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THE SAFETY POTENTIAL OF CURRENT AND IMPROVED FRONT FOG LAMPS

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16. Abstract

This document reviews various sources of evidence in an effort to evaluate the safety potential of current and improved front fog lamps. Crash data are reviewed to identify the specific safety consequences of fog, and studies of the visual effects of front fog lamps are reviewed. Finally, there is a discussion of the likely effects of current and improved front fog lamps on driver behavior and on overall safety. The conclusions are that there is very little evidence for a safety benefit from current front fog lamps relative to low beams, that there is little reason to expect that there would be a safety benefit even from improved lamps, and that, in terms of vehicle lighting, the most promising approach to improving safety in fog would be the use of rear fog lamps. In spite of a lack of evidence for safety benefits in fog, fog lamps are a popular optional form of forward lighting that many drivers apparently value. It may be that their main value is more as supplements to low-beam lighting for all conditions, rather than specifically in fog.

Given the uncertainties in our present knowledge about how current fog lamps, and potential new fog lamps, affect vision and safety, it would be beneficial to learn more about those issues before adopting new standards for fog lamps, or retiring the current standards. One approach that seems particularly important would be studies that examine the possibly complex reactions of drivers to fog and fog lamps in terms of steering behavior, speed control, and decisions about where and when to risk driving in fog. A second area would be to do a more complete analysis than has yet been done of the crash data concerning fog, perhaps focusing specifically on the issue of how fog affects road-departure crashes.

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Introduction

At about 1:50 a.m. on January 9, 1995, a portion of Interstate 40 near Menifee, Arkansas was covered by a patch of fog that was apparently relatively localized and recently developed. A tractor semitrailer combination hauling cattle, traveling west, slowed from 65 to about 35 mph as it entered the fog. It was soon hit from behind by a second combination that had slowed to about 40 mph. The driver of the second truck later reported that he was afraid to slow more because he knew there was traffic approaching him from the rear. Within about two minutes, six more tractor semitrailers and a commercial van had entered the fog at speeds varying from 15 to 60 mph and collided. In all, eight tractor semitrailer combinations and the van were involved. Five people were killed and four of the trucks were destroyed or heavily damaged by explosions and fire. The National Transportation Safety Board investigated the crash and issued a report describing the probable cause of the incident, and discussing possible countermeasures (NTSB, 1995). The crash on I-40 was unusual in that it involved a large number of heavy commercial vehicles—and only commercial vehicles—but it was in other ways typical of multiple-vehicle rear-end collisions in fog. The NTSB report considered a range of possible countermeasures, including better use of citizens band radios, and laser and radar detection systems. The report discussed, and dismissed, the possibility of front fog lamps as a solution in a single short paragraph, which also included a favorable mention of rear fog lamps (pp. 37-38). Was this conclusion justified? The incident occurred at night, when forward illumination might be expected to have an effect on visibility. Was the incident typical of the kind of crashes that need to be addressed to improve safety in fog? And how much potential does front fog lighting have to improve overall safety in fog? This report is an attempt to address these questions.

Front fog lamps have become a popular optional form of lighting. A survey in 1996 found that they were installed on about 13% of vehicles (Sivak, Flannagan, Traube, Hashimoto, & Kojima, 1996), and the frequency of installation has probably increased since then. Partly because of this increase in usage, the Society of Automotive Engineers (SAE) has for several years been engaged in an effort to revise its standard covering fog lamps (Folks & Kreysar, 2000). There have been two major goals in that effort: to reduce glare from fog lamps to oncoming drivers, and to improve the light output of fog lamps in order to enhance the safety of the drivers using the lamps. Progress was made on the first goal by the publication of a revised fog lamp standard earlier this year (SAE, 2001). The second goal—improved seeing light—is still under discussion in the SAE. This report is related to the second goal. It reviews the effects of fog on safety, summarizes research on the visual effects of fog lamps, and draws some conclusions about the safety potential of current fog lamps and of possible future fog lamps that might result from a revision of the fog lamp standard.

Effects of Fog on Crash Statistics

Few crashes occur in foggy conditions. Tamburri and Theobald (1967) reviewed three years of crash data in California and found that 2.71% of crashes were coded as foggy. Johnson (1973) analyzed crashes on the main motorways in the U.K. and found that 4% occurred in fog, and that about 3% occurred in fog at night, an amount roughly proportional to the overall proportion of nighttime crashes in the sample. A report by the OECD Road Research Group (1976) presented data for crashes in fog for several countries in Europe and North America. Fog crashes as a percent of all crashes were in rough agreement, mostly between 1 and 5%. The report stated that differences in data reporting and processing methods prevented a comparative analysis of the data between countries. A summary of several analyses of crash data resulted in an estimate that between 2 and 3% of crashes occur in fog (Koth, McCunney, Duerk, Janoff, & Freedman, 1978). Presumably, some proportion of the crashes that occur in foggy conditions are not caused primarily by the fog, so that the percentage of all crashes that are actually attributable to fog is even lower. The low number of crashes in fog is due in part to the infrequency of foggy conditions. Fog is quite variable both over time and over space (Codling, 1971), making it difficult to estimate the proportion of traffic exposed to fog conditions that are likely to affect driver vision. In the U.S., some limited areas experience thick or dense fog (visibility less than 200 m) for at least part of the day on over 100 days a year, while the majority of the country (in terms of land area) experiences heavy fog on fewer than 20 days a year (Shepard, 1996).

One consequence of the relative infrequency of fog-related crashes is that there is considerable statistical uncertainty in many analyses of the crash data. Perhaps the most important level of uncertainty, concerning the overall effect of fog on crash rates, was expressed by Kocmond and Perchonok (1970), who stated:

> . . . it is possible to conclude that fog does induce [certain kinds of] accidents. On the other hand, it is likely that fog induces increased caution on the part of drivers. It is therefore unclear at this point as to whether the net effect of fog is to increase, or to decrease, the likelihood of an accident. (p. 20)

In spite of the uncertainties in the crash data, there are a few empirical generalizations that seem reliable. Koth et al. (1978) made a comprehensive review of the crash data available at that time. One of the trends they noted was that, although fog crashes were relatively infrequent, they tended to be spectacular, often involving multiple vehicles. Fog seems to have different effects, depending on the type of roadway. The relative risk on interstates versus other roads is higher in fog than in clear weather, by a factor estimated to be from 1.05 to 4.12. Finally, they point out that the majority of fog crashes involve collisions with other vehicles (62.6%), and conclude, "By far the most pragmatic target for visibility improvement to reduce fog accident hazard is the vehicle" (p. 127). One particularly detailed study of crashes in foggy and clear conditions (Codling, 1971) found that the crashes most affected by fog were those involving more than two vehicles. Such crashes were 260% more frequent in fog (visibility less than 200 m) than in clear weather, even though there was a slight decrease (17%) in total crashes in fog, presumably because of reduced driving.

One of the most widely recognized advantages of fog lamps is the increased lane guidance that they allow by providing illumination that is very wide in comparison to low beams (e.g., Koth et al., 1978; OECD Road Research Group, 1976). However, the sources that cite this advantage do not provide documentation of increases in road-departure crashes in fog. Presumably these would be the types of crashes that would result from diminished lane guidance in fog, and which would therefore by addressed by the increased wide illumination from fog lamps. Given the uncertainties in the fog crash data, the possible existence of an increase in road-departure crashes in fog cannot be ruled out, but, on the other hand, there does not appear to be clear evidence for it either.

Visual Effects of Front Fog Lamps

Fog has negative effects on driver vision. Fog lamps are designed to reduce those effects as much as possible, but they cannot restore vision to the level it would be at in clear atmosphere. Therefore there is a compromise inherent in the design of fog lamps: they are intended to improve vision at relatively short distances, but they do nothing to improve vision at relatively long distances, and they possibly even reduce vision at long distances. They accomplish this by putting a large amount of light in the near foreground and to the sides of a vehicle, but very little down the road. Fog lamps can be seen as a point on one end of a continuum that also includes high and low beams. High beams put light furthest down the road, the reach of light from low beams is reduced relative to high beams, and the reach of light from fog lamps is reduced even further. Several studies of the visual effects of front fog lamps have provided quantitative data that is essentially consistent with this characterization of the design philosophy of fog lamps.

Koth et al. (1978) developed a computer model of the light levels produced by scattering in fog and used it to evaluate the visibility provided by front fog lamps under both nighttime and daytime conditions (in which the fog lamps were evaluated as marking lamps for the vehicle on which they were mounted, rather than as devices to illuminate the road). They computed visibility levels (quantified as the contrast of a target relative to a threshold contrast) for high-beam, low-beam, and fog lamps at distances ranging from 50 to 250 ft (15.2 to 76.2 m). For nighttime conditions, with unlighted targets, the fog lamp always provided considerably lower visibility than either the low or high beams. The high beam provided better visibility than the low beam at all distances tested except 100 ft (30.5 m), at which there was a slight reversal. They did not test the visibility levels provided by combinations of lamps, such as fog lamps used with low beams. Because the reduction in light at and above horizontal that characterized the fog lamp design hurt rather than helped with visibility at distant points on the road, they concluded that the value of front fog lamps was not to promote target detection, but rather to promote driver comfort and guidance on the road by increasing side illumination at very short distances:

> Front fog lamps are designed primarily to increase driver comfort and security rather than to promote collision avoidance visibility. The peripheral illumination production of front fog lamps enhances driver visibility of positional cues needed for vehicle control. Situational target visibility is enhanced only under extremely dense fog conditions. Low driving speeds are implicit in the design rationale of front fog lamps. (pp. 3-4)

Folks and Kreysar (2000) extended the work of Koth et al., applying the same computer model to more recent lamp designs, and also evaluating the visibility produced by combinations of fog and low-beam lamps, as well as by individual lamp types. They used data for two fog lamps, one to represent typical performance of lamps that met the then-current SAE fog lamp standard, and one to represent typical performance of lamps that would meet a proposed new fog lamp standard. The main variable that they used to assess lamp performance was an index of target contrast, for which higher values represent better visibility. Some of their results, for medium density fog, are shown in Figure 1. (Results for lighter and heavier fog were similar.)

Comparisons of fog lamps used alone (the dashed lines) to low-beam lamps used alone (the filled circles) indicated that the fog lamps provided greater visibility than the low-beam lamps at very short range (10 m), but that at longer distances (20 and 40 m) the low-beam lamps provided greater visibility. The comparisons of low beams used alone to low beams used with fog lamps (the solid lines with open symbols) yielded a pattern that was very similar, with the added fog lamps increasing the visibility provided by the low beams at short range, but reducing visibility at longer distances. Although the performance of the proposed new fog lamp was somewhat better than the current fog lamp at most distances, the results for the current and new fog lamps relative to the low beam were very similar. Except for a slight reversal at 20 m for the new fog lamp when used with the low beam, the low beam alone provided better target contrast for all conditions beyond 10 m.

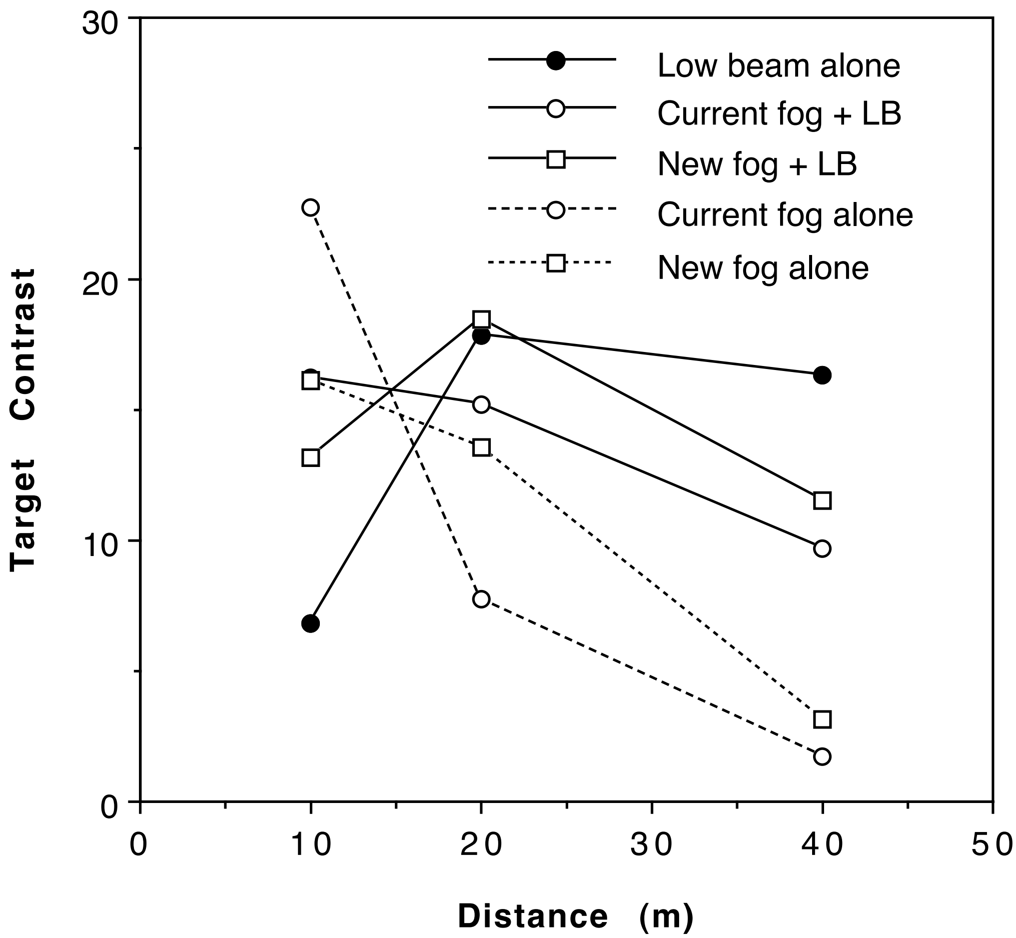

Figure 1. Target contrast in medium density fog provided by low beams alone, and by two different fog lamps, by themselves or in combination with low beams (Folks & Kreysar, 2000).

Yokoi and Hashimoto (1999) measured the visibility provided by fog lamps and low beams in actual fog. They set up a car, a lamp stand, and a variety of targets on a straight, level parking area on a mountainside where fog was frequent. They had an observer in the car indicate when each of the various targets was visible, as fog density varied naturally. Their main dependent measure was the maximum density of fog (quantified as visible range in meters) at which each of the targets was visible under the various lighting conditions. Representative data are shown in Figure 2, which illustrates the visible range in meters for targets at 15, 20, and 30 m, under illumination by two different fog lamps (one with reflector optics and one with projector optics) or two different low beams (one meeting the ECE standard and one meeting the Japanese standard). Combinations of low beams and fog lamps were not included in the study. The data shown here are for headlamps mounted 600 mm above the ground and fog lamps mounted at 350 mm. Yokoi and Hashimoto also investigated the same fog lamps mounted at 600 mm. The fog lamps performed better when they were mounted higher, but comparisons to the low beams were similar. At all distances at which visibility thresholds could be measured, the low beams offered better visibility (corresponding to denser fog, quantified by shorter visible range) than fog lamps. These results are not completely consistent with those of Folks and Kreysar, since they fail to show an advantage of fog lamps even at short distances. However, the shortest distance tested by Yokoi and Hashimoto was somewhat longer (15 m) than the distance at which Folks and Kreysar found most of the evidence for an advantage of fog lamps (10 m). The two studies are consistent at least in the finding that low beams perform better than fog lamps, in fog, at longer distances. And there is some suggestion in Yokoi and Hashimoto's data that the advantage of the low beams might be growing with distance (partly, because they were not able to make observations for the fog lamps beyond 20 m).

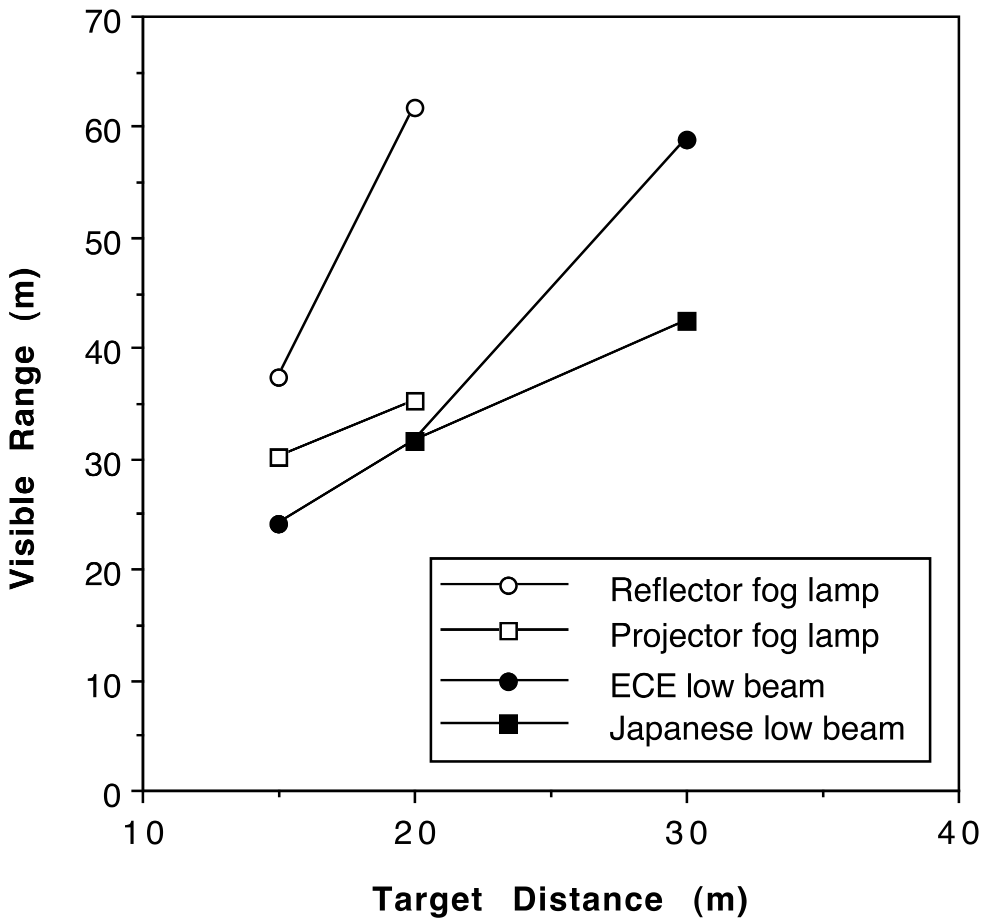

Figure 2. Maximum fog density, measured as visible range in meters, at which each of several targets was visible under different lighting conditions. Lower values of visible range indicate denser fog, and therefore better lamp performance. (Yokoi & Hashimoto, 1999)

The Road Research Group of the Organisation for Economic Co-operation and Development (OECD) published a comprehensive analysis of the problem of crashes in fog, along with evaluations of many countermeasures, including vehicle lighting as well as approaches such as fog abatement and traffic control methods (OECD Road Research Group, 1976). Although the documentation is not thorough, they review photometric aspects of front fog lamps and low- and high-beam headlamps, and recommend the use of high-beam headlamps in all but very thick fog:

> Despite this [increased scatter from high beams], the high beam headlights are advantageous as regards the identification of non-illuminated objects, especially with regard to larger objects such as the outlines of vehicles. . . . Only if very thick fog develops, that is fog below this threshold [100 m standard sight distance], should low beam headlights be used. . . . With regard to the gain in sight distance in order to recognize non-illuminated objects the effectiveness of fog lamps is frequently overestimated . . . (p 46)

An indirect measure of the visibility offered by fog lamps is provided by an observational study of how drivers actually use fog lamps. If one can assume that drivers have some knowledge of how well they can see, and if that knowledge affects when they switch their fog lamps on or off, then the influence of darkness and fog on fog lamp use can be used to indicate how fog lamps perform in those conditions. Sivak, Flannagan, Traube, Hashimoto, & Kojima (1996) made observations of vehicles in normal traffic in southeastern Michigan, during the day and at night, under four weather conditions: (1) clear, (2) moderate rain, (3) light to moderate fog (only in the day condition), and (4) moderate to heavy fog. (Density of fog varied because the observations were made over a variety of road conditions.) The main results are shown in Table 1. At night, weather conditions seem to have no effect on whether drivers activate their fog lamps; of drivers who have fog lamps installed, just under two thirds use them at night under all weather conditions that were investigated. The pattern is much different during the day, when weather has a strong effect on fog lamp use. In the day, decreased visibility causes an increase from a very low usage rate up to 50%. This pattern suggests that most drivers believe that they can see better at night with fog lamps activated, but that they experience this benefit under all weather conditions. Therefore, at night, the fog lamps appear to be functioning as auxiliary driving lamps, rather than as fog lamps per se. During the day, drivers may believe that the fog lamps increase their conspicuity to other drivers, and that this benefit is particularly valuable when atmospheric visibility is reduced.

Table 1. Percentages of vehicles with illuminated fog lamps, of those with fog lamps installed (Sivak et al., 1996).

	Clear	Moderate rain	Light to moderate fog	Moderate to heavy fog
Day	2.8	10.4	30.8	50.0
Night	64.5	63.0	---	60.6

Effects of Front Fog Lamps on Safety

The work reviewed above suggests that fog lamps, used either as substitutes for low beams or as supplements to low beams, do not provide better visibility for objects on the road, at least not at distances that would allow adequate preview time for avoiding collisions at moderate or high speeds. However, as suggested by Koth et al. (1978), drivers do seem to value fog lamps, and the wide spread light that they provide may be the primary reason:

> The most apparent visual effect of the very wide beam patterns of [fog lamps] is the high degree of roadway edge or curb illumination produced. This was quite useful in clear weather to provide peripheral cues regarding lane position and roadway directional changes without requiring foveal fixation of these visual elements. . . . The overall impression of the effectiveness of front fog lamps in fog or clear weather is that they are useful for providing visual comfort for vehicle control tasks, but that object visibility and forward distance visibility were deficient compared to conventional headlighting. While the increased comfort allowed the driver more opportunity to attend visually to objects ahead, front fog lamps do not contribute significantly to situational cue seeing. (pp. 180-181)

What effect would fog lamps therefore be expected to have on overall driving safety? The statistics on crashes in fog seem to suggest that the major safety issue in fog is increased collisions with other vehicles. If fog lamps do not increase the visibility of objects on the road, then they may be neutral with respect to safety. However, the mechanism alluded to by Koth et al. in the above quotation—that improved peripheral vision may allow drivers to attend more closely to objects ahead—suggests a possible indirect benefit that may reduce collisions with other vehicles. But, on the other hand, increased guidance vision and driver comfort may not always have positive safety effects. For example, Kallberg (1993) found indications that equipping a road with post-mounted delineators, thereby increasing lane guidance, resulted in increased speed and increased crashes.

Similarly, there have been questions about the overall effectiveness of a set of airport-type pavement inset lamps that were installed in the mid 1970s to provide guidance in fog on Interstate 64 where it crosses Afton Mountain in Virginia (Shepard, 1977). The lamps apparently serve to define the lanes very well, but it is unclear whether they do anything to improve drivers' abilities to detect obstacles on the road. Shepard indicated that the small numbers of crashes in data collection periods before and after the installation of the system prohibited a statistical test of the effect of the system on overall safety. A more recent summary of crash data suggests that there are still too few cases to allow firm conclusions (Lynn, Schreiner, & Campbell, 2000). Shepard (1977) studied effects of the system on traffic flow and arrived at the following conclusion about the likely effects on safety:

> Overall, the lighting system led to higher nighttime speeds, an increase in speed differentials for various cases during both daytime and nighttime, and to an increase in nighttime headways and a decrease in queuing. These changes in traffic flow characteristics may be construed as producing an increase in the potential for accidents; however, they are thought by the author to be a result of the inset lighting system providing improved delineation for the guidance of motorists. This improvement in guidance, especially during fogs at night, may provide safer driving conditions than hitherto existed. (p 23)

It has been suggested that even in typical night driving situations guidance vision is often too good, relative to drivers' abilities to detect pedestrians and other objects on the road, leading drivers to feel overconfident and therefore overdrive the visibility provided by their headlamps (Leibowitz & Owens, 1977). Leibowitz and Owens have proposed that it is important to distinguish between two visual systems that are both important in night driving: the focal and ambient systems. One role of the focal system in driving is to detect potential obstacles on the road, such as pedestrians or other vehicles. It is therefore critical for avoiding collisions. The main role of the ambient system is spatial orientation, including lane guidance. Citing various sources of data, Leibowitz and Owens propose that the two systems differ markedly in their sensitivity to low levels of light: the performance of the focal system degrades significantly within the range of light levels normally encountered in night driving, whereas the ambient system is relatively robust, maintaining a high level of performance even at the lowest levels of light normally encountered in night driving. As a result, drivers at night are often in situations in which their ability to maintain lane position is good but their ability to detect obstacles is selectively (and unexpectedly) degraded:

> Since the major tasks of driving [dynamic spatial orientation, including lane keeping] are relatively unimpaired by reduced illumination, the driver does not anticipate and is not prepared to deal with stimuli for which the focal system suffers a selective deficit. In effect, the driver is unjustifiably reassured by the high performance level of the dynamic spatial orientation system and is unaware of a loss in focal visual abilities. Since the visual deficit is only partial and of consequence only for low-probability stimuli [such as obstacles in the road], the

driver is unaware of the loss of function and does not take the necessary precautions. (p. 423)

Recent studies of the effects of darkness on fatal crashes have provided results consistent with this selective degradation hypothesis. Sullivan and Flannagan (1999) specifically investigated the effects of darkness on collisions with pedestrians (a crash type that should be closely related to the performance of the focal system) and single-vehicle, road-departure crashes (which should be closely related to the performance of the ambient system). Their results indicated that, although pedestrian risk in the dark increased by a factor of about 5, the risk of running off the road was unaffected by darkness. (Road-departure crashes are more common at night than during the day, but the difference seems to be due to alcohol and fatigue rather than road visibility.) This pattern is just what would be expected if lane keeping depended on a system that was robust with respect to low light (the ambient system) and pedestrian detection depended on a system that was degraded at typical night driving light levels (the focal system). It is unclear whether these results can be extended to fog conditions, but they illustrate the need to consider the possibility of some relatively subtle effects of vision on safety. Given our present knowledge, it is not clear what the net effect of improved guidance vision from fog lamps may be.

It is not clear that front fog lamps offer a safety benefit (at least a safety benefit specific to fog, rather than for night driving in general). But it has been suggested (Koth et al., 1978; Lancashire, 1978; OECD Road Research Group, 1976; Tamburri & Theobald, 1967) that the most important safety problem associated with fog—visibility of other vehicles ahead—could be addressed by a different form of vehicle lighting, specifically rear fog lamps. Rear fog lamps are potentially much more efficient in marking the presence and position of a forward vehicle, and, given the close relationship to the problem of multiple-vehicle collisions in fog, this approach should be further investigated.

Summary and Conclusions

From existing studies, there is very little evidence that current front fog lamps offer visual benefits relative to low beams that are likely to result in improved safety. Indeed, some studies of the visibility provided in fog by various types of front lamps suggest that low beams, or even high beams in some cases, perform better than fog lamps except at very short ranges (perhaps as short as 10 m). Furthermore, given that collisions with other vehicles appear to be the major safety problem associated with fog, it is not clear that any improved version of front fog lamps would offer a significant gain in safety. There is no clear evidence for an increase in road-departure crashes in fog, and there are theoretical reasons to expect that there would not be such an increase (Leibowitz & Owens, 1977). Even if fog is associated with road-departure crashes, attempting to address that problem with fog lamps that provide extra lane guidance without providing light at significant distances down the road might have both positive and negative effects. The net effect of such lamps is difficult to predict because it may depend strongly on relatively complex aspects of drivers' judgment and behavior. Drivers may drive too fast, or sometimes fail to pull over, if they feel confident about lane guidance but are at the same time subject to a deficit in obstacle detection that they do not fully recognize.

In terms of vehicle lighting, the most promising approach to improving safety in fog may be the use of rear fog lamps. Such lamps would appear to be very effective in addressing the important problem of collisions with other vehicles in fog.

In spite of a lack of evidence that they provide safety benefits in fog, fog lamps are a popular optional form of forward lighting that many drivers apparently value. It may that their main value is in supplementing low-beam lighting under all conditions, rather than providing visibility in fog.

Given the uncertainties in our present knowledge about how current fog lamps, and potential new fog lamps, affect vision and safety, it would be beneficial to learn more about those issues before adopting new standards for fog lamps, or retiring the current standards. One approach that seems particularly important would be studies that examine the possibly complex reactions of drivers to fog and fog lamps in terms of steering behavior, speed control, and decisions about where and when to risk driving in fog. A second area would be to do a more complete analysis than has yet been done of the crash data concerning fog, perhaps focusing specifically on the issue of how fog affects road-departure crashes.

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