this study. There were 6 younger subjects (ranging from 21 to 24 years old, with a mean of 22.5), and 6 older subjects (ranging from 60 to 71 years old, with a mean of 66.0). Each age group included 3 males and 3 females. All subjects were licensed drivers.

Procedure

Each subject was tested individually in a single experimental session lasting about an hour. Each session started at least one hour after sunset. There were 28 trials in each experimental session, consisting of two replications of all 14 combinations of:

- 7 lamp conditions (see Table 3), and
- 2 types of trials (ascending and descending).

In the ascending trials, T2 was first shown with all 8 neutral density filters in place, and was made progressively more intense by the removal of individual filters until a conspicuity match was achieved. In the descending trials, T2 was first shown with no filters in place, and was made progressively less intense by the addition of the filters until a conspicuity match was achieved.

The total set of 28 trials was divided into two blocks of 14 trials each. These 14 trials contained 1 replication of each combination of the 7 lamp conditions and the 2 directions (ascending and descending). The ascending and descending trials for each stimulus condition were run back-to-back.

In the first block, the order of the 7 lamp conditions was randomized individually for each subject, as was the order of the direction (ascending first, descending first). In the second block, the order of the trials was the reverse order of the first block for each subject (including a reversal of the order of the direction).

Each subject was given two initial practice trials (one ascending and one descending) for a randomly selected lamp condition.

Dependent variable

The dependent variable was the intensity of T2 when it was perceived to be as conspicuous as T1. There were nine levels of T2. These nine levels were obtained by applying zero through eight levels of 0.15 neutral density filter (transmittance of 71% each) to T2. The nominal intensity of the unfiltered T2 was 800 cd.

Photometry

The aiming (with the help of a laser mounted on the light rack) and photometry of the lamps were performed at night, just prior to the beginning of each experimental session. Illuminance from each lamp was measured at the approximate eye location of the subjects by using a Minolta T-1 illuminance meter. The height used was 1.11 m above the pavement, which corresponds to the mean seated driver eye height on current U.S. cars

(Sivak et al., 1996). The photometry was performed without the windshield between the photometer and the light source. Background light levels (averaging 0.08 lux) were subtracted from the readings to obtain the actual lamp intensities. These corrected illuminance readings were then used to calculate luminous intensity directed towards the subject's eyes. The actual transmittance of each of the filter combinations was also photometered, using one of the turn signals as the light source.

Data analysis

The ratio of the actual intensity of T2 to the actual intensity of T1 at conspicuity match was calculated for each trial. All statistical analyses used these T2/T1 intensity ratios, but the results will be presented in terms of the corresponding intensity of T2 at conspicuity match with T1 of 200 cd.

RESULTS

Location of the second masking lamp

The first analysis examined whether “sandwiching” the turn signal between two lamps had a different effect on the conspicuity of the turn signal than if the two masking lamps were in an L-shape relation to the turn signal (one to the left and one below). This analysis included only Conditions 2 through 8 (see Table 3); Condition 1 (in which neither of the two auxiliary lamps was energized) was not included. The independent variables in this analysis were location of the second masking lamp (below or to the right), luminous intensity of the second masking lamp (250, 500, or 1000 cd), replication (first or second), subject age group (younger or older), and subject sex (male or female). The results show that the effect of the location of the second masking lamp was not statistically significant, $F(1, 8) < 1$. (See below for the effects of the other variables.)

Presence of a second masking lamp and its luminous intensity

Given that the location of the second masking lamp had no significant effect on conspicuity, the data from the two locations were combined, and the location factor was eliminated from the next analysis of variance. This analysis was performed on all of the data (including those from Condition 1). The independent variables in this analysis were luminous intensity of the second masking lamp (0, 250, 500, or 1000 cd), replication (first or second), subject age group (younger or older), and subject sex (male or female).

The effect of luminous intensity was statistically significant, $F(3, 24) = 3.9$, $p < .05$. The mean luminous intensities of T2 at conspicuity match with T1 are shown in Table 4. None of the other main effects or interactions was statistically significant.

Table 4
Mean luminous intensities of T2 at conspicuity match with T1. (T1 was set at 200 cd.)

Luminous intensity of A1 or A2 (in cd)	Condition(s) in Table 3	Mean luminous intensity of T2 (in cd) at conspicuity match with T1 at 200 cd	T2/T1 at conspicuity match
0	1	288	1.44
250	2 and 5	344	1.72
500	3 and 6	334	1.67
1000	4 and 7	384	1.92

Spacing between lamps

Condition 1 (see Table 3) involved a single masking lamp of the same intensity (1000 cd) for both the control and experimental sets of lamps. The only difference between the two sets of lamps was that in the control set the center-to-edge distance was 100 mm, while in the experimental set it was 50 mm. To evaluate the effect of lamp spacing on conspicuity, a *t*-test was performed on the data from Condition 1. The results showed that at conspicuity match the luminous intensity of T2 (at a distance of 50 mm from a headlamp) was significantly different from the luminous intensity of T1 (at a distance of 100 mm from a headlamp), $t(11) = 3.83, p < .01$. The mean intensities at conspicuity match were 288 cd for T2 and 200 cd for T1.

DISCUSSION

Spacing between lamps

One of the main findings of this study is that to match the conspicuity of a turn signal that is 100 mm from a low-beam headlamp (center-to-edge), a turn signal that is 50 mm from a low-beam headlamp has to be about 1.44 times as intense. The direction of this effect is consistent with previous research, showing that the visibility of turn signals is decreased when lamp spacing is smaller (e.g., SAE, 1978; Alferdinck and Varkevisser, 1991; Palmer and Kantowitz, 1994). However, the magnitude of the effect is substantially smaller than the magnitudes obtained by Palmer and Kantowitz (an intensity factor of 3.4 for equal performance at 50-mm and 100-mm spacing) and recommended by SAE (an intensity factor of 2.5 for equal performance at 50-mm and 100-mm spacing).

As indicated above, Alferdinck and Varkevisser (1991) found only a small effect of spacing if the headlamp-to-turn signal lamp intensity ratio was low (3.2 to 1). The ratio in the present study was also only modest (5 to 1), suggesting that a large ratio might be required for a strong spacing effect.

Alternatively, another way of reconciling the apparent discrepancy in the magnitudes of the effects in the present study and those in SAE (1978) and Palmer and Kantowitz (1994) is to assume that lamp spacing has different masking effects on threshold phenomena (such as detection) than on suprathreshold phenomena (such as conspicuity). The present findings are consistent with the hypothesis that conspicuity is less sensitive to lamp spacing than is threshold visibility. This is an intriguing hypothesis. Consequently, a replication and an extension of the present study to other conditions would be desirable.

Presence of a second masking lamp and its luminous intensity

The effect of adding a second masking light source at the same lamp spacing as the first masking light source (50 mm, center-to-edge) depended on the intensity of the second light source. Figure 3 shows the mean intensity of T2 at conspicuity match with T1 at 200 cd, as a function of the second masking lamp.

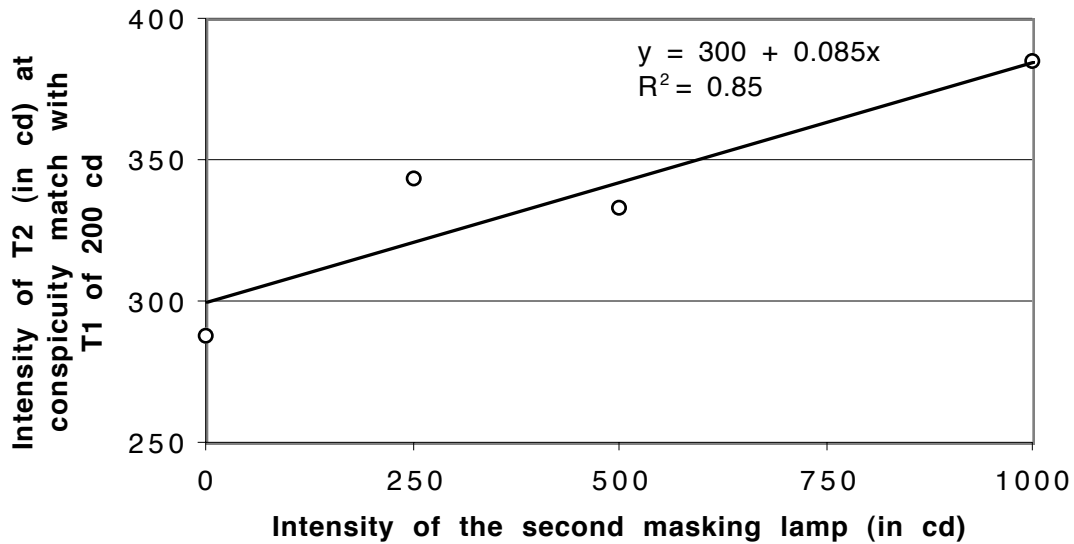


Figure 3. The relationship between the intensity of the second masking lamp and the required intensity of the turn signal lamp for maintaining the same conspicuity.

Figure 3 also contains the best-fitting linear regression. The equation for this regression is:

$$\text{Intensity of T2 (at conspicuity match with T1 of 200 cd)} = 300 + 0.085(\text{intensity of A1 or A2})$$

This equation implies that the effect of the second masking source (at a 50-mm spacing) on the conspicuity of a turn signal can be compensated for by an increase in the turn signal intensity corresponding to 8.5% of the intensity of the second masking source. For example, if a fog lamp 50 mm from a turn signal lamp directs 250 cd towards the eyes of the oncoming driver, then the turn signal lamp will maintain its conspicuity unchanged if its intensity is increased by 21 cd from its initial value of 200 cd.

At what level of the intensity of the second masking lamp is there a practical need for a compensatory increase in the turn-signal intensity? The regression equation from Figure 3 can be used to help us answer that question in terms of maintaining a given conspicuity of the turn signal. First we need to establish a criterion change in intensity of the turn signal that is of practical importance. A frequently used criterion for whether a change in a photometric value matters is 25%. This value is based on the findings that to detect a change in intensity of a stimulus, the intensity needs to be increased or decreased

by about 25% (Huey, Decker, and Lyons, 1994; Sayer, Flannagan, Sivak, Kojima, and Flannagan, 1997). The regression equation from Figure 3 indicates that a 25% change needed to maintain the conspicuity of a 200 cd turn signal would be reached when the second masking source is at 588 cd. (25% of 200 cd is 50 cd. 50 cd divided by 0.085 is 588 cd.) In other words, the present results suggest that a second light source (such as a fog lamp), spaced 50 mm from a turn signal, does not need to be compensated for by increased turn-signal intensity, unless the intensity of the second light source exceeds about 600 cd.

There is one potential pitfall in using the 25% criterion. One could envision a scenario with several features influencing the desirable intensity of a turn signal (e.g., the number, spacing, and color of the masking lamps). It is possible that each feature would call for an adjustment of less than 25% in the intensity of the turn signal, and yet if the effects of the features in question were additive, their combined effects might exceed the 25% criterion. However, applying the 25% criterion to each individual feature would result in no apparent need to increase the intensity of the turn signal.

Location of the second masking lamps

This study compared the effects on turn-signal conspicuity of the following two spatial arrangements of two masking light sources: an arrangement in which the turn signal was “sandwiched” between the two lamps, and an arrangement in which the two lamps were in an L-shape relation to the turn signal. We selected these two arrangements as representing two relatively extreme conditions. It could be argued that if the spatial arrangement has an effect on conspicuity, the greatest effect should be obtained when the turn signal is sandwiched between two lamps, because such an arrangement minimizes the likelihood that any part of the turn-signal-lamp area will be unaffected by the illumination from the masking lamps. For analogous reasons, it could be argued that the nearer the two masking lamps are to each other, the smaller the masking effect would be—thus our L-shape arrangement.

We found no differences in conspicuity for the two spatial arrangements of the two masking lamps. Consequently, this finding suggests that the spatial arrangements of two masking lamps vis-a-vis a turn signal is unlikely to be of major importance for turn-signal conspicuity.

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