UMTRI-2000-15

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Report No. UMTRI-2000-15
June 2000

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UMTRI-2000-15		

4. Title and Subtitle	5. Report Date
The Effect of Lead-Vehicle Size on Driver Following Behavior	June 2000
	6. Performing Organization Code 302753
7. Author(s) James R. Sayer, Mary Lynn Mefford, and Ritchie Huang	8. Performing Organization Report No. UMTRI-2000-15
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, Automotive Lighting, BMW, Britax International, Corning, DaimlerChrysler, Denso, Donnelly, Federal-Mogul Lighting Products, Fiat, Ford, General Electric, GM NAO Safety Center, Guardian Industries, Guide Corporation, Hella, Ichikoh Industries, Koito Manufacturing, Libbey-Owens-Ford, LumiLeds, Magna International, Meridian Automotive Systems, North American Lighting, Osram Sylvania, Pennzoil-Quaker State, 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

The effect that lead-vehicle size (specifically, height and width) has on a passenger car driver's gap maintenance under near optimal driving conditions (e.g., daytime, dry weather, free-flowing traffic) was examined. The data were obtained from a random sample of licensed drivers who drove an instrumented passenger car, unaccompanied, as their personal vehicle for two to five weeks.

The results show that passenger car drivers followed light trucks at shorter distances than they followed passenger cars by an average of 5.6 m (18.6 ft), but at the same velocities and range-rates. This result is discussed in the context of a passenger car driver's ability to see beyond the lead vehicle to assess the status of traffic downstream.

While it is necessary that following drivers be able to see the stop lamps on lead vehicles, this is not by itself sufficient for safety. The results of this study suggest that knowing the state of traffic beyond the lead vehicle, even by only one additional vehicle, affects gap length. Specifically, it appears that when dimensions of lead vehicles permit following drivers to see through, over, or around them, drivers maintain significantly longer (i.e., safer) distances.

17. Key Words		18. Distribution Statement	
headway, light truck, passenger car, stop lamp, time gap, transmittance		Unlimited	
19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
None	None	36	

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
Automotive Lighting
BMW
Britax International
Corning
DaimlerChrysler
Denso
Donnelly
Federal-Mogul Lighting Products
Fiat
Ford
General Electric
GM NAO Safety Center
Guardian Industries
Guide Corporation
Hella
Ichikoh Industries
Koito Manufacturing
Libbey-Owens-Ford
LumiLeds
Magna International
Meridian Automotive Systems
North American Lighting
Osram Sylvania
Pennzoil-Quaker State
Philips Lighting
PPG Industries
Reflexite
Reitter & Schefenacker
Stanley Electric
Stimsonite
TEXTRON Automotive
Valeo
Visteon
Yorka
3M Personal Safety Products
3M Traffic Control Materials

Appreciation is also extended to members of the UMTRI Engineering Research Division for their part in conducting the study from which the present data were derived, and their assistance in the reduction of that data for analysis in this study.

CONTENTS

INTRODUCTION

Hypothesis

This study was designed to contribute to understanding how light trucks might influence gap maintenance behavior when they precede passenger cars. Vehicles that are classified as light trucks include sport utility vehicles, minivans, passenger vans, and pickup trucks. We expected, a priori, that light trucks might lead to longer average gaps, and thus possibly contribute to a reduction in traffic throughput on highways. This was hypothesized on the basis that light trucks would obstruct the view beyond the immediate lead vehicle for passenger car drivers that follow them. Specifically, we anticipated that passenger car drivers would leave longer gaps between the front of their vehicle and the rear of a lead vehicle when the lead vehicle was a light truck.

It is not unusual for drivers to report, at least anecdotally, that they avoid following large vehicles. The basis for aversion to following large vehicles is generally attributed to a driver's recognition of how visual information regarding the forward scene may be obstructed. In some driving environments the potential for obstructing the forward view is perhaps more troublesome than in others. When closely following a tractor-trailer combination on surface streets, it is not uncommon to have difficulty locating overhead traffic signals. Whereas closely following the same tractor-trailer combination on limited access highway, where overhead signals are generally nonexistent, the same issue is no longer a factor (although the driver's view of overhead signs is still reduced). Similarly, large vehicles can obstruct a driver's view of stop lamps on vehicles that are in the same lane but are beyond the immediate lead vehicle (downstream). The apparent need for visual information of the forward scene and anecdotal reports suggest that passenger car drivers would be expected to maintain longer gaps on average between themselves and larger vehicles than they maintain between themselves and passenger cars (see Figure 1). The rationale for leaving longer gaps is to allow more time to respond to events for which drivers have little or no advance notice due to the forward scene being obstructed, at least in part, by a large vehicle which the following driver cannot "see beyond."

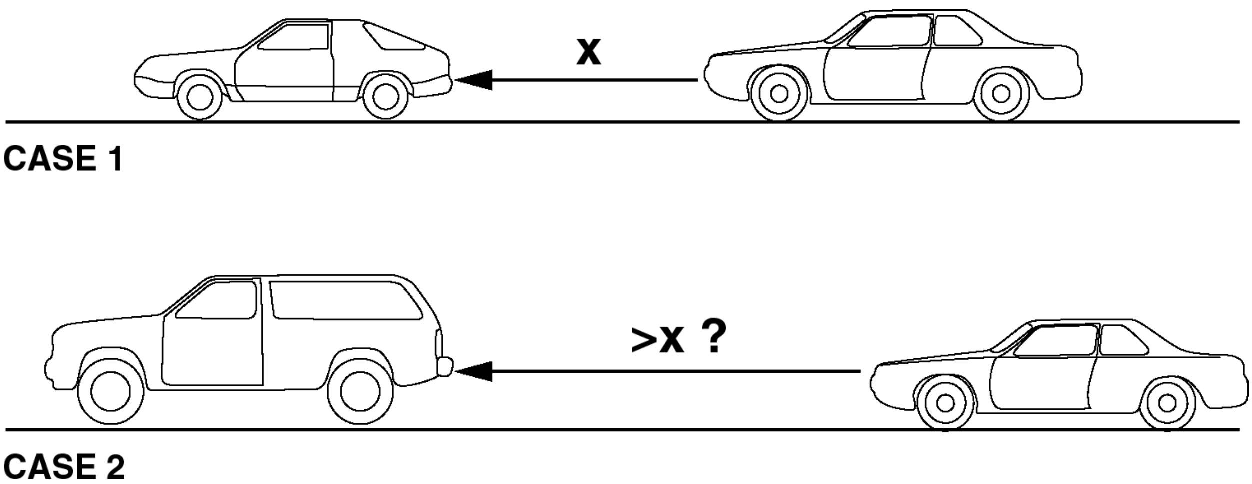

Figure 1. Hypothesized following relationship between light trucks and passenger cars.

Previous Research

There have been several research studies over the years attempting to describe or model driver gap and headway maintenance. Rockwell (1972) provides a historical review of the literature, and Wilson (1994) offers a review of more recent efforts involving naturalistic data collection. However, previous work in this area that is specifically associated with lead-vehicle size or class is surprisingly limited. The majority of the research effort has concentrated on understanding how a driver perceives changes in gap size (closing or separation) as a function of the rate of change of the related image size on the retina (looming effect). In studies in which vehicle class has been assessed, passenger vehicles were either lumped into one group or vehicle size was based on mass rather than vehicle dimensions. Even related efforts such as a recent extensive analyses of rear-end accident data do not differentiate between passenger cars and light trucks (Knipling, Wang, and Yin, 1993).

Previous studies can be divided into two classes, based on slightly different approaches: those that studied headway and those that studied gap or following distance. Headway is defined as the distance from the front bumper of the lead vehicle to the front bumper of the following vehicle. Gap, or following distance, is defined as the distance between the rear bumper of the lead vehicle and the front bumper of the following vehicle. The length of the lead vehicle therefore affects measures of headway, whereas measures of gap are independent of lead-vehicle length. Measures of headway may be misleading as measures of driver following behavior unless lead-vehicle length is accounted for.

Headway as a function of lead-vehicle length. A series of studies from the General Motors Research Laboratories in the late 1970s related driver's response to looming, and investigated how driver and vehicle characteristics contribute to headway and gap maintenance. Herman, Lam, and Rothery (1973) first observed that a platoon of small cars on a test track required significantly less road surface than the same number of large cars. Furthermore, the differences were greater than could be attributed solely to differences in car length, indicating that the gaps between small cars were proportionately smaller than gaps between larger cars. Evans and Rothery (1976) investigated this effect in the laboratory and concluded that the differences in gap were attributable to how much road surface the driver could see between his vehicle and a lead vehicle, and that the visible road surface decreased with increasing hood length and height. The authors tested and ruled out lead-vehicle width as a contributing factor in gap maintenance, but the height of the lead vehicle was not addressed.

In a later effort to describe the effect of vehicle size on freeway capacity, Wasielewski (1981) had one lane of traffic on a local expressway videotaped from two angles during near-peak capacity. The merged images from the two video cameras were then viewed frame-by-frame in order to determine vehicle headways and vehicle size classifications. Vehicle size was based on overall vehicular length, and did not take width or height into consideration. The assumption was that the observed average headway as a function of vehicle length in near-capacity conditions would be a representative measure of capacity for same or similarly sized vehicles in a platoon. The author reported some interesting, and somewhat surprising, results. Drivers of medium-sized cars, 4.57-5.46 m (180-215 in), maintained significantly shorter time headways (mean difference of 0.09 s) than either large- or small-sized cars. Furthermore, this difference in headway was independent of the length of the lead vehicle. Wasielewski speculated that the significantly shorter headways observed when the following car was medium in length were related to either perceptual or behavioral attributes of the following driver.

Evans and Wasielewski (1983) reported combined findings that included characteristics of the driver (age and sex) and vehicle (mass, make, and model) based upon video image interpretation and state licensing records. The primary objective of that research was to examine the relationship between driver and vehicle characteristics and risky driving practices, such as maintaining short headways or gaps. The most applicable findings for the present study include the effects of driver age and vehicle mass (with mass as a surrogate measure for the size of the vehicle). The authors reported a significant, and generally monotonic effect of driver age on observed headways. Specifically, as driver age increased, so did the headway that the driver maintained. Vehicle mass also had a significant effect on headway, and interestingly, the mass category most similar to the medium-sized car class that Wasielewski (1981) had found to be associated with short headways (1,500 to 1,900 kg) was also associated with the shortest headway. With the exception of vehicle mass, the authors reported that all the driver and vehicle characteristics examined showed an approximately linear relationship with risky driving. The authors did not offer any speculations as to why vehicle mass was not monotonically related to headway maintenance.

Gap length as a function of lead-vehicle size or class. One research study that examined gap maintenance strategies associated with lead-vehicle class and size was that of Postans and Wilson (1983). Standing on a motorway overpass, the authors visually examined, and manually recorded, tailgating behavior. Postans and Wilson defined a gap of one second or less as tailgating for a particular stretch of motorway in Bedfordshire, England, under dry weather conditions. The authors report that lorries (large trucks, articulated or fixed, with an unladen weight of at least 3 tons) were not more likely to be observed tailgating, but that they were disproportionately more likely to be involved as the striking vehicle in rear-end accidents (based upon local accident statistics). The tailgating vehicle was a car in more than 68% of all tailgating observations (N = 2306 observations). In only 13% percent of these cases was the lead vehicle larger than a car (lorry, van, or coach), despite the fact that lorries alone accounted for 22% of the total vehicle count. These results suggest that drivers of passenger cars, under the observed conditions, are less likely to tailgate a large vehicle than another passenger car. However, Postans and Wilson, unfortunately, only reported tailgating events (i.e., gaps of one second or less) and did not examine general gap maintenance strategies (e.g., average gaps). Furthermore it is not clear whether maneuvers such as attempts at passing or recent cut-ins were considered in calculating gaps. Nonetheless, these results do provide insight into some general gap-maintenance strategies. Specifically, gaps of one second or less are not uncommon, even in mixed traffic where large vehicles are followed by small cars.

Green and Yoo (1999) investigated gap maintenance as a function of vehicle size in a driving simulator. Four different lead vehicles were simulated (passenger car, pickup truck, bus, and tractor-trailer combination), and participants were instructed to follow these vehicles without passing. The authors report that older participants maintained longer gaps on average than did young participants; however, the values of gap tended to be longer than corresponding gaps seen in on-the-road studies. Participants followed 10% closer when the lead vehicle was a passenger car than when the lead vehicle was a pickup, bus, or truck. As the authors noted, one serious potential disadvantage of conducting this type of research in a simulator is the inability to adequately simulate the onset of stop lamps in terms of their intensity and visibility as viewed through the glass of successive lead vehicles. Furthermore, there were no vehicles beyond the immediate lead vehicle that required monitoring.

The Present Study

Data for the present study were obtained from the 1996-97 Intelligent Cruise Control Field Operational Test (ICC FOT), a detailed description of which is in Fancher, Ervin, Sayer, Hagan, Bogard, Bareket, Mefford, and Haugen (1998). The primary goal of the ICC FOT was to examine naturalistic use of a new type of cruise control, commonly known as adaptive cruise control (ACC). Each of ten vehicles involved in this ICC FOT was equipped with an ACC system and supporting equipment, including an infrared sensor that was used to measure distance and rate of closure to vehicles in the lane ahead, a global positioning (GPS) system, and an extensive data collection system. A group of 108 participants drove an instrumented passenger vehicle as their personal car. The participants were selected at random from the population of licensed drivers in southeastern Michigan, and used the vehicles for a minimum of two weeks (24 drivers were given vehicles for five weeks each). During this period, the vehicles were put into naturalistic use, without constraining where, when, or how participants drove. Each driver was free to choose between operating manually or with conventional cruise control (CCC) during the first week, and between manual operation and ACC during the second (or subsequent) weeks. Table 1 summarizes the scope of usage covered by the 108 drivers. Note that the bulk of the mileage was under manual control. While most of the mileage was accrued in the state of Michigan, some participants took long trips throughout the United States. Digital video of the forward scene was continuously collected whenever the car was in operation. Samples of these video data were saved at regular intervals (every 5 or 10 minutes) to provide the opportunity to assess general traffic conditions to which drivers were exposed.

Table 1. Participant vehicle usage during the ICC FOT.

	All Trips	Manual	CCC Used	ACC Used
Distance, km	183,497	109,809	17,319	56,368
Duration, hr	3,049	2,350	165	534

The goal of the present study was to better understand driver following behavior by taking advantage of the unique opportunity offered by the sampled video data from the ICC FOT. By examining the video data of the forward scene, it can be determined what effects, if any, lead-vehicle size (grouped by vehicle class) had on driving behavior in following situations in which the following vehicle was controlled manually. Only data for following events at velocities greater than 64 km/h (40 mph), which were more likely than lower velocities to take place in free-flowing traffic scenarios permitting the driver to maintain a desired gap, were examined. A total of 1845 video clips, each 2.5 seconds long, were analyzed in order to examine the variables of lead-vehicle size and the following driver characteristics that may have influenced gap size. This research attempted to examine the effect that lead-vehicle size (passenger cars or light trucks) has on passenger car drivers' gap maintenance under near optimal driving conditions (daytime, dry weather, and free-flowing traffic).

METHOD

Participant Recruitment and Screening

Participants were recruited with the assistance of the Michigan Secretary of State (Michigan's driving license bureau). A random sample of 6,000 driving records was drawn from the population of licensed drivers in eight counties in southeastern Michigan (all within approximately a one-hour drive of UMTRI). An initial screening of driver records excluded persons on the basis of the following criteria: a) they possessed more than four (citation) points on their total driving record, b) they had more than two crashes, c) they had at least one crash resulting in a serious injury or fatality, and d) they had been convicted of either driving while intoxicated, or under the influence of alcohol or a controlled substance.

Potential participants were contacted through U.S. mail to solicit their participation in the field operational test. The initial contact, via postcard, did not mention the nature of the study but indicated only that participants would be asked to drive a car and would receive financial compensation for their time. Interested persons were asked to call UMTRI. A total of 443 individuals contacted UMTRI expressing an interest in participating in the study. A research assistant screened all participants to ensure that they met the predetermined qualifications for participation. A detailed description of the participant selection and screening is contained in Fancher et al. (1998).

Experimental Design

The experimental design was based in part on findings from previous research (Fancher, Bareket, Sayer, Johnson, Ervin, and Mefford, 1995) and two power analyses. Only the independent variables associated with driver characteristics were treated in the context of a controlled experimental design. For the purpose of this analysis, the driver characteristic variables were limited to three levels of driver age and two levels of gender. Other variables such as roadway type, weather conditions, and time of day were uncontrolled in the sense that they represented whatever situations the driver encountered in his or her naturalistic use of the vehicle. In total, 108 individuals participated in the ICC FOT. These participants were evenly divided among the two genders and three age groups.

Participants received hands-on instruction for the research vehicle and ACC system. Accompanied by a researcher, each participant experienced the ACC operation during an orientation drive to ensure the participant's understanding of the research vehicle and ACC-system use. The orientation drive lasted approximately 25 minutes and was conducted on a local section of state limited-access highway (in normal midday traffic). The researcher who provided the orientation was thereafter the primary point of contact for the participant should any questions or concerns arise regarding the research vehicle. Each research vehicle was equipped with a cellular telephone that could be used by participants to contact researchers as necessary. Two researchers carried pagers, having one common number, at all times, so that participants were assured of contacting a researcher, if the need arose, on a 24-hour-a-day basis.

The Base Vehicle

The vehicles used in the ICC FOT were 1996 Chrysler Concordes. The Concorde is a five-passenger sedan belonging to the family of Chrysler LH-platform cars. The vehicles were 5.08 m (200 in) in length and had a gross vehicle weight of 2120 kg. Each of the ten vehicles involved in this FOT was equipped with an ACC system and supporting equipment such as a GPS system and a data acquisition system. All vehicles used infrared sensors mounted in the front grill as a means of distance measurement. Data were continuously collected whenever the car was in operation.

Video Data. In each research vehicle a CCD video camera was mounted on the inside of the windshield, behind the rearview mirror (Figure 2). The camera had a wide-angle forward view, and it continuously digitized and stored captured video to internal buffers in the video computer of the data acquisition system.

Figure 2. Forward-looking CCD camera.

The video computer system continuously sampled output from the windshield-mounted camera. The system saved 2.5-second exposures to a file (819,200 bytes each) every 5 minutes for 2-week drivers and every 10 minutes for 5-week drivers. The system hard disk contained 420 contiguous preallocated exposure files. The files were created once and never deleted, which minimized write time and prevented the disk from becoming fragmented. The video computer included a CX100 frame grabber that was programmed to capture an image of 486 rows by 512 pixels in NTSC high-resolution mode. Each image frame contained two interlaced fields (243 rows by 512 pixels). The video software sampled a stripe from the even field, which was 64 rows by 512 pixels, every six frames, or 0.1 seconds.

Upon return of the research vehicle to UMTRI, the exposure files were converted to QuickTime movies. The images were doubled in height to recapture the original aspect ratio (only the even rows are contained in the sample) and compressed. The resulting videos are 200 to 350 K bytes in size. The first frame of each exposure was a title frame showing the driver number, trip number, and date/time of the exposure. Subsequent frames displayed the frame number and frame timestamp at the bottom. Examples of individual frames from the exposure videos are provided in Figures 3 and 4.

Figure 3. Example frame from exposure video showing a light truck as a lead vehicle.

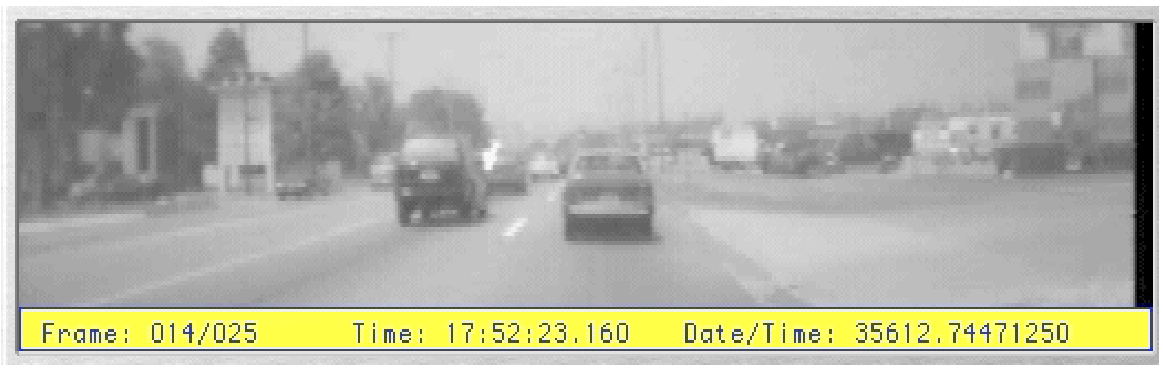

Figure 4. Example frame from an exposure video showing a passenger car as the lead vehicle.

Numerical Data of Following Behavior

The numerical data for range (gap length) to the lead vehicle and velocity were collected at a rate of 10 Hz from the infrared distance sensor and the vehicle's engine control unit. The two remaining data channels, range rate and headway time, were computed on-line and stored at the same sampling rate (Table 2).

Table 2. Numerical data collected at 10 Hz.

Channel	Definition	Units
Range	Distance to lead vehicle	ft
Velocity	Host vehicle velocity	ft/s
Range Rate	Rate of change of range	ft/s
Headway Time Margin	Range/Velocity	s

A numerical database associated with 20,768 video exposure files from the ICC FOT were queried to determine if the host vehicle was actively following a lead vehicle throughout the time of the exposure video. For the purpose of this investigation, active following was initially defined as:

- the host vehicle was being operated manually (as opposed to the use of cruise control),
- an object was detected by the infrared sensor,
- the velocity of the host vehicle was greater than, or equal to, 64 km/h (40 mph), and
- range rate, the rate of change of range, was within +/- 1.5 m/sec (5 ft/sec).

The minimum velocity criterion was selected in an attempt to eliminate scenarios where frequent stopping might be observed. Range rate was limited to +/- 1.5 m/sec (5 ft/sec) in order to eliminate scenarios in which the host vehicle was either rapidly closing in on, or falling back from, a lead vehicle. Relatively large values of range rate indicated that the velocities of the host and lead vehicle are likely too different to be consistent with "active following," and may instead be the beginning or the end of a passing maneuver.

Lead-Vehicle Size Classification Procedure

A total of 2,843 video clips from the ICC FOT satisfied the above criteria for the numerical data. Each clip was then viewed in order to apply several additional, visually based, limiting criteria. The criteria imposed on the basis of visual interpretation were weather conditions, time of day, and lateral movement (specifically lane changes or merges). Only clips that were recorded during daylight with no precipitation and no lateral motion by either the lead or host vehicles were selected for further analyses. These criteria were imposed because both low illumination and poor visibility seriously inhibited the accurate classification of the lead vehicles, and instances of merging, passing, or cut-ins were dramatically different from following events. Of the initial 2,843 video clips, 610 were eliminated on the basis of taking place either at night or in precipitation, 157 were eliminated due to lateral movement by one of the two vehicles, 3 did not contain a lead vehicle (i.e., false target), and in 102 the lead vehicle could not be seen well enough for accurate classification. Commercial trucks and buses, which accounted for an additional 126 video clips, were also eliminated. This was done because only a small number of participants had sufficient data for the analyses performed. Specifically, the analyses required a minimum of two observations for each vehicle size class, and only 20 out of the original 108 participants had sufficient observations for passenger cars, light trucks, and commercial vehicles.

As a result, only 1,845 of the video clips—representing the daytime, dry roadway, and valid target conditions—remained. Of the 102 clips in which the lead vehicle could not be accurately classified, limited camera resolution was the most frequent cause. Accurate classification was possible at a maximum of approximately 3 seconds of headway time at highway speeds. Due to this restriction in image resolution, a broad classification scheme was adopted. The question to be answered in classifying the lead vehicle was "does the size and configuration of the lead vehicle, based primarily on its apparent height and width, permit the following driver the possibility to see through the glazing of the lead vehicle to traffic downstream," recalling that all video was shot from ten identical passenger cars. For purposes of classifying lead vehicles, passenger cars were defined as those vehicles that were short enough in height to permit the following driver, in a passenger car, to see through them (referred to in the Results section as passenger car). Light trucks (sport utility vehicles, minivans, vans, pickup trucks) were defined as larger/taller, vehicles that did not permit the following driver, in a passenger car, to see through them (referred to in the Results section as light truck). Only three motorcycles were observed and treated as passenger cars in the analyses.

One researcher classified the lead vehicle in each of the 1,845 video clips. This individual entered the classification into a spreadsheet that contained the numerical data associated with each of these video clips. An independent spot check by a second researcher was performed to confirm the classification of the lead vehicles in which approximately one out of every thirty clips was reviewed for accuracy. All 102 clips in which the lead vehicle could not be accurately identified were reviewed and confirmed by the second researcher as being inconclusive prior to their elimination.

RESULTS

Data Reduction

Because data were collected from naturalistic driving as individuals went about their daily lives, there were unequal numbers of observations across conditions. Data from the 1845 video clips were reduced by identifying participants with a minimum of two observations for each of the two vehicle sizes (passenger car and light truck), and the mean for each class was calculated separately for each of the four dependent measures (range, velocity, headway time margin and range-rate). All data from individuals with less than two observations for either size vehicle were eliminated from further analyses. Data from a total of seventy individuals, representing 1,698 observations, remained after this reduction technique. The distributions of the seventy individuals by age and gender are provided in Table 3.

Table 3. The number of participants by age and gender.

		n
Age	Young	29
	Middle-Aged	23
	Older	18
Gender	Female	25
	Male	45

Because of the unequal number of observations making up each participant's mean, a weighting of the means was performed. The weighting procedure took into account the number of observations and the associated variance of each mean, and was performed separately for each of the four dependent measures and two vehicle sizes. A standard error of the mean was calculated separately for each participant for each of the eight combinations of dependent measure and vehicle size. The two standard errors associated with vehicle size were squared and summed. The square root of the sum was calculated and the inverse value taken. The resulting value then served as a single weighting variable, calculated individually for each participant and each dependent measure, taking into account the individual's number of observations and the associated variance collectively for the two vehicle sizes. See Equation 1 for an example of the calculation of the individual weights.

Equation 1. Example calculation of an individual weight for headway time margin (HTM).

$$
\begin{aligned}
&\text{If :}\\
&\sigma_{HTM_{PassengerCar}} = 0.59\\
&\sigma_{HTM_{LightTruck}} = 0.39\\
&n_{HTM_{PassengerCar}} = 26\\
&n_{HTM_{LightTruck}} = 6\\
\\
&\text{And :}\\
&\text{Standard Error of the Mean of HTM } (SEM_{HTM}) = \sigma_{HTM} / \sqrt{n_{HTM}}\\
&Weight_{HTM} = 1 / \sqrt{((SEM_{HTM_{PassengerCar}})^2 + (SEM_{HTM_{LightTruck}})^2)}\\
\\
&\text{Then :}\\
&Weight_{HTM} = 5.10
\end{aligned}
$$

Analyses of Variance

Four analyses of variance (ANOVAs) were performed using the mean weighted values of range, velocity, headway time margin, and range-rate as the dependent measures. A final adjustment was made to the mean weighted values across all participants prior to the ANOVA by multiplying them by a constant, independently for each dependent measure, that adjusted the total number of observations back to seventy. Without this final adjustment to the mean weighted dependent measures, the *F* statistics from the resulting ANOVAs would have been artificially inflated or deflated due to the use of an incorrect number of observations. In each of the four ANOVAs the within-subjects variable was lead-vehicle size (passenger car or light truck). The between-subjects factors were participant age (young (20–30), middle-aged (40–50), and older (60–70)), and participant gender.

Vehicle size. The main effects of vehicle size (passenger car or light truck) on the dependent measures of range and headway time margin were statistically significant, $F(1,64) = 22.8$, $p < .001$ and $F(1,64) = 17.9$, $p < .001$, respectively. Figure 5 shows that participants followed light trucks *more closely* than passenger cars by an average of 5.6 m (18.6 ft).

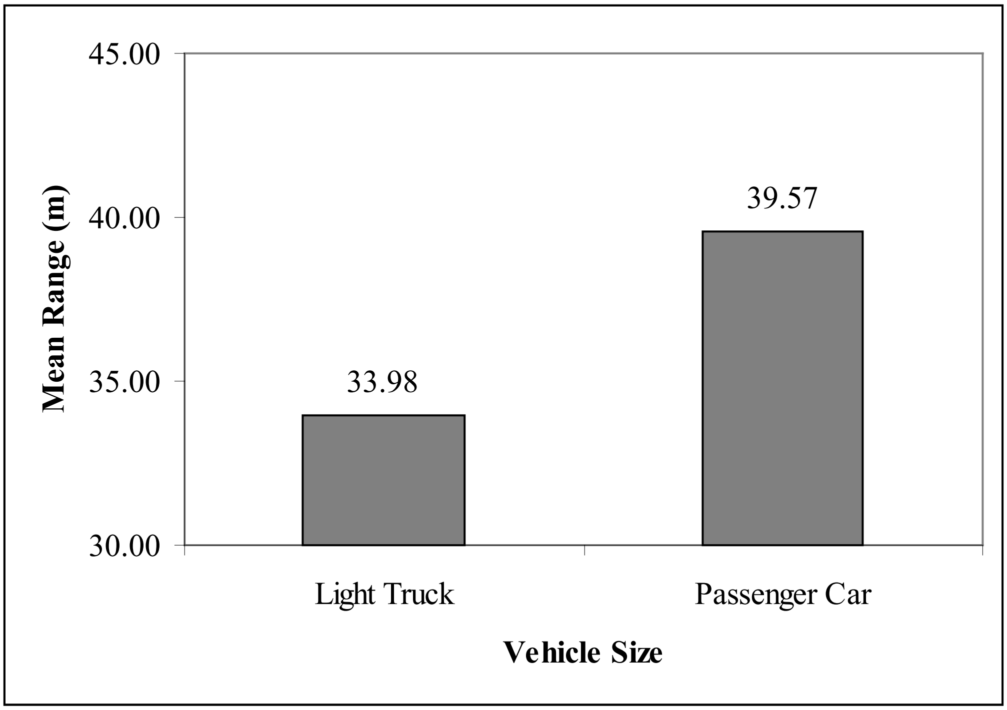

Figure 5. The significant main effect of vehicle size on range.

Neither velocity nor range-rate systematically varied with lead-vehicle size. Therefore, as would be expected, headway time margin decreased, due to the reduction in range, by an average of 0.19 seconds when following light trucks (Figure 6). This effect was consistently observed across all age groups (Figure 7), where the difference was greatest for older participants. The lack of a significant effect of vehicle size on either velocity or range-rate suggests that the observation/exposure conditions were comparable for both levels of vehicle size. In other words, there is no indication that one size of vehicle traveled in a different lane or on a different class of roadway than the other.

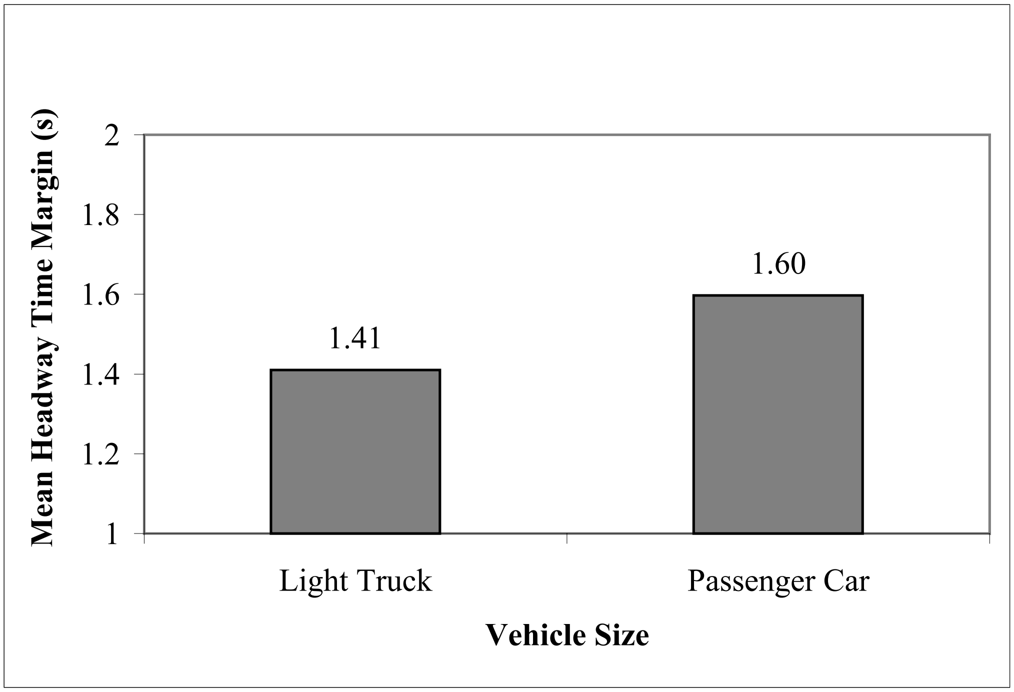

Figure 6. The significant main effect of lead-vehicle size on headway time margin.

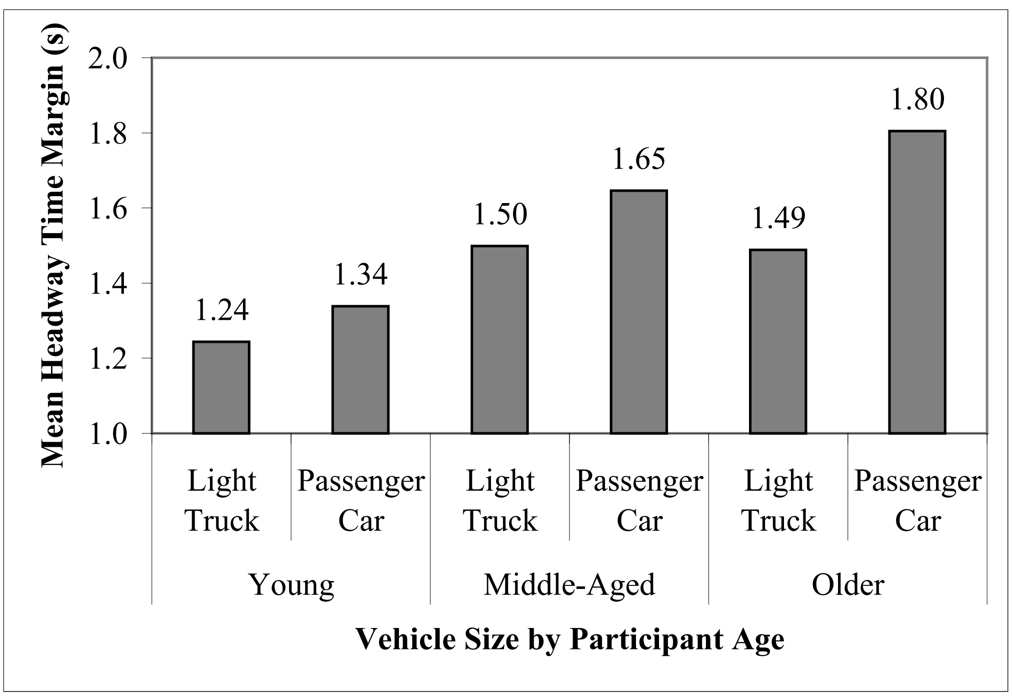

Figure 7. The effect of lead-vehicle size on headway time margin by participant age, depicting a consistent pattern of following behavior across age groups.

Participant age. The main effects of participant age on range and headway time margin were statistically significant, $F(2,64) = 7.14$, $p = .002$, and $F(2,64) = 6.77$, $p = .002$, respectively. Figures 8 and 9 show that the average range and headway time margins increased monotonically as participant age increased (by 8.7 m and 0.36 s, respectively). Student-Newman-Keuls post hoc analyses indicate that the age groups are all significantly different from one another for range, but that the middle-aged and older participants do not differ from one another for headway time margin.

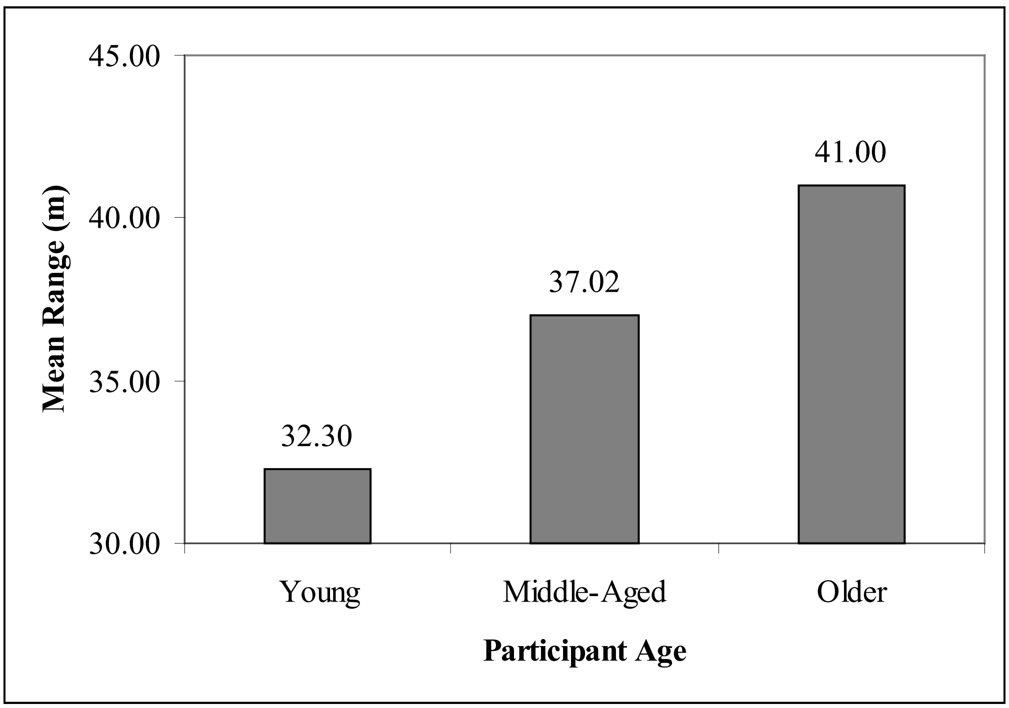

Figure 8. The significant main effect of participant age on range.

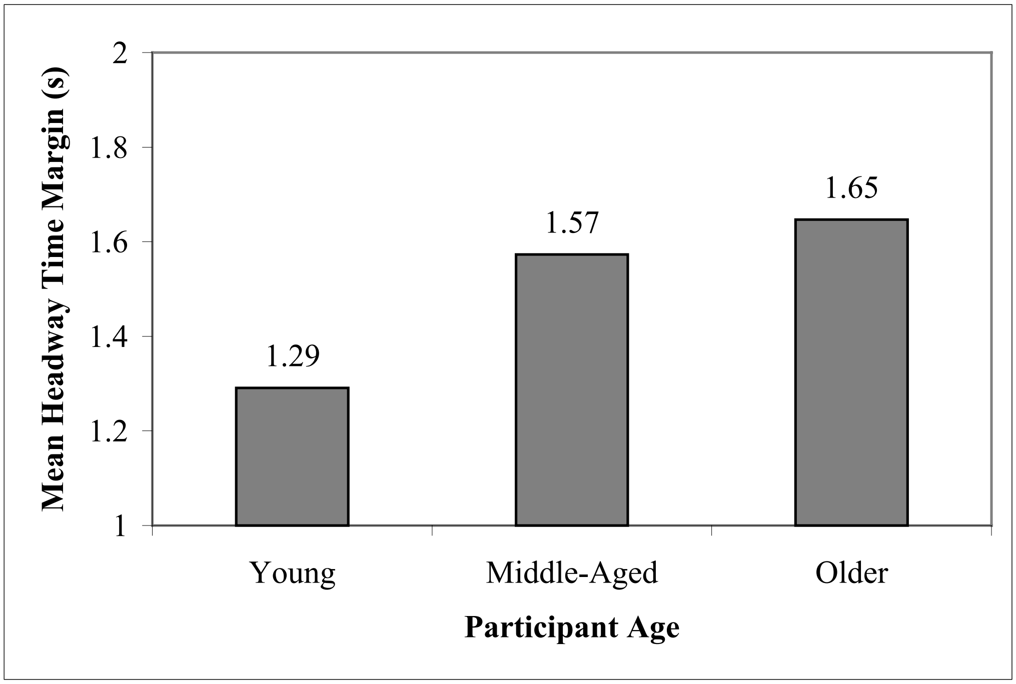

Figure 9. The significant main effect of participant age on headway time margin.

Participant gender. There were no significant main effects associated with the gender of the participant.

Participant age and gender. The interaction of participant age and participant gender for the dependent measure of headway time margin was the only statistically significant two-way interaction, $F(2,64) = 4.2$, $p = .019$ (Figure 10). The results for the female participants show monotonically increasing values of headway time margin with increasing age, whereas for male participants the effect was not monotonically related to age. Older male participants maintained an average headway time margin that was statistically significantly shorter than that maintained by middle-aged male participants, and only slightly longer than the young male participants.

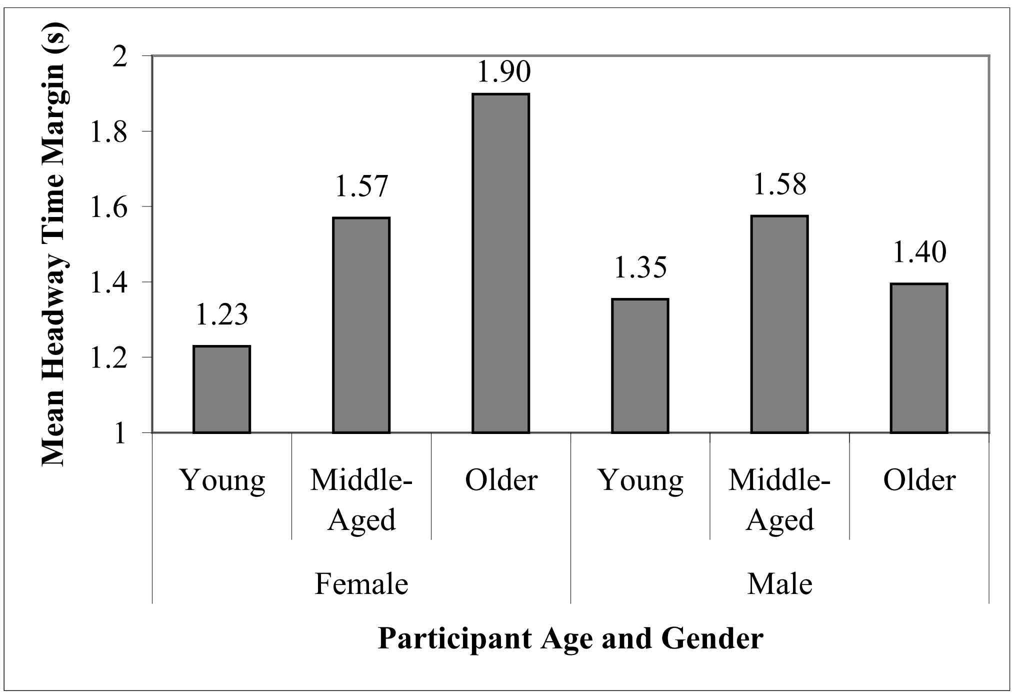

Figure 10. The interaction of participant age and gender for headway time margin.

Participant age, gender, and vehicle size. The interaction of participant age, gender, and vehicle size for the dependent measure of velocity was the only statistically significant three-way interaction, $F(2,64) = 4.6$, $p = .014$ (Figure 11).

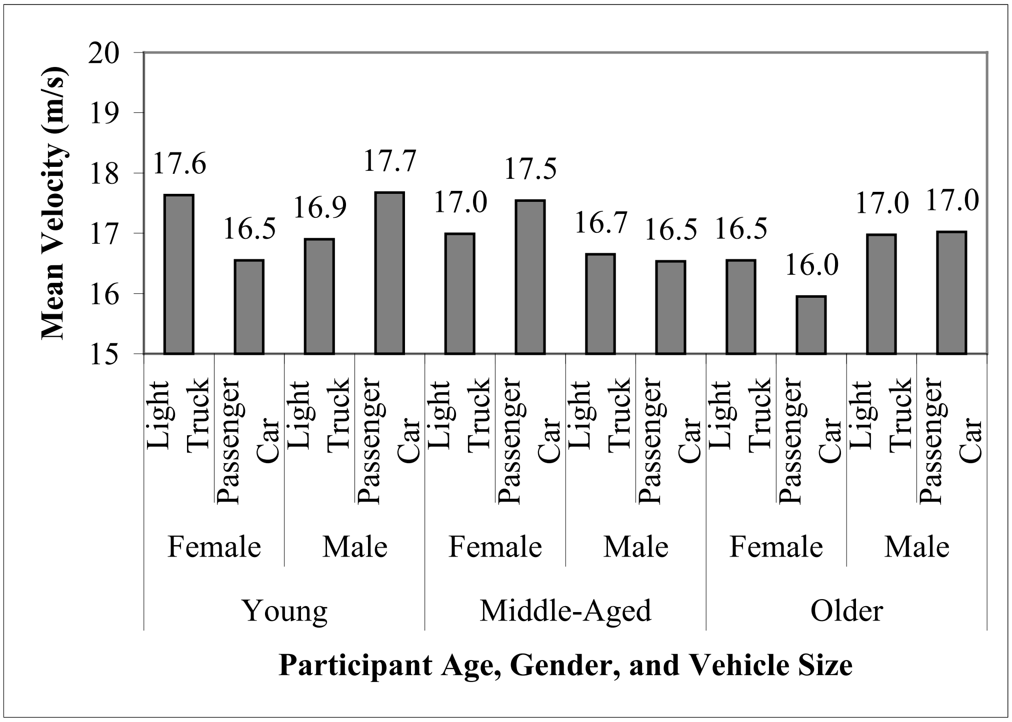

Figure 11. The interaction of participant age, gender, and vehicle size for velocity.

DISCUSSION

There are two results from this study that, in particular, warrant discussion. The most prominent is the result that passenger car drivers, on average, follow light trucks at shorter distances (gaps) and headway time margins than they follow passenger cars. The second result is that older passenger car drivers generally maintain longer gaps than do younger drivers. Recall that these data are from unconstrained, naturalistic driving. The results presented here are representative of how a random sample of licensed drivers actually drove a passenger car as their personal vehicle, unaccompanied by an experimenter, for an extended period of time.

Why Passenger Car Drivers Follow Light Trucks at Shorter Gaps than they Follow Other Passenger Cars

The main result of this study shows that passenger car drivers, on average, follow light trucks at shorter distances than they follow other passenger cars under daytime, dry road conditions. Maintaining shorter gaps behind larger vehicles may seem counterintuitive and is contrary to what drivers report anecdotally. One scenario that would account for the difference in gap is if light trucks traveled at lower average velocities. In such a scenario passenger car drivers would be more likely to become "stuck" behind large vehicles and might maintain shorter gaps either out of frustration or in the process of attempting to pass. If passenger car drivers were becoming "stuck" behind light trucks, then one would expect to see associated differences in values of range, velocity, and range-rate and a reduced frequency, relative to the proportion of vehicles on the road, of light trucks as lead vehicles (due to increased passing maneuvers). However, there were no differences in velocity or range-rate associated with vehicle size, other than the one three-way interaction of age, gender, and vehicle size for velocity as the dependent measure. Furthermore, 65% of all lead vehicles were passenger cars, while 35% were light trucks. The proportion of passenger cars to light trucks observed as lead vehicles is believed to be fairly representative of the proportion of vehicles on the road, however the actual proportion is not known. These findings are important because they suggest that the conditions in which these results were obtained were comparable for both levels of vehicle size. What then could explain the difference in gap length associated with lead-vehicle size observed in these data? Three potential explanations are discussed.

Big vehicles take longer to stop. One possible explanation of the observed difference in gap length is that drivers believe large/tall vehicles have lower rates of deceleration due to their weight. If lead vehicles had lower rates of deceleration, then following drivers would have more time in which to bring their vehicles to a complete stop, subsequent to lead-vehicle braking. While this is true for large commercial vehicles, which were eliminated from these analyses, the difference in braking ability between light trucks and passenger cars is not as great. While there is no uniform data on breaking performance for passenger cars and light trucks, some recent data on braking performance from a study funded by the National Highway Traffic Safety Administration are available. While investigating the feasibility of developing a testing procedure of braking performance for light vehicles, Schultz and Babinchak (1999) recorded braking performance to a stop from 100 km/h for a number of passenger cars and light trucks. The results of their study showed that the difference in stopping distance between the passenger cars and light trucks, without payloads, having 4-wheel anti-lock braking systems was 4.34 meters, were the mean stopping distances for passenger cars and light trucks were 46.48 and 50.82 m, respectively. This is an 8.5% difference in stopping distance, yet the difference in gap size between vehicle classes is 14%. While driver impressions of stopping distance associated with vehicle size may account for some of the observed difference in following distance, this would require a conscious effort, or implicit learning, on the part of drivers to regularly follow large/tall vehicles at shorter distances than small/short vehicles. Such behavior does not seem likely given the free-flowing traffic conditions, where drivers have the choice and opportunity to avoid following large vehicles, and the velocities under which these observations were made. Furthermore, the result is contrary to what drivers report anecdotally when queried (Green and Yoo, 1999).

A visual illusion gives the impression of a larger gap. Most drivers would likely report that they follow large/tall vehicles at longer distances due to the inability to “see beyond” these vehicles. The results of this study are inconsistent with such reports. Results from a simulator study by Green and Yoo (1999) also provide evidence that subjectively reported preferences for gap length are not representative of gap lengths drivers actually maintain. When asked to subjectively rank four vehicles for preferred following distance, participants in the Green and Yoo study reported their shortest preferred distance to be for a car, then a pickup, and finally a bus and tractor-trailer. However, the only difference in the gaps they maintained in simulator driving was when following a car versus the remaining three vehicles. The gap length was shortest when following a simulated passenger car, but there were no differences in observed gap length among the simulated pickup, bus, or tractor-trailer. In other words, while participants in the simulator study reported preferring gaps that increased with the increasing size of the preceding vehicle, in practice they maintained very similar gaps for all three large/tall vehicles. Thus, preferences for, or perceptions of, gap length are not necessarily representative of observed gap maintenance, at least in a simulated environment. We know of no research examining the relationship between self-reported following behaviors and discretely observed on-road performance that might provide further insight on this issue.

What you can't see won't hurt you! or Ignorance is bliss. In an annotated bibliography on driver passing/overtaking behavior, Berggrund (1973) reported the results of two Swedish studies conducted by Åhman (1968 and 1972). The results of these two on-road studies lend support to the explanation that drivers do not necessarily worry about what they *cannot* see with regard to road conditions ahead. Åhman reported in both studies that when a vehicle occupies the oncoming lane, the probability of passing is less than when the status of the oncoming lane cannot be determined (due to a curve or elevation in the roadway), all other conditions being equal. In other words, if there is a known obstacle in the oncoming lane, drivers are less likely to pass than when they do not have adequate knowledge of the presence or absence of an obstacle. Not being able to see oncoming traffic due to a curve or crest arguably reduces a driver's awareness of traffic conditions in the adjacent lane. However, Åhman's research suggests that uncertainty of the road condition does not appear to inhibit attempts at passing/overtaking behavior. In a similar fashion, not being able to see traffic beyond the lead vehicle due to the size of the lead vehicle reduces a driver's awareness of traffic conditions ahead, but does not appear to inhibit close following behavior.

Reducing a driver's awareness of traffic downstream, beyond the immediate lead vehicle, by only permitting decisions that are based upon the lead vehicle could contribute to a driver's strategy of gap maintenance that is influenced primarily by the lead vehicle, and less by other vehicles or traffic conditions. In some respects, limiting a driver's monitoring of forward traffic to a single immediate lead vehicle lends itself to applying a much simpler following strategy. Rather than having to monitor multiple vehicles in the same lane, possibly through successive layers of automotive glass, a driver might reduce his/her effort by concentrating solely on, and responding only to, the immediate lead vehicle. This reduction in the number of vehicles to be monitored could potentially result in a reduction in driver workload. Specifically, driver eye movement patterns might be limited to specific locations on the lead vehicle, such as a single stop lamp, and not require, nor provide opportunity for, monitoring a broader region of the same lane encompassing vehicles downstream.

Older Drivers Maintain Longer Headways

The finding that older drivers maintain longer headways than younger drivers under almost all conditions is consistent with previous research (Evans and Wasielewski, 1983; Fancher et al., 1995; Fancher et al., 1998; Green and Yoo, 1999). This result is also consistent with findings that drivers increasingly adopt compensatory strategies (such as longer gaps) as they age, in part to reduce the stress and anxiety of driving, as well as to reduce perceived risk (Kostyniuk, Trombley, and Shope, 1998). However, differences that may be associated with driver age in the selection of road class or the time of day have not been accounted for in these data. Existing research suggests that older drivers avoid certain roadways especially during periods of peak usage, which is primarily reflected in the times of day older persons avoid driving (Kostyniuk, Trombley, and Shope, 1998).

General Implication of the Findings

Light truck sales currently account for 49% of all new vehicle sales in the United States, and sales have steadily increased with the increasing popularity of sport utility vehicles and minivans (Goodman, 1999). Drivers of passenger cars following light trucks are less likely to possess the same amount of information regarding traffic conditions downstream as a result of not being able to “see beyond” the lead vehicle as opposed to the information available if the lead vehicle were a passenger car. If, as suggested, drivers do not modify their behavior to follow farther behind large vehicles they *cannot* see beyond, then the design of light trucks becomes increasingly critical with their increased presence on the roadways. However, this is the only known study of its type, and consequently there is a need to replicate this finding.

Despite an absence of comparable data in which both the lead and following vehicles are light trucks, it is further suggested that concern should not be limited to the case of a passenger car following a light truck. Even drivers of light trucks can have difficulty seeing beyond the lead vehicle when that lead vehicle is also a light truck. In the case of a light truck following another light truck it is not an issue of lead-vehicle size and associated viewing geometry, but rather primarily one of transmittance of the lead vehicles rear glazing. While we were unable to investigate the effects of rear-window transmittance of the lead vehicle on the ability of following drivers to see beyond the vehicle due to limited resolution of the images, we can make some assumptions regarding the ability of drivers following a light truck to see beyond the lead vehicle on the basis of its dimensions and the likelihood that it has tinted rear glazing.

The current Federal Motor Vehicle Safety Standard for glazing materials (FMVSS Standard 205, Glazing materials) does not specify minimum transmittance levels for windows, but instead defers to ANSI/SAE Z26.1-1977. Specifically, Z26.1-1977 does not require that glazing to the rear of the driver in buses, trucks, or truck tractors meet requirements for luminous transmittance where the rearmost glazing is not "used for driving visibility" or "other means of affording visibility of the highway to the side and rear are provided." However the term "driving visibility" is not defined in the standard, nor is "other means of affording visibility." While the "other means" caveat is acceptable for buses, trucks, and multipurpose passenger vehicles, it does not apply to passenger cars according to FMVSS 205. The transmittance requirement for glazing behind the driver in passenger cars is the same as that for the windshield and side windows—not less than 70%.

The difference in requirements stems from commercial light trucks, such as panel vans, that are not required to have rear glazing. This has carried over to light trucks that are not intended for commercial applications, but are rather passenger vehicles (sport utility vehicles and minivans). Furthermore, reference in Z26.1-1977 to "other means of affording visibility," such as exterior rearview mirrors on both the driver and passenger sides of the vehicle, would seem just as applicable to passenger cars. This statement seems to suggest that exterior rearview mirrors provide sufficient view to the rear of a vehicle to facilitate a backing maneuver, such that rear glazing is not necessary. However, this is not true, as evidenced by additional wide-angle mirrors mounted on the rear of many commercial trucks, the use of auditory backup signals to warn pedestrians, and the more recent implementation of ultrasonic sensors to detect obstacles and provide a backup warning to the driver. The need for these types of devices implies that conventional exterior rearview mirrors, while beneficial, are not sufficient to aid drivers when backing, in particular when backing large vehicles.

A survey of rear window transmittance for the top 20 vehicles sold in April 1999 confirmed that there is a major difference in the transmittance levels of rear windows for passenger cars versus light trucks having privacy options (Table 4). In a review of the literature, Sayer and Traube (1994) pointed out that even modest levels of window tinting have an effect on driver visual performance. On the basis of a re-examination and compilation of previously reported data, it was shown that transmittance has generally a linear effect on driver visual performance, with a reduction in transmittance levels from 100 to 50% resulting in a reduction in visual performance between 10 and 20%. If the lead vehicle happens to be a light truck with a low-transmittance rear window, perhaps 18% on the basis of our survey, then regardless of the size of the following vehicle, the following driver's ability to see through the lead vehicle to detect the onset of stop lamps will be considerably reduced.

Attempts by passenger car drivers to see beyond light trucks are also made difficult by the taller and wider body styles of light trucks. A survey of vehicle dimensions, as published in *Ward's Automotive Yearbook*, for the same top 20 vehicles sold in April 1999, found that the top 10 light truck models were, on average, 374 mm (14.7 in) taller and 138 mm (5.4 in) wider than the top ten selling passenger cars (Table 5). When the average height and width dimensions are combined with the average following distances observed in this study, the difference in subtended visual angle for passenger cars versus light trucks was about 0.6 degrees (2.3 and 2.9 degrees, respectively).

Table 4. Rear window transmittance for Ward's top 20 units sold (April 1999), which includes 10 passenger cars and 10 light trucks (8 with the privacy glass option and 2 without)[1].

Vehicle Surveyed	Mean Transmittance	Standard Deviation
Passenger Cars	77.2%	3.7%
Light Trucks w/ privacy option	18.0%	5.3%
Light Trucks w/o privacy option	73.0%	9.9%

[1] Window transmittance was measured normal to the glass surface using a Laser Labs, Inc. Model 200 Tint Meter (wavelength = 550 nanometers, accuracy = +/- 3 percentage points) on new vehicles at the respective dealerships, prior to sale. Privacy option was based upon the information provided on each vehicle's inventory sticker.

Table 5. Width and height of Ward's top 20 units sold (April, 1999), which happens to include 10 passenger cars and 10 light trucks.

No.	Make	Model	Class	Width (in)	Height (in)
1	Ford	Pickup (150XL)	Light Truck	78.4	72.7
2	Chevy	Pickup (CK)	Light Truck	78.5	71.2
3	Toyota	Camry	Passenger Car	70.1	55.4
4	Ford	Explorer XL 4wd	Light Truck	70.2	67.7
5	Dodge	Ram Pickup	Light Truck	79.4	71.9
6	Honda	Accord	Passenger Car	70.3	56.9
7	Ford	Ranger	Light Truck	69.4	64.9
8	Ford	Taurus	Passenger Car	73.0	55.1
9	Honda	Civic	Passenger Car	67.1	54.7
10	Dodge	Caravan	Light Truck	76.8	68.5
11	Jeep	Grand Cherokee	Light Truck	72.3	69.4
12	Ford	Expedition XLT	Light Truck	78.6	74.3
13	Chevy	Cavalier	Passenger Car	67.9	54.7
14	Ford	Escort	Passenger Car	67.0	53.3
15	Toyota	Corolla	Passenger Car	66.7	54.5
16	Chevy	Malibu	Passenger Car	69.4	56.4
17	Chevy	Blazer	Light Truck	67.8	64.3
18	Saturn	SL2	Passenger Car	66.7	54.5
19	Pontiac	Grand Am	Passenger Car	70.4	55.1
20	Dodge	Durango	Light Truck	71.5	72.9
		Average	Overall	71.58	62.42
			Passenger Cars	68.86	55.06
			Light Trucks	74.29	69.78
			Difference (in)	5.43	14.72
			Difference (mm)	137.92	373.89
		Std. Dev.	Overall	4.40	7.94
			Passenger Cars	2.11	1.02
			Light Trucks	4.47	3.42

Given the likelihood of decreased transmittance of rear windows for light trucks, along with their average height and width, Figure 13 displays scenarios in which either lead-vehicle size or rear window transmittance could lead to the reduction of a following driver's knowledge of traffic conditions downstream. Case 1 demonstrates one of the most innocuous scenarios, assuming that the rear window of the center vehicle does not have aftermarket tinting. In Case 1 the driver of the last vehicle can see through the glazing of the center vehicle to the center high-mounted stop lamp (CHMSL) of the first vehicle. In Case 2 the driver of the last vehicle cannot see the first car due to the size of the center vehicle. In this case the driver of the last vehicle only has information regarding traffic conditions downstream as provided by the center vehicle (i.e., deceleration and stop lamp illumination). In Case 2 the light transmittance for the rear window of the center vehicle is not as relevant as is vehicle size. However, the rear window transmittance of the center vehicle is relevant for the scenario depicted in Case 3. Specifically, in Case 3 if the first vehicle is a light truck then it is possible for the driver of the last vehicle to see through and detect the onset of a CHMSL on the first vehicle, provided that the rear window of the center vehicle is not heavily tinted. The same is true in Case 4.

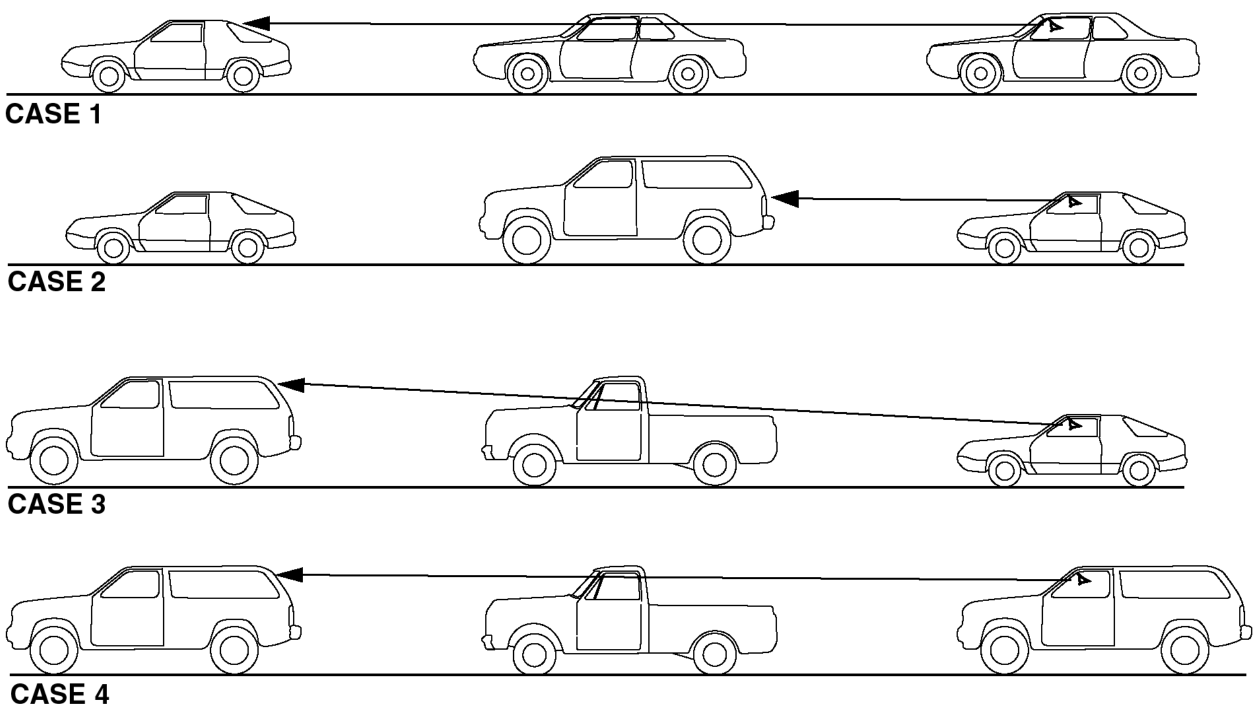

Figure 13. A depiction demonstrating how a reduction in transmittance of rear windows on light trucks could reduce the following driver's ability to see beyond the lead vehicle and monitor vehicles downstream (i.e., to detect the onset of stop lamps) independent of the following vehicle's size.

Strengths and Weaknesses of the Present Study

The strengths of the present study include the naturalistic nature of data collection, and the quantitative nature of the vehicular data. Drivers in the study were a random sample of the licensed driving population that were permitted to go about their daily driving completely unrestricted and undisturbed by the presence of an experimenter. Furthermore, these data represent a broad sampling of driving situations over an extended time (one year), on a wide variety of roadways.

There are several weaknesses of this study. First, only data from drivers residing in southeastern Michigan were collected and examined. Second, the vehicles that participants drove were all the same length and mass, so that relative gap lengths observed in the present study may not be representative of gaps for other following-vehicle sizes. Third, the quality of the video images that were the basis of the analysis did not permit certain hypotheses to be examined. Fourth, because the video images were only of the forward scene, we have no means of determining what traffic events occurring to the rear or sides of the host vehicle might have influenced following behavior. Fifth, the analyses have not specifically examined differences that roadway class or time-of-day might have on following behavior.

Future Research Needs

Subsequent research is needed that attempts to replicate the main findings of this study. In addition to the need for higher resolution images of naturalistic following behavior by a broader variety of drivers to examine regional differences, the next logical step would be to attempt to record where drivers are looking while following lead vehicles of different sizes. Certainly, the difficulty of doing such research lies not only in the accuracy of eye tracking techniques, but also in the ability to track eye movements unobtrusively. Another approach to further investigating the effects of lead-vehicle size and window tinting on following behavior would be to examine whether light trucks are more likely to be struck by a passenger car than would be predicted on the basis of exposure. If light trucks are found to be overly represented as the struck vehicle in rear-end accidents, such a finding might suggest that light trucks contribute to lessening the efficacy of center high-mounted stop lamps that might otherwise be seen through intervening layers of vehicle glazing. Perhaps the simplest approach to furthering this research would be to conduct a study similar to that of Postans and Wilson (1983) by observing from an overpass, or from the side of a roadway, the gaps maintained between pairs of vehicles as a function of vehicle class.

CONCLUSIONS

The results of the present study suggest that lead vehicles that are taller, or generally larger, than passenger cars were followed more closely than passenger cars by drivers of passenger cars. This result was discussed in the context of ability to see beyond the lead vehicle to assess the conditions of traffic downstream. Given that it is unlikely we will see a reduction in the sale of light trucks, relative to passenger cars, in the near future, it is important to further investigate the gap maintenance behavior associated with vehicle size.

If future investigations on the relationship of vehicle size and gap maintenance support the general finding of this study, then some specific measures that might be taken are suggested. First, requiring that rear windows of light trucks meet a certain minimum transmittance requirement might improve the situation by furthering the ability of following drivers to see traffic conditions downstream. Second, enhanced design requirements for the stop lamps of light trucks and all large vehicles, such as increased luminous intensity and faster rise times, could provide the driver following a large vehicle additional time to react to traffic events occurring downstream that they cannot directly detect (Sivak, Flannagan, Sato, Traube, and Aoki, 1994). Third, distance sensors used for features such as adaptive cruise control, forward collision warning or forward collision avoidance might also be used to provide information to the driver regarding the relative safety of the following distances they maintain (i.e., provide a dynamic display of relative following behavior). Distance sensors do not differentiate vehicles on the basis of size, therefore differences in following behavior associated with vehicle size might be reduced if drivers were given appropriate feedback regarding the gaps they maintain.

Although it is necessary that following drivers be able to see the stop lamps on lead vehicles, it is not by itself sufficient for safe driving. The results of this study suggest that knowing the state of traffic beyond the lead vehicle affects gap maintenance. Specifically, it is suggested that when a lead vehicle permits a following driver to see through, over, or around it, drivers maintain significantly longer (i.e., safer) following distances.

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