UMTRI-99-10

ACCEPTABLE DELAYS IN SWITCHING BETWEEN PRIMARY AND SECONDARY LIGHT SOURCES IN DISTRIBUTED LIGHTING

Michael Sivak
Michael J. Flannagan

March 1999

ACCEPTABLE DELAYS IN SWITCHING BETWEEN PRIMARY AND SECONDARY LIGHT SOURCES IN DISTRIBUTED LIGHTING

Michael Sivak
Michael J. Flannagan

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

Report No. UMTRI-99-10
March 1999

Technical Report Documentation Page

1. Report No. UMTRI-99-10	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Acceptable Delays in Switching between Primary and Secondary Light Sources in Distributed Lighting		5. Report Date March 1999 6. Performing Organization Code 302753
7. Author(s) Sivak, M. and Flannagan, M.J.		8. Performing Organization Report No. UMTRI-99-10
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, BMW, Bosch, Britax International, Corning, DaimlerChrysler, Denso, Federal Mogul Lighting Products, Ford, GE, GM NAO Safety Center, Guide Corporation, Hella, Hewlett-Packard, Ichikoh Industries, Koito Manufacturing, LESCOA, Libbey-Owens-Ford, Magneti Marelli, North American Lighting, Osram Sylvania, Philips Lighting, PPG Industries, Reflexite, Reitter & Schefenacker, Stanley Electric, Stimsonite, TEXTRON Automotive, Valeo, 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

This report reviewed evidence concerning acceptable delays in switching between a primary and a secondary light source in distributed lighting. The specific question posed was as follows: The industry considers a delay of 100 ms technically achievable, but is it acceptable from the human factors point of view? The evidence considered included consequences for the quality of driver performance and possible startle effects. In discussing the quality of driver performance, the following aspects were considered: eyeblinks, voluntary occlusions of vision during driving, fixations away from straight ahead (on rearview mirrors, vehicle controls and displays, and navigation systems), head movements when checking traffic in the blind spots, and time-to-collision and time-to-lane-crossing measures. Possible effects of different implementations of the secondary light source (high-intensity discharge and incandescent) were also briefly discussed.

Based on the available evidence concerning the quality of driver performance (excluding startle effects), a delay of 100 ms or less is unlikely to create safety problems. Furthermore, although little evidence exists on the likelihood and nature of startle responses, it is unlikely that a delay of 100 ms or less will lead to major negative startle consequences.

17. Key Words distributed lighting, switching delays, headlighting, high-intensity discharge, incandescent, failure		18. Distribution Statement Unlimited	
19. Security Classification (of this report) None	20. Security Classification (of this page) None	21. No. of Pages 17	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
BMW
Bosch
Britax International
Corning
DaimlerChrysler
Denso
Federal Mogul Lighting Products
Ford
GE
GM NAO Safety Center
Guide Corporation
Hella
Hewlett-Packard
Ichikoh Industries
Koito Manufacturing
LESCOA
Libbey-Owens-Ford
Magneti Marelli
North American Lighting
Osram Sylvania
Philips Lighting
PPG Industries
Reflexite
Reitter & Schefenacker
Stanley Electric
Stimsonite
TEXTRON Automotive
Valeo
Visteon
Yorka
3M Personal Safety Products
3M Traffic Control Materials

CONTENTS

INTRODUCTION

Current vehicles contain dozens of individual light sources that provide light for headlamps, stop lamps and other signal lamps, as well as interior illumination. A novel concept in automotive lighting that is currently being considered is so-called distributed lighting. In the most extreme version of distributed lighting, the many light sources currently in vehicles would be replaced by a single, centralized light source. The light from this source would then be "distributed" through optic fibers or other light guides to individual light-emitting areas. In less extreme versions of distributed lighting, there would be more than one light source, but each would serve several light-emitting areas.

Of concern with distributed lighting is the possibility of a failure of a centralized light source. In the most extreme version, with a single light source for the entire vehicle, loss of that light source would result in a total absence of any lighting, including headlighting.[1] Because of this concern, there are currently proposals to include in single-source distributed lighting systems (and any distributed lighting that provides illumination for headlamps) a back-up light source that would be automatically switched on if a failure of the primary light source occurred.

The natural next question is: How much of a delay between the offset of the primary light source and the onset of the secondary light source can a driver tolerate? This report addresses that question by reviewing potentially relevant literature. The following topics will be discussed: loss of vision due to eyeblinks, driver performance during visual occlusion, eye fixations away from the roadway ahead (fixations on vehicle displays, controls, and rearview mirrors), head movements when checking traffic in the blind spots, and time-to-collision and time-to-lane-crossing measures.

Our discussions with industry suggest that limiting the delay to no more than 100 ms is technically feasible. Thus, the specific question that this study addressed is as follows: Is a delay of 100 ms between the offset of the primary source and the onset of the secondary source acceptable from the human factors point of view?

There are two considerations that affect the acceptability of a gap in visual input. One deals with the effects of the gap on the quality of driver performance, assuming the occurrence of no startle responses (e.g., panic braking). The other consideration involves the startle effects themselves. We will briefly address both of these considerations.

---

[1] Such a catastrophic failure would not be unique to distributed lighting. Current vehicle lighting is also susceptible to a total loss of headlamp illumination (e.g., through a failure of the headlamp switch) or even a complete failure of its electrical system with a consequent loss of all illumination.

EFFECTS ON THE QUALITY OF DRIVER PERFORMANCE

In this section, we will review available evidence relevant to the effects of a temporary loss of visual input on driver performance, assuming no startle responses. Some of the evidence is from basic settings, while other evidence is from applied, driving research.

Eyeblinks

We continuously interrupt our own visual input by eyeblinks. An eyeblink is defined "as a temporary closure of both eyes, involving movements of the upper and lower lids" (Lawson, 1948, p. 154). There are three general classes of eyeblinks: involuntary (in response to the drying of the cornea), reflex (in response to external stimulation, such as a puff of air), and voluntary (initiated by our own free will). Of primary interest here are involuntary eyeblinks, because they can occur up to 20 times per minute (Lawson, 1948), although a more typical frequency is 5-10 times per minute (Moses, 1975; Lawson, 1948). The duration of an involuntary eyeblink is on the order of 250 to 400 ms (Lawson, 1948; Gordon, 1951; Doane, 1980). The length of the time that the pupil is covered by the eyelid—and thus the length of the visual blackout—is typically between 100 to 300 ms (Lawson, 1948; Gordon, 1951). The frequency and duration of involuntary eyeblinks indicate that they can result in vision being occluded for more than 10% of the time (Lawson, 1948), but we are not usually aware of these interruptions in visual input.

Eye fixations away from the road ahead

The roadway ahead is not the sole focus of driver eye fixations in actual driving. For example, some eye fixations are directed towards in-vehicle displays and controls, as well as rearview mirrors. During such fixations, the roadway ahead is at relatively large peripheral angles (e.g., 45° for a typical outside rearview mirror on the driver side). Under photopic (daytime) ambient conditions, vision is best in the fovea, and decreases with the increasing peripheral eccentricity. This is the case for detection (Lie, 1980), motion sensitivity (Johnson and Leibowitz, 1975), acuity (Johnson, Keltner, and Balestrery, 1978), contrast sensitivity (Pointer and Hess, 1989), and reaction time (Flannagan, Sivak, and Traube, 1999). Under scotopic (nighttime) ambient conditions, visual sensitivity is best at about 10° eccentricity, with the sensitivity declining as the peripheral angle either decreases or increases from 10° (Lie, 1980). However, even under scotopic conditions, vision at large peripheral angles (over 25°) is worse than vision in the fovea (Lie, 1980). The nasal (towards the nose) and temporal (towards the temple) retinal sensitivities are similar, with one major exception. Near 15° in the temporal periphery, there is an area called the blind spot (where the optic nerve leaves the retina), with no sensitivity at all.

Because of the generally lower sensitivity in the periphery than in the fovea, durations of fixations that are away from the roadway ahead provide an indication of acceptable performance costs, and are of some relevance to the issue at hand. Examples of recent reviews of driver eye fixations on rearview mirrors, and in-vehicle displays and controls are Kurokawa (1990), Taoka (1990), and Green (1999). What follows are sample findings only, presented for illustrative purposes.

Fixations on rearview mirrors. Mourant and Donohue (1974) monitored driver eye fixations in expressway driving. They found that the average duration per fixation on the driver-side exterior rearview mirror in lane-change maneuvers was 1.0 s. (Furthermore, their data indicate that, in the same situations, the average time for a head turn to make a direct look was 1.5 s.) In comparison, Rockwell (1988) reports that in a set of three studies, eye fixations on the driver-side mirror averaged 1.1 s.

Fixations on traditional displays and controls. Taoka (1990) analyzed the data from Wierwille, Antin, Dingus, and Hulse (1988) and Rockwell (1988) concerning durations of eye fixations on in-vehicle displays and controls. His analysis indicates that the eye fixations averaged 0.6 s for speedometer, 1.1 s for temperature gauge, and 1.1 s for defroster.

Fixations on navigation displays. Dingus et al. (1995) present eye fixation data for drivers operating a real navigation system in actual traffic. A variety of interface types were tested. The mean eye-fixation duration was about 1.0 s. Wierwille et al. (1988) found that driver eye fixations on a navigation system averaged between 1.2 and 1.7 s, depending on the navigation task required. (In comparison, the mean durations of eye fixations on conventional displays or controls were all 1.2 s or less in this study.)

Summary. Field data indicate that the durations of eye fixations on rearview mirrors, displays, and controls can exceed 1.0 s. If a head movement is required, then additional time is needed. Concerning an upper limit, Rockwell (1988) points out that "drivers are loath to go without roadway information for more than 2 s (and rightly so)" (p. 322).

Voluntary occlusions of vision while driving

Additional evidence concerning acceptable delays between the offset of a primary light source and the onset of a secondary light source comes from studies that measured durations of voluntary occlusions of vision. The classic work in this area was performed by Senders in the late 1960s (e.g., Senders et al., 1967). In this research, drivers were wearing on their heads a device that had two states. In the open state, the drivers had a relatively unrestricted field of view. In the closed state, their vision was occluded with a translucent visor "through which no road or vehicle detail could be seen" (p. 22).

The basic approach developed by Senders has since then been used, with modifications, in many studies (e.g., Farber and Gallagher, 1972; Zwahlen and Balasubramanian, 1974; Riemersma, 1987). For illustrative purposes, we will highlight here the results of Godthelp, Milgram, and Blaauw (1984) and Fitzpatrick et al. (1999). The former study dealt with driving on straight portions of roads, while the latter concentrated on a more demanding task—driving on curves.

Godthelp et al. (1984) gave drivers unobstructed views lasting 0.55 s each. The dependant variable was the acceptable occlusion time between successive views. Of interest for our purpose is the finding that the occlusion time varied as a function of speed, averaging about 5.5 s at 20 km/h and about 2.5 s at 120 km/h.

Fitzpatrick et al. (1999) included both actual driving and driving in a simulator. The subjects were given unobstructed glimpses lasting 0.5 s each. As expected, the acceptable delay between successive glimpses varied as a function of the type of the curve. In general, however, the mean delays between the offset of a glimpse and the onset of the successive glimpse in actual driving were between 0.5 and 1.0 s—substantially less than the delays obtained by Godthelp et al. (1984) on straight roads.

Time-to-collision and time-to-lane-crossing

Of potential relevance to the issue at hand is research on when corrective actions (steering or braking) occur in cases of impending collisions or lane departures. This type of research uses two related concepts: time-to-collision (TTC) and time-to-lane-crossing (TLC). TTC represents "the time required for two vehicles to collide if they were to continue their speed and were to remain on the same path" (van der Horst, 1990, p. 26). Minimum TTC, in turn, is defined as the time remaining before impact when a corrective action (that lengthens the TTC) is performed. Analogously, TLC "represents the time necessary for the vehicle to reach either edge of the lane, assuming a fixed steering strategy" (Godthelp et al., 1984, p. 261). Minimum TLC, in turn, is defined as the time remaining before crossing the edge of the lane when a corrective action is performed.

The research on TTC and TLC is quite extensive (e.g., Lee, 1976; Schiff and Detwiller, 1979; McLeod and Ross, 1983; Gothelp et al., 1984; Cavallo and Laurent, 1988; Hoffmann and Mortimer, 1994; van Winsum and Heino, 1996). One of the most comprehensive works is by van der Horst (1990). His data indicate that for a variety of conflict situations, the median values of the minimum TTC tend to be between 1.5 s and 2.5 s. In comparison, the minimum TLCs are generally substantially greater, and they vary with speed. For example, Godthelp et al. (1984) found that on straight roadways the median values of TLC ranged from about 11 s at 20 km/h to about 3.5 s at 120 km/h.

In summary, the TTC and TLC data indicate that corrective actions in situations involving conflicts with other motorists or lane departures tend to occur at more than 1.5 s before the conflict or lane departure.

Summary of the data reviewed

The findings from this section are summarized in Table 1, by listing typical values.

Table 1
Typical values of variables with potential relevance to the quality of driver performance.

Aspect	Duration (ms)
Periods with no visual input during eyeblinks	200
Voluntary occlusions of vision while driving in experimental settings	>500
Fixations on rearview mirrors, and conventional controls and display	1000
Fixations on navigation systems	>1500
Head turns prior to lane changes	1500
Time-to-collision and time-to-lane-crossing at initiation of a corrective action	>1500

Relevance of the data reviewed

The data reviewed above have differing relevance to the issue at hand. We have informally divided the data into two broad categories: data having some relevance, and data having substantial relevance.

Some relevance. The durations of eye fixations on in-vehicle displays, controls, and navigation systems, as well as rearview mirrors are of some relevance, because the quality of vision straight ahead is reduced (but not eliminated) during such fixations. Similarly, data on time-to-collision and time-to-lane-crossing at the time of a corrective action are of some relevance, because they provide information that is related to the available safety margins. However, these times cannot be directly translated into safety margins, without knowing the specifics of the situation and the nature of the corrective action (e.g., the intensity of braking).

Substantial relevance. Three sets of data appear to be of substantial relevance: durations of eyeblinks, voluntary occlusions of vision in actual driving, and head turns during lane change maneuvers. The first two sets of data are of substantial relevance because during both eyeblinks and voluntary occlusions there is no visual input at all. Similarly, during some head turns there is no visual input from straight ahead. The eyeblink data are probably of greatest relevance, because they best mimic the situation of interest. From among these three sets of data, head-turn data are probably the least relevant, because head turns are generally well planned, and they are usually executed only if conditions permit.

STARTLE EFFECTS

The previous section discussed potential effects on certain aspects of driver performance of a delay between the offset of a primary light source and the onset of a secondary light source. That section did not deal with possible startle effects. Instead, the explicit assumption was that, while the quality of the driving performance might be affected, no major startle effect would take place. Nevertheless, possible startle effects are of some concern. Unfortunately, no direct research evidence exists concerning this issue. The lack of any directly relevant data is primarily a consequence of ethical considerations in testing driver startle reactions.

Furthermore, because of ethical considerations, no studies are available on the existence and nature of startle reactions of drivers to other catastrophic failures (e.g., tire blowouts), or unexpected events (e.g., sudden, strong crosswinds). Studies that dealt with tire blowouts, for example, investigated performance of alerted drivers (e.g., Anderson, Nidey, McCormick, and Russoniello, 1975), as was the case for studies on the effects on gusts of crosswind (e.g., MacAdam, Sayers, Pointer, and Gleason, 1990).

The literature on driver reactions to unexpected road hazards was also examined for possible relevant information. Probably the most relevant study was performed by Olson, Cleveland, Fancher, Kostyniuk, and Schneider (1984). This study evaluated driver response time to an unexpected obstacle on the road. The obstacle was a foam rubber block, 15 cm high and 91 cm wide positioned in the path of travel. The obstacle became visible after cresting a hill. The subjects were not informed about the true purpose of the study, and thus only one trial per subject could be collected. Although startle reactions were not the topic of this research, Olson et al. do not mention occurrence of any panic responses.

Because of the lack of direct research evidence, only indirect inferences can be made concerning possible startle effects in our present situation. The startle effects of primary concern are panic brakings, although sudden major steering maneuvers are also possible. While we do not have any basis for estimating the likelihood of panic braking as a function of the delay in restoring headlamp illumination, we can consider the likely consequences of such actions. Panic braking has potential effects on both the driver who does the braking, as well as other motorists. Panic braking can lead to a loss of control, especially if the surface has a low coefficient of friction, or if it occurs on a curve. However, antilock brakes would mitigate these negative consequences. (In the U.S., 73% of ’97 model vehicles had factory installed antilock brakes [Ward’s Automotive Yearbook, 1998]. Furthermore, because of their expense, there will likely be a positive correlation between having distributed lighting and antilock brakes on the same vehicle.) The primary consequence of panic braking on other motorists is an increase in the likelihood of rear-end collisions involving closely following vehicles. However, in close-following situations, the road illumination from the headlamps of the following vehicle is likely to be sufficient to minimize the likelihood of startle effects.

NATURE OF IMPLEMENTATION

The preceding discussion dealt with the potential safety consequences of an interruption of visual input for a limited amount of time. However, depending on the implementation of a distributed lighting system, it is possible that the onset of the secondary light source would be perceptually more prominent than the offset of the primary light source.

Specifically, if the secondary light source is high-intensity discharge (HID), then it is likely that the initial level of light output would be substantially greater than the steady state level (of both the primary and secondary sources). This is the case because HID light sources have, typically, a briefly elevated level of output after the voltage is switched on (see Figure 1).

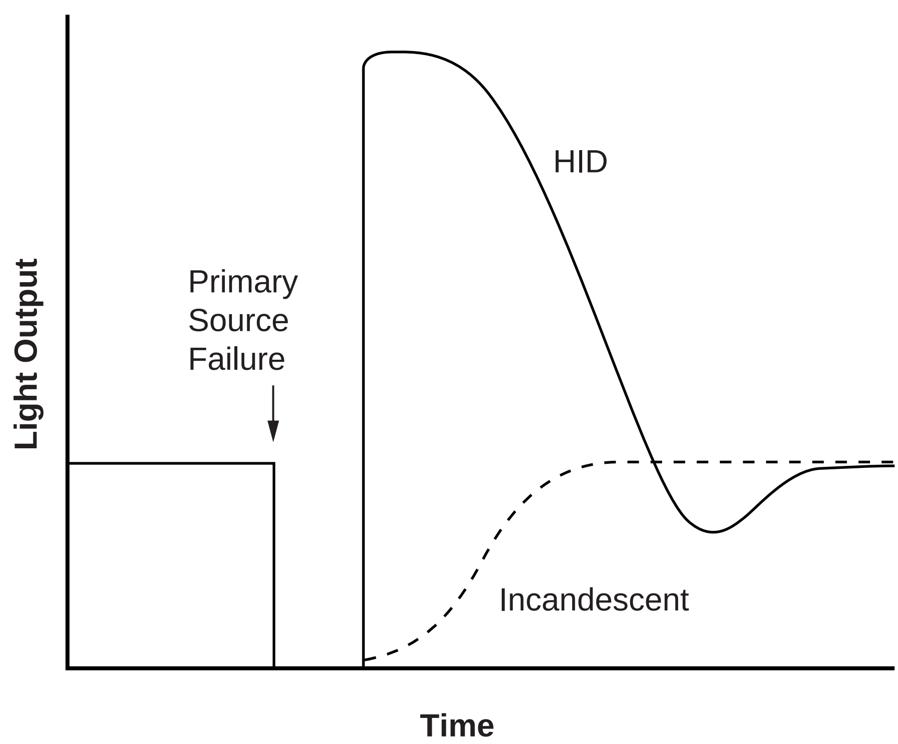

Figure 1. A schematic representation of the effects of the light source type on the initial time course of light output.

There are two likely consequences of such a situation. First, the bright flash of the secondary light source might retroactively "mask" the dark interval after the offset of the primary source. In other words, this bright flash might make the delay imperceptible. The likelihood of masking would depend on the specific light levels and time delays in question. (Raab [1963] and Kahneman [1968] are two examples of comprehensive reviews of visual-masking phenomena.) Second, the bright flash of the secondary light source might be more perceptible than the delay, even if full masking does not take place.

Using an incandescent secondary light source would reduce these effects, because the light output does not overshoot the desired asymptotic level (see Figure 1). However, because of the relatively long rise time of incandescent sources (e.g., Flannagan and Sivak, 1989), the effective delay between the two light sources would be greater than the nominal delay.

In summary, the specific implementation of the secondary light source will likely affect the consequences of a delay. Certain types of secondary light sources (e.g., HIDs) might cause the onset of the secondary light source to be more perceptually salient than the offset of the primary source. Other types (e.g., incandescent) might increase the perceived delay. However, it remains to be ascertained which implementation would be perceptually more acceptable.

SUMMARY AND CONCLUSION

This report reviewed evidence concerning acceptable delays in switching between a primary and a secondary light source in distributed lighting. The specific question posed was as follows: The industry considers a delay of 100 ms technically achievable, but is it acceptable from the human factors point of view? The evidence considered included consequences for the quality of driver performance and possible startle effects. In discussing the quality of driver performance, the following aspects were considered: eyeblinks, voluntary occlusions of vision during driving, fixations away from straight ahead (on rearview mirrors, vehicle controls and displays, and navigation systems), head movements when checking traffic in the blind spots, and time-to-collision and time-to-lane-crossing measures. Possible effects of different implementations of the secondary light source (high-intensity discharge and incandescent) were also briefly discussed.

Based on the available evidence concerning the quality of driver performance (excluding startle effects), a delay of 100 ms or less is unlikely to create safety problems. Furthermore, although little evidence exists on the likelihood and nature of startle responses, it is unlikely that a delay of 100 ms or less will lead to major negative startle consequences.

REFERENCES

Anderson, R.L., Nidey, R.A., McCormick, G., and Russoniello, F. (1975). *Control of large commercial vehicle accidents caused by front tire failure* (Contract No. DOT-FH-11-8562). Pheonix, AZ: Ultrasystems.

Brown, J.L. (1965). Flicker and intermittent stimulation. In C.H. Graham, N.R. Bartlett, J.L. Brown, Y. Hsia, and C.G. Mueller (eds.), *Vision and visual perception* (pp. 251-320). New York: Wiley.

Cavallo, V. and Laurent, M. (1988). Visual information and skill level in time-to-collision estimation. *Perception*, *17*, 623-632.

Dingus, T.A., McGehee, D., Hulse, M., Jahns, S., Manakkal, N., Mollenhauer, M., and Fleichman, R. (1995). *TravTek evaluation task C3—Camera car study* (Report No. FHWA-RD-94-076). Washington, D.C.: Federal Highway Administration.

Doane, M.G. (1980). Interaction of eyelids and tears in corneal wetting and the dynamics of the normal human eyeblink. *American Journal of Ophthalmology*, *89*, 507-516.

Farber, E. and Gallagher, V. (1972). Attentional demands as a measure of the influence of visibility conditions on driving task difficulty. *Highway Research Record*, *414*, 1-5.

Fitzpatrick, K., Wooldrige, M.D., Tsimhoni, O., Collins, J.M., Green, P., Bauer, K., Parma, K.D., Koppa, R., Harwood, D.W., Krammes, R.A., and Poggioli, B. (1999). *Alternative design consistency rating methods for two-lane rural highways* (Contract No. DTFH61-95-R-00084). College Station, TX: Texas Transportation Institute.

Flannagan, M.J. and Sivak, M. (1989). *An improved braking indicator* (SAE Technical Paper Series No. 890189). Warrendale, PA: Society of Automotive Engineers.

Flannagan, M.J., Sivak, M., and Traube, E.C. (1999). *Quantifying the direct field of view when using driver-side rearview mirrors* (SAE Technical Paper Series No. 1999-01-0656). Warrendale, PA: Society of Automotive Engineers.

Godthelp, H., Milgram, P., and Blaauw, G.J. (1984). The development of a time-related measure to describe driving strategy. *Human Factors*, *26*, 257-268.

Gordon, G. (1951). Observations upon the movements of the eyelids. *British Journal of Ophthalmology*, *35*, 339-351.

Green, P. (1999). *Visual and task demands of driver information systems* (in preparation). Ann Arbor, MI: The University of Michigan Transportation Research Institute.

Hoffmann, E.R. and Mortimer, R.G. (1994). Drivers' estimates of time to collision. *Ergonomics*, *26*, 511-520.

Johnson, C.A., Keltner, J.L., and Balestrery, F. (1978). Effects of target size and eccentricity on visual detection and resolution. *Vision Research*, *18*, 1217-1222.

Johnson, C.A. and Leibowitz, H.W. (1975). Velocity-time reciprocity in the perception of motion: foveal and peripheral determinations. *Vision Research*, *16*, 177-180.

Kahnemann, D. (1968). Method, findings, and theory in studies of visual masking. *Psychological Bulletin*, *70*, 404-425.

Kurokawa, K. (1990). *Development of an evaluation program for automobile instrument panel design* (Ph.D. dissertation). Blacksburg, Virginia: Virginia Polytechnic Institute and State University, Industrial and Systems Engineering Department.

Lawson, R.W. (1948). Blinking: its role in physical measurements. *Nature*, *161*, 154-157.

Lee, D.N. (1976). A theory of visual control of braking based on information about time-to-collision. *Perception*, *5*, 437-459.

Lie, I. (1980). Visual detection and resolution as a function of retinal locus. *Vision Research*, *20*, 967-974.

MacAdam, C.C., Sayers, M.W., Pointer, J.D., and Gleason, M. (1990). Crosswind sensitivity of passenger cars and the influence of chassis and aerodynamic properties on driver preferences. *Vehicle Systems Dynamics*, *19*, 201-236.

McLeod R.W. and Ross, H.E. (1983). Optic flow and cognitive factors in time-to-collision estimates. *Perception*, *12*, 417-423.

Moses, R.A. (1975). The eyelids. In R.A. Moses (ed.), *Adler's physiology of the eye* (6^{th} edition). St. Louis: Mosby.

Mourant, R.R. and Donohue, R.J. (1974). *Mirror sampling characteristics of drivers* (SAE Technical Paper Series No. 740964). Warrendale, PA: Society of Automotive Engineers.

Olson, P.L., Cleveland, D.E., Fancher, P.S., Kostyniuk, L.P., and Schneider, L.W. (1984). *Parameters affecting stopping sight distance* (NCHRP Report No. 270). Washington, D.C.: Transportation Research Board.

Pointer, J.S. and Hess, R.F. (1989). The contrast sensitivity gradient across the human visual field: with emphasis on the low spatial frequency range. *Vision Research*, *29*, 1133-1151.

Raab, D.H. (1963). Backward masking. *Psychological Bulletin*, *60*, 118-129.

Riemersma, J.B.J. (1987). *Visual cues in straight road driving*. Soest, The Netherlands: Drukkerij Neo Print.

Rockwell, T. (1988). Spare visual capacity in driving—revisited. In A.G. Gale, M.H. Freeman, C.M. Haslegrave, P. Smith, and S.P. Taylor (eds.), *Vision in vehicles II* (pp. 317-324). Amsterdam: Elsevier Science.

Schiff, W. and Detwiler, M.L. (1974). Information used in judging impending collision. *Perception*, *8*, 647-658.

Senders, J. W., Kristofferson, A. B., Levison, W. H., Dietrich, C. W., and Ward, J. L. (1967). The attentional demand of automobile driving. *Highway Research Record, 195*, 15-33.

Taoka, G. (1990). Duration of drivers' glances at mirrors and displays. *ITE Journal*, *60* (10), 35-39.

van der Horst, A.R.A. (1990). *A time-based analysis of road user behavior in normal and critical encounters*. Soesterberg, The Netherlands: TNO Institute for Perception.

van Winsum, W. and Heino, A. (1996). Choice of time-headway in car-following and the role of time-to-collision information in driving. *Ergonomics*, *39*, 579-592.

Ward's Automotive Yearbook (60th edition). (1998). Southfield: Ward's Communications.

Wierwille, W.W., Antin, J.F., Dingus, T.A., and Hulse, M.C. (1988). Visual attentional demand of an in-car navigation display system. In A.G. Gale, M.H. Freeman, C.M. Haslegrave, P. Smith, and S.P. Taylor (eds.), *Vision in vehicles II* (pp. 307-316). Amsterdam: Elsevier Science.

Zwahlen, H.T. and Balasubramanian, K.N. (1974). A theoretical and experimental investigation of automobile path deviations when drivers steers with no visual input. *Transportation Research Record*, *520*, 13-24.