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James R. Sayer
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James R. Sayer
Mary Lynn Mefford
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The University of Michigan
Transportation Research Institute
Ann Arbor, MI 48109-2150
U.S.A.

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16. Abstract

A dynamic field experiment was conducted, both during the day and at night, to examine the effects of rear-window transmittance and backup-lamp intensity on driver backing behavior (stopping distance, velocity, acceleration, and trial duration) toward a known stationary object. In addition, three years of crash data from the General Estimates System (GES) file were examined for backing crashes. Specific variables of interest in the GES data were driver age, ambient light condition, and the type of passenger vehicle involved (car versus minivan or sport utility vehicle).

The results of the field experiment indicate that drivers do not adjust their backing behavior to variations in the amount of available light, at least under conditions where there is little uncertainty regarding obstacles. However, drivers do appear to adjust their backing behavior as they grow older, for the most part driving more cautiously. Nevertheless, the crash data indicate that older drivers are still over-represented in backing crashes. Minivans and sport utility vehicles, which are much more likely to have rear-window tinting, are also over-represented in backing crashes.

Based on the crash data, despite the findings of the field experiment, it is suggested that older drivers might benefit from higher-transmittance windows, higher-intensity backup lamps, and rearward detection and warning devices. These same modifications might also benefit the drivers of minivans and sport utility vehicles.

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INTRODUCTION

Backing Behavior and Backing Crashes

Very little published research exists on driver behavior when performing backing maneuvers. It has only been in the past ten years, with the development of rear-obstacle detection systems, that an interest in driving performance while reversing has emerged. However, approaches to reducing backing crashes are not limited to the development of electronic rear-obstacle detection systems. Automotive lighting suppliers and manufacturers have also expressed an interest in improving existing backup lamps in order to provide drivers with better visibility under levels of insufficient ambient illumination. Whether drivers view the area to the rear of the vehicle directly (looking over the shoulder) or indirectly (via rearview mirrors), it seems logical to assume that the amount of light available to the drivers' eyes will affect backing behavior. Consequently, one might expect to observe this effect by examining how drivers perform backing maneuvers while varying the amount of light reaching the drivers' eyes.

When considering backing maneuvers that involve direct viewing, four main factors contribute to a driver's detection of objects in the rear: the rearward field of view, the transmittance of the rear glazing, the amount of available light (either from backup lamps or ambient sources), and the composition of the rearward scene (specifically obstacle contrast). The emphasis of this investigation is on how the transmittance of the rear glazing and the amount of available light contribute to driver backing behavior.

In an examination of the General Estimates System (GES) database, Wang and Knipling (1994) reported that in 1990 there were 181,500 police-reported backing crashes (2.8% of all police reported crashes) that resulted in 22,000 injuries, 1,500 incapacitating injuries, and 185 fatalities (0.4% of all fatalities). The authors stated that a vehicle could be expected to be involved in 0.01 police-reported backing crashes during its operational life. Unfortunately, backing accidents are a significant cause of injury to young children (Brison, Wickund, and Mueller, 1988; Walker, 1993; Winn, Agran, and Castillo, 1991).

In analyzing backing crashes, Wang and Knipling concentrated on what they identified as encroachment type crashes. Using a crash-type taxonomy similar to that of Tijerina, Hendricks, Pierowicz, Everson, and Kiger, (1993), Wang and Knipling defined encroachment backing crashes as those involving a vehicle backing into: (a) a pedestrian or pedalcyclist, (b) a vehicle or object on a parallel path, or (c) a vehicle or object on a curved path, or as (d) a cross-path crash involving another vehicle. Of the 78,000 encroachment backing crashes in 1990, roughly 4% involved a pedestrian or pedalcyclist, 56% involved parallel path vehicles or objects, and 40% involved a vehicle or object on a curved path. Encroachment backing crashes accounted for 112 fatalities, 100 of which were a pedestrian or pedalcyclist.

Tijerina et al. (1993) reported that nearly 60.8% of crashes occurred because the driver did not see the object or pedestrian, and 26.6% were caused by improper backing maneuvers. The remaining crashes were attributed to vehicle defects (5.7%), driver intoxication (3%), or some other miscellaneous factor (3.7%). In light of the findings of Tijerina et al., one might expect that the transmittance of the rear glazing and the amount of available light would be contributing factors in many backing crashes.

In an attempt to better understand the behavior of drivers when backing, and consequently how best to design rear-obstacle detection and warning systems, Huey, Harpster, and Lerner (1995) reported observations made on an assortment of naturalistic backing tasks. Using their own vehicles, 21 participants performed eight backing maneuvers in real-world driving conditions during the daytime. The specific backing maneuvers examined were: backing out of an angled slot in a parking lot, parallel parking against a curb and between vehicles, extended-curve backing, backing to a wall, and backing both into and out of a perpendicular parking slot. The vehicles were instrumented in order to collect data on glance direction, hand position, car speed, and the distance to an object behind the vehicle.

In summarizing their findings, Huey et al. reported that glance direction varied greatly by the type of backing task performed. Furthermore, older drivers were more likely to use the interior rearview mirror than were younger drivers. However, over all conditions, drivers were most likely to look over their right shoulder upon the initiation of a maneuver. The authors also report that younger drivers backed at faster rates than did older drivers, and that males backed faster than did females. The maximum backing speeds averaged around 4.8 km/h, and did not exceed 11.3 km/h, except for the extended-curve backing maneuver. The authors did not examine the effects of vehicle type or the transmittance of the rear window.

Rear Window Tinting

The current Federal Motor Vehicle Safety Standard for glazing materials (FMVSS 205) specifies minimum transmittance levels for windows by reference to ANSI/SAE Z26.1-1977. The ANSI standard does not require glazing to the rear of the driver in buses, trucks, or truck tractors to meet requirements for luminous transmittance if the rearmost glazing is not "used for driving visibility" or if "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 such as minivans and SUVs, it does not apply to passenger cars according to FMVSS 205. The transmittance requirement for the rear window in passenger cars is the same as that for the windshield and side windows—not less than 70%.

The difference in requirement stems from the commercial use of 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 rather as passenger vehicles (minivans and sport utility vehicles). 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 the driver with a backup warning that have been implemented in a variety of passenger vehicles. The use of these devices suggests that conventional exterior rearview mirrors, while beneficial, are not always sufficient to aid drivers when backing, particularly when backing large vehicles.

Various studies have shown decrements in driver visual performance associated with rear-window tinting. The results include increased reaction time to detect a child located behind a vehicle with decreased transmittance (Boyce and Gu, 1992); decreased detection probability of children and debris with decreased transmittance (Freedman, Zador, and Staplin, 1993); and increased subject response bias—the tendency to say a target exists when it does not exist—to low contrast targets with decreasing window transmittance in a signal detection task (Stackhouse and Hancock, 1992). Detailed reviews, and additional studies addressing the effects of window transmittance, are provided in Sayer and Traube (1994).

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 generally has a continuous, approximately 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%. Nevertheless, a recent survey of rear-window transmittance for the best-selling vehicles sold in the U.S. (Sayer, Mefford, and Huang, 2000) confirmed that a major difference exists in the transmittance levels for rear windows of passenger cars versus light trucks with privacy options (Table 1).

Table 1. Rear-window transmittance for the 10 best-selling passenger cars and 10 best-selling light trucks (including minivans and SUVs) in the U.S. in April 1999 (Sayer et al., 2000).

Vehicle Surveyed	N	Mean Transmittance	Standard Deviation
Passenger Cars	10	77.2%	3.7%
Light Trucks w/ Privacy Option	8	18.0%	5.3%
Light Trucks w/o Privacy Option	2	73.0%	9.9%

The Present Study

The present study consists of two components. The first component is a field experiment that was performed to examine the effects of backup-lamp intensity and rear-window transmittance on driver backing performance. Previous investigations on the effects of rear-window transmittance have not examined vehicle performance data, but have instead concentrated on visual performance measures, often in static or simulated scenarios. The second component of this study is an examination of crash data, looking specifically for incidences of backing crashes. Previous investigations of the crash data typically combined all passenger vehicles into one class, without consideration for the fact that most minivans and SUVs have heavily tinted rear windows.

In the field experiment, the driver's task was to perform a backing maneuver toward a known stationary object, located behind the vehicle on a straight path. This maneuver was selected because it is a practical backing maneuver that could be expected to rely heavily on direct viewing by the driver (although use of the interior rearview mirror was permitted). Of interest was whether dependent measures such as stopping distance from an object, the time it took to complete a backing maneuver, and rates of travel during the maneuver would be affected by the amount of light reaching the driver's eyes from objects located behind the vehicle, particularly under nighttime driving conditions. Restricting the drivers to direct viewing or use of the interior rearview mirror, and not permitting use of the exterior rearview mirrors, was necessary in order to examine the effects of rear-window transmittance.

The examination of the crash data included three years (1996 through 1998) of data from the General Estimates System (GES) files, looking specifically for incidences of backing crashes as a function of lighting conditions, driver age, and vehicle class (passenger cars versus minivans and sport utility vehicles).

FIELD EXPERIMENT METHODOLOGY

Participant Recruitment and Screening

Twelve licensed drivers were paid $30 each to participate in this study. The duration of their participation was approximately two hours total (one-half hour under daytime conditions, and one and a half hours under nighttime conditions). Six participants were in an older age group (62-71 years, mean = 66.2 years) and six were in a younger age group (20-28 years, mean = 22.5 years). All participants were recruited from a list of persons potentially interested in participating in UMTRI studies. Eleven of the twelve participants had visual acuity of 20/35 or better as determined by an Optec® 2000 vision tester. The remaining participant had visual acuity of 20/50.

Task and Experimental Setup

The task in this experiment was to perform repeated backing maneuvers toward a stationary object (a recycling dumpster) using an instrumented research vehicle. Levels of rear-window transmittance, backup-lamp intensity, and starting distance from the object were presented in a random order. Participants were instructed to get as close to the dumpster as possible while leaving sufficient space to get between the car and the dumpster. Participants were allowed to view the dumpster directly by looking over their shoulder, or indirectly through use of the interior rearview mirror. The exterior rearview mirrors were intentionally misaimed to prevent their use. The complete instructions were as follows:

> *Thank you for agreeing to participate in this study. The purpose of this experiment is to investigate the effects of rear-window transmittance and backup lamp intensity on driver performance. You will be asked to perform a series of backing maneuvers while we vary the amount of light available to perform the maneuver.*
>
> *I would like you to imagine that you are dropping off a trunk-load of newspapers at the local recycling center. The task is to back up to the blue recycling dumpster leaving enough room for you to get between the dumpster and the car but minimizing the distance you have to carry the papers. I would like for you to be as consistent as possible in your assessment of the available space. Between trials I will ask you to look down at the floor while we make changes.*
>
> *You will be given three practice trials at the beginning of the experiment.*

The experiment was conducted in two sessions, one during daylight and one at night (without fixed lighting) in the UMTRI parking lot. In all instances, participants performed the daytime session before the nighttime session. Participants were given three practice trials at the beginning of each session, and were allowed to exit the vehicle to examine the available space left between the rear of the vehicle and the dumpster for these three trials. There was no time limit placed on performing the individual backing maneuvers. Participants began the backing maneuvers from one of three starting positions in which the distance from the rear of the car to the dumpster was 5 m, 10 m, or 15 m. A researcher in the vehicle directed participants to the appropriate starting position for each trial. Participants were instructed to look at the floor of the research vehicle between trials while changes to the rear-window transmittance and backup-lamp intensity were made. Only after the vehicle was positioned for the next trial, with the transmission in the park position, were any changes made to the rear-window transmittance or backup-lamp intensity.

The lane in which the backing was performed was 3.6 m wide, and marked on both sides by orange traffic cones. The dumpster that participants backed towards measured 1.91 m wide x 1.38 m high x 1.32 m deep. The dumpster was painted a glossy navy blue and the backdrop for the dumpster was a light colored concrete wall. Figure 1 presents an overhead diagram of the experimental setup. The instrumented research vehicle was a 1992 Toyota Corolla with an automatic transmission. The rear of the research vehicle was equipped with a Senix ultrasonic sensor (Model ULTRA-U) mounted on the lid of the trunk (Figure 2). The ultrasonic sensor was used to measure the distance from the rear of the vehicle to the dumpster to within an accuracy of 2.5 cm, at a sampling rate of 10 Hz.

Vehicle velocity was measured using a Datron longitudinal speed sensor (Model DLS2) positioned under the vehicle’s front bumper, and vehicle acceleration was derived. Values of mean velocity were calculated by averaging velocities greater than 0.1 m/s over the duration of the maneuver, at a sampling rate of 20 Hz. Velocity was differentiated to produce acceleration by plotting a least-squares line for two-second intervals of the velocity data. The slopes of the best-fit lines were used as the measures of acceleration.

Trial duration was determined in post-processing of the velocity data. The beginning of each trial was defined as that point in time when velocity was greater than 0.5 km/h, and stayed greater than 0.5 km/h for two seconds. The end of each trial was defined as that point in time when velocity was less than 0.5 km/h, and stayed less than 0.5 km/h for two seconds.

Data from the ultrasonic sensor and the longitudinal speed sensor were stored on a personal computer located in the rear seat of the vehicle. The data collection system used custom software, and was controlled by a researcher in the rear seat. The researcher in the vehicle sat directly behind the driver so as not to obstruct the driver's view.

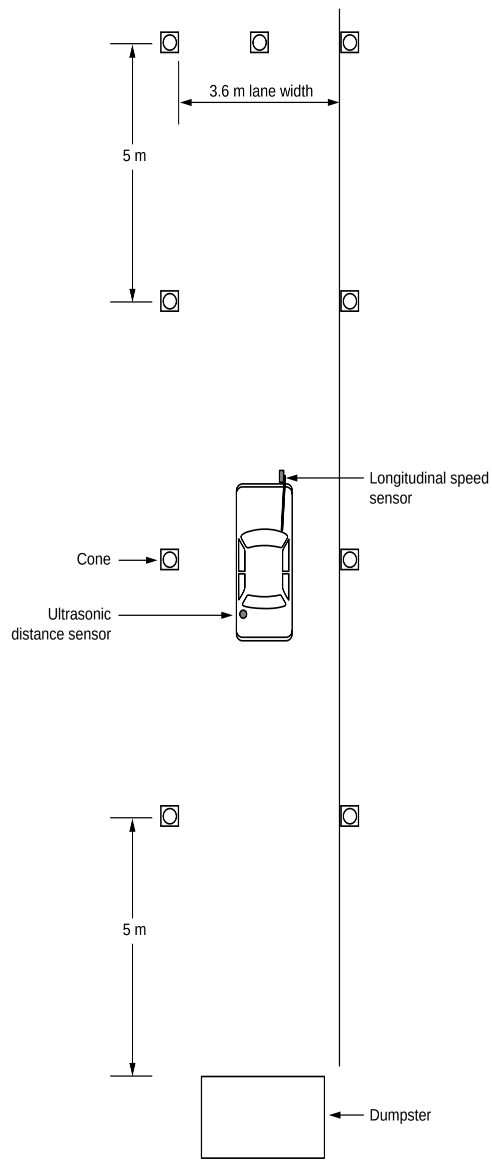

Figure 1. An overhead diagram of the experimental setup.

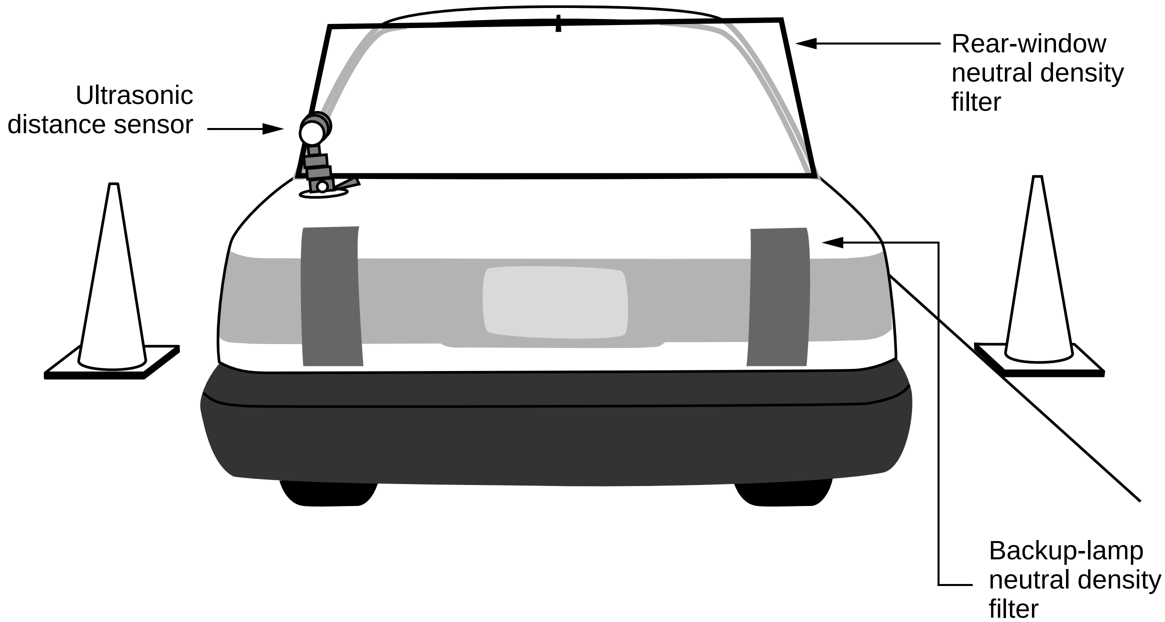

Figure 2. A diagram of the rear of the research vehicle.

The standard 1156 tungsten bulbs in the backup lamps of the research vehicle were replaced with 50-watt halogen bulbs. Three levels of neutral density filter were used on the backup lamps, ND = .6, .3 and .02. These three filters produced backup-lamp intensities at the optical axis of the backup lamps of 33, 65, and 116 cd, respectively. The filters measured 35 cm x 13 cm and were mounted on the rear of the car using magnets to allow for fast installation and removal.

Three levels of backlight filter were used, ND = .6, .3 and .02. The backlight filters, in combination with the transmittance of the original rear window (80%), produced transmittance levels of 21%, 41%, and 75%, respectively. Measurements of transmittance were made normal to the window surface using a Laser Labs Model 200 tint meter. The filters measured 128 cm x 61 cm and were installed in aluminum frames, held in place with mounting brackets.

Experimental Design

Two full-factorial repeated-measure designs were employed (one for the daytime condition and one for the nighttime condition). The same 12 participants took part in both daytime and nighttime sessions. The daytime session consisted of 27 trials (3 starting positions x 3 levels of rear-window transmittance x 3 repetitions). The intensity of the backup lamps was constant at 116 cd during the daytime sessions. Each nighttime session consisted of 81 trials (3 starting positions x 3 levels of rear-window transmittance x 3 levels of backup intensity x 3 repetitions). In both sessions, the order in which trials were presented was randomized. Four dependent measures of backing performance were obtained: stopping distance from the dumpster (rear bumper to dumpster), vehicle velocity, vehicle acceleration, and the duration of the backing maneuver. The independent variables included driver age group, starting position, rear-window transmittance, and backup-lamp intensity.

FIELD EXPERIMENT RESULTS

Results from the daytime and nighttime sessions are reported separately. Repeated measure ANOVAs were performed separately for the two sessions for the four dependent measures (stopping distance, velocity, acceleration, and trial duration). Repeated measure analyses included an adjustment of the degrees of freedom using the Greenhouse-Geisser conservative test (Winer, Brown, and Michels, 1991). Analyses for the daytime session included three independent variables (driver age, starting position, and rear-window transmittance), whereas the analyses for the nighttime session included four independent variables (driver age, starting position, rear-window transmittance, and backup-lamp intensity). In the Discussion below, only statistically significant effects will be presented.

Daytime

Stopping distance. The distance that participants stopped from the dumpster was significantly affected by the starting position of the vehicle, $F(1.6,13.2) = 19.4$, $p < 0.001$. Mean stopping distances increased with the increasing distance of the starting position from the dumpster (Figure 3).

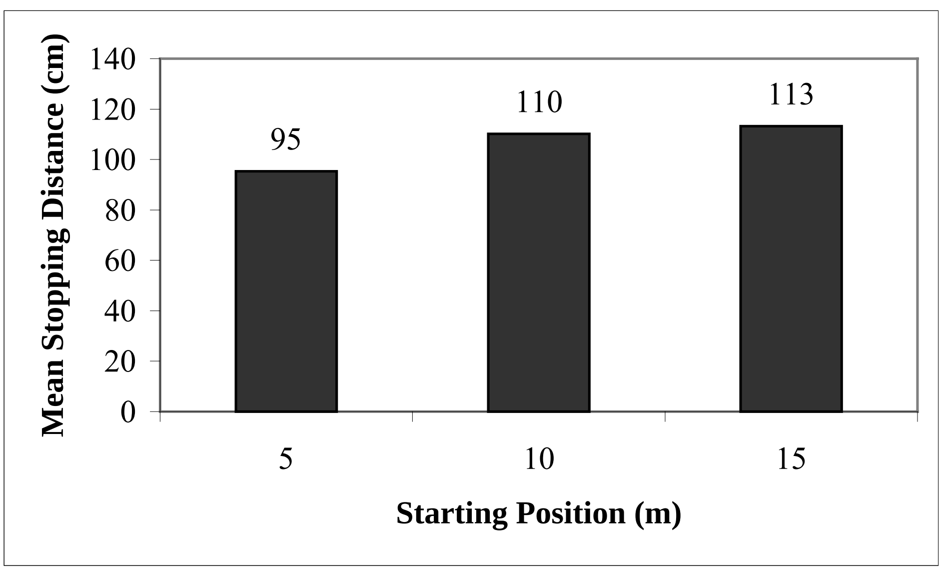

Figure 3. Daytime stopping distance as a function of starting position.

There was also a significant effect of driver age, $F(1,8) = 9.5$, $p < 0.05$, with older drivers stopping closer to the dumpster than younger drivers (Figure 4). Furthermore, there was a significant interaction of starting position and rear-window transmittance for stopping distance, $F(1.7,13.6) = 4.2$, $p < 0.05$ (Figure 5).

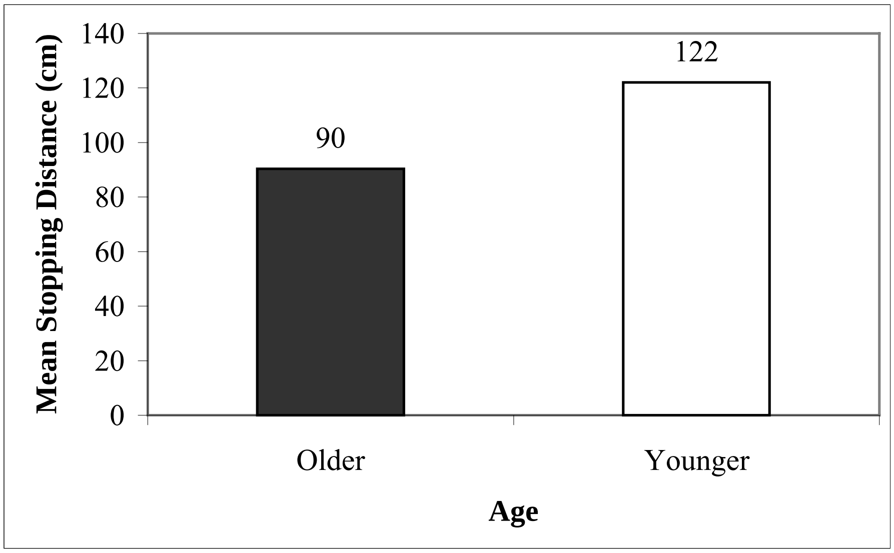

Figure 4. Daytime stopping distance as a function of driver age.

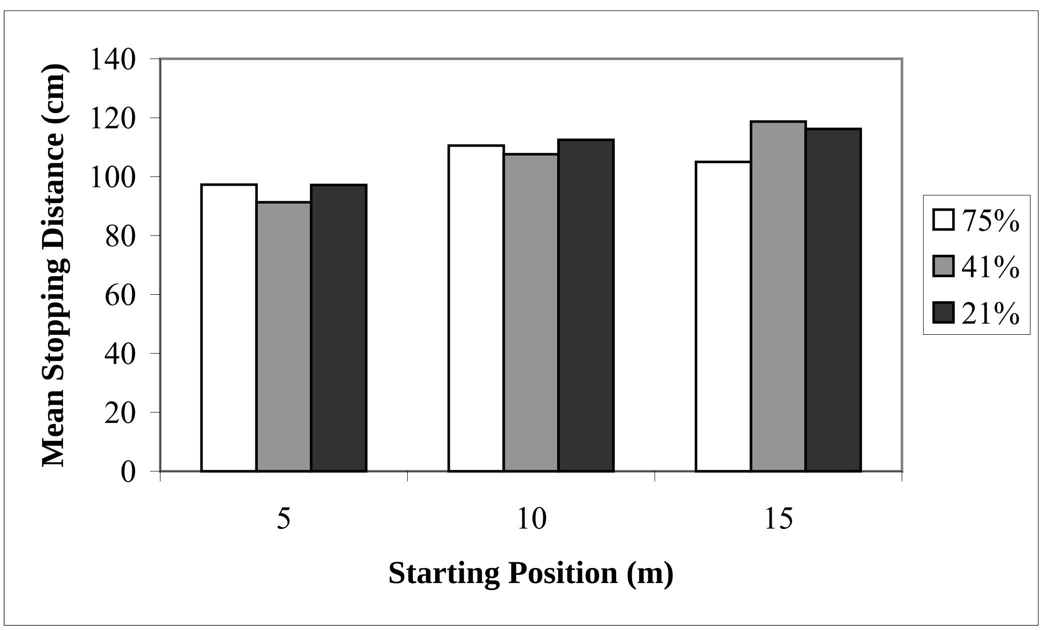

Figure 5. Daytime stopping distance as a function of starting position and rear-window transmittance.

Vehicle velocity. The velocities at which participants performed the backing maneuvers in the daytime were significantly affected by the starting position, $F(1.2,9.8) = 263$, $p < 0.001$. Mean velocities increased with increasing distance of the starting position from the dumpster (Figure 6). There was also a significant main effect of driver age, $F(1,8) = 32.9$, $p < 0.001$, with younger drivers having higher mean velocities than older drivers (Figure 7).

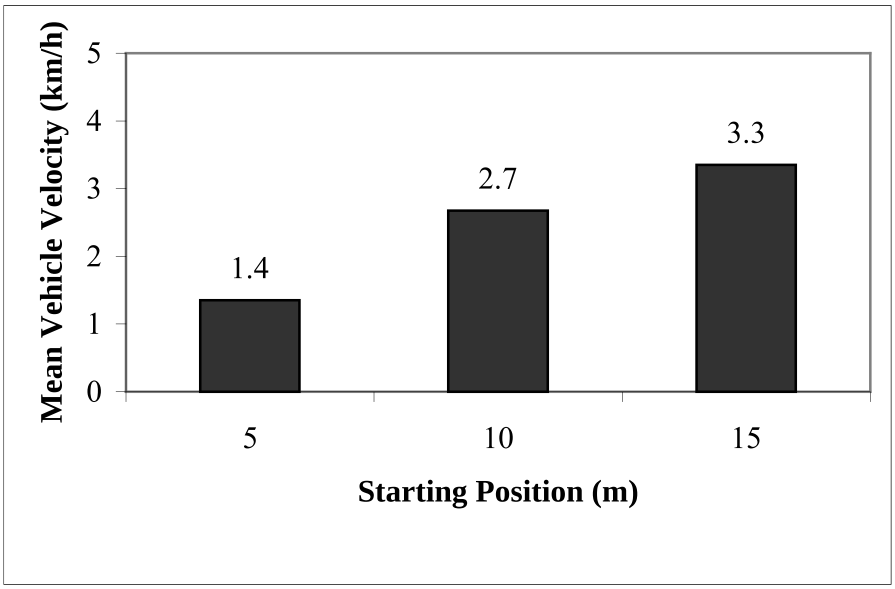

Figure 6. Daytime velocity as a function of starting position.

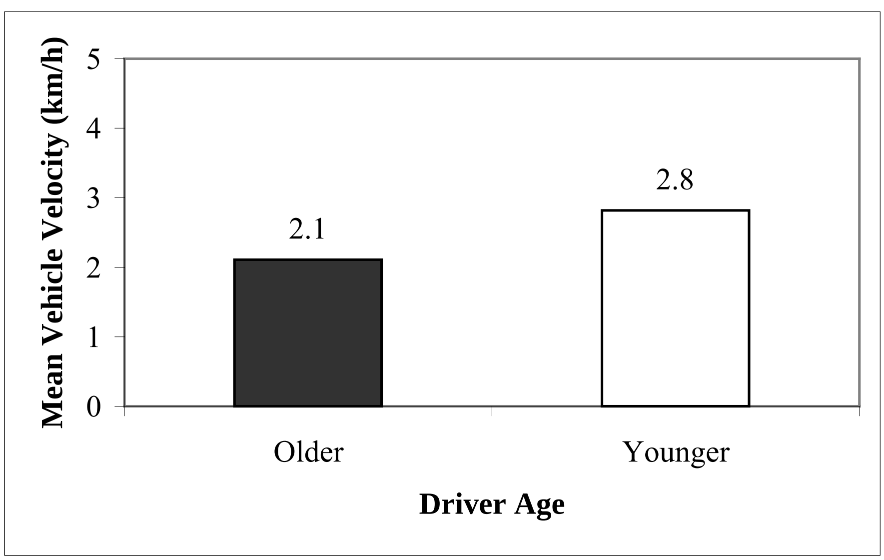

Figure 7. Daytime velocity as a function of driver age.

The velocities at which participants performed the backing maneuvers in the daytime were significantly affected by the interaction of starting position and driver age, $F(1.2,9.8) = 16.9$, $p < 0.01$ (Figure 8), with the difference between younger and older drivers increasing as the starting position from the dumpster increased.

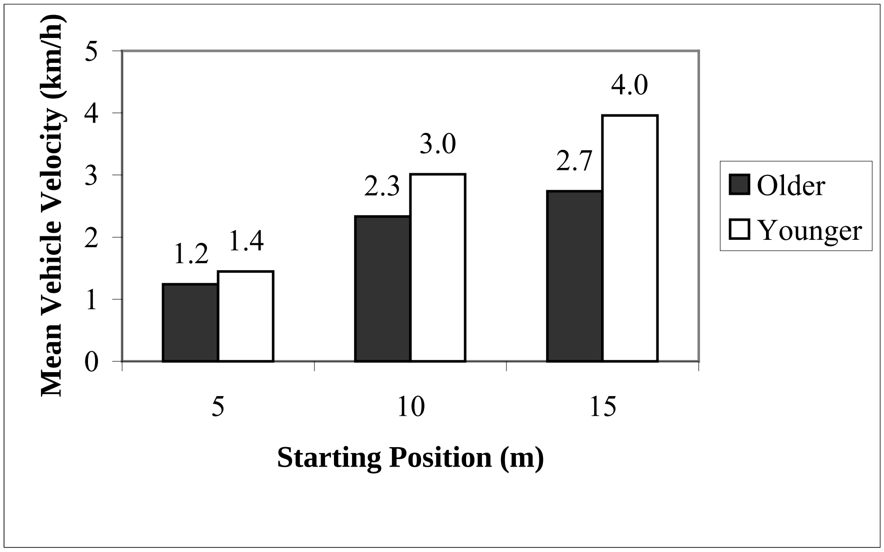

Figure 8. Daytime velocity as a function of starting position and driver age.

Vehicle acceleration. In the daytime condition, only the starting position of the vehicle significantly affected acceleration, $F(1.3,10.2) = 11.3$, $p < 0.01$, with mean accelerations being highest for the 5 m starting position (Figure 9).

Trial duration. The duration of daytime backing maneuvers was significantly affected by the starting position, $F(1.2,9.9) = 294$, $p < 0.001$, driver age, $F(1,8) = 15.6$, $p < 0.01$, and the interaction of starting position and driver age, $F(1.2,9.9) = 16.8$, $p < 0.01$. As might be expected, the shortest mean trial duration was associated with the closest starting position, and the longest duration was associated with the farthest starting position (Figure 10). Older drivers had longer mean trial durations than younger drivers (Figure 11), and this difference increased as the starting position from the dumpster increased (Figure 12).

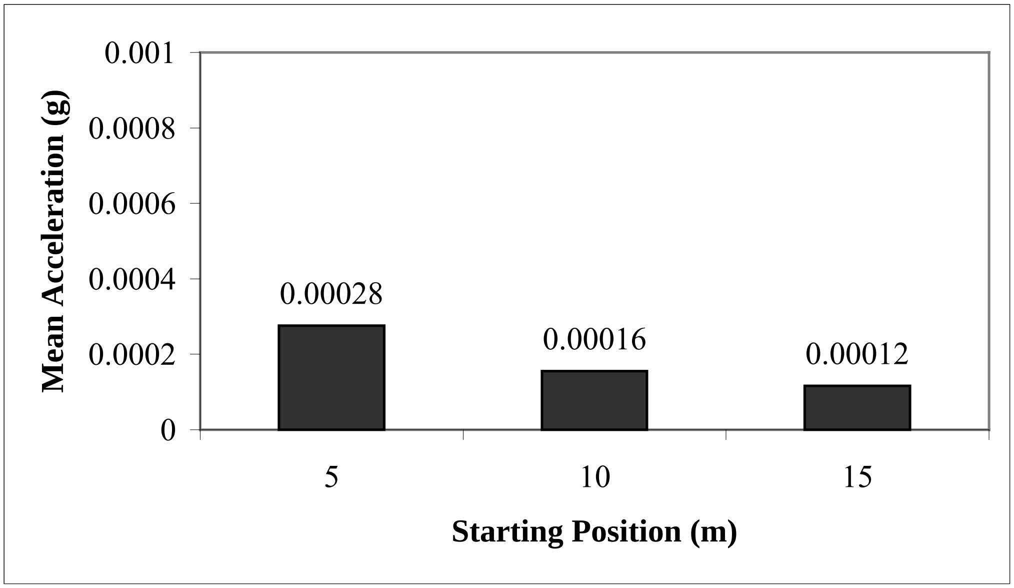

Figure 9. Daytime acceleration as a function of starting position.

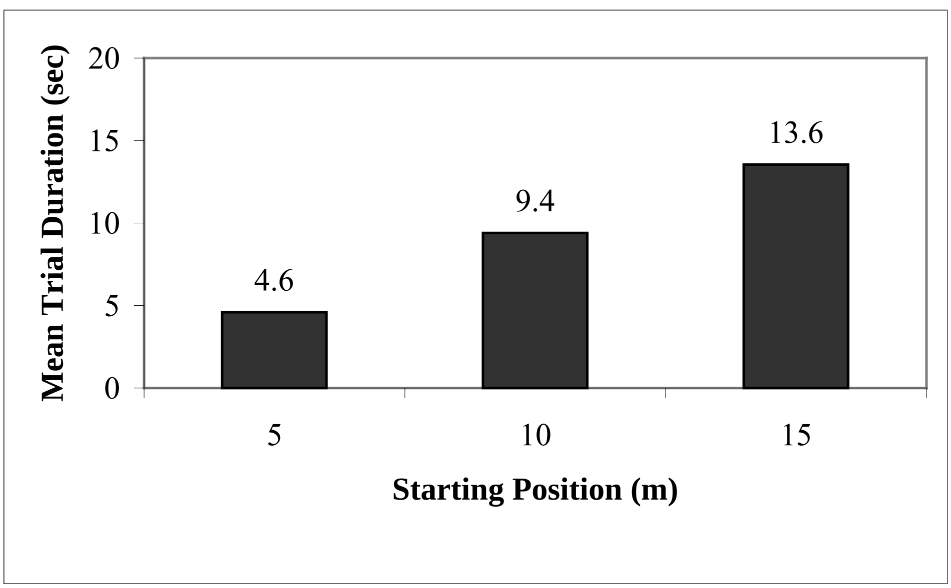

Figure 10. Daytime trial duration as a function of starting position.

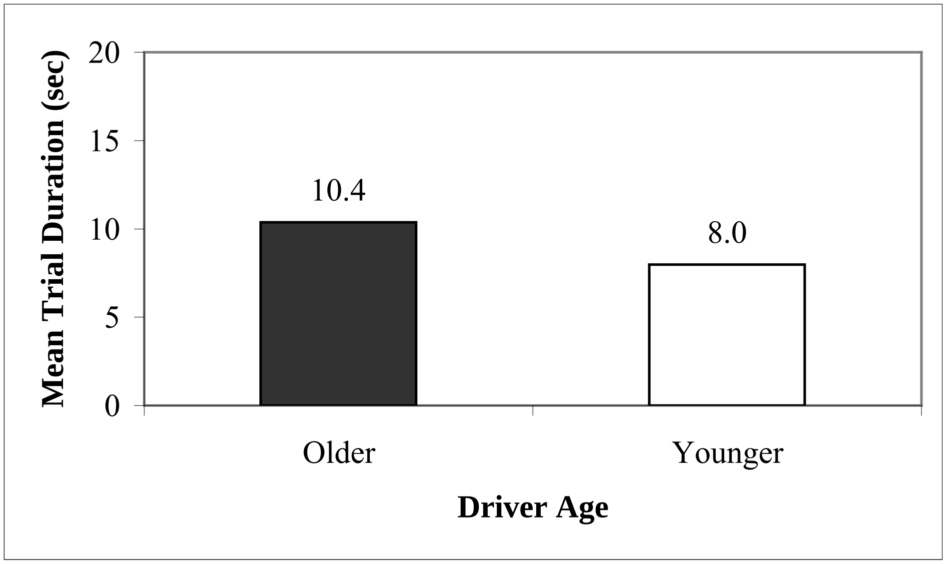

Figure 11. Daytime trial duration as a function of driver age.

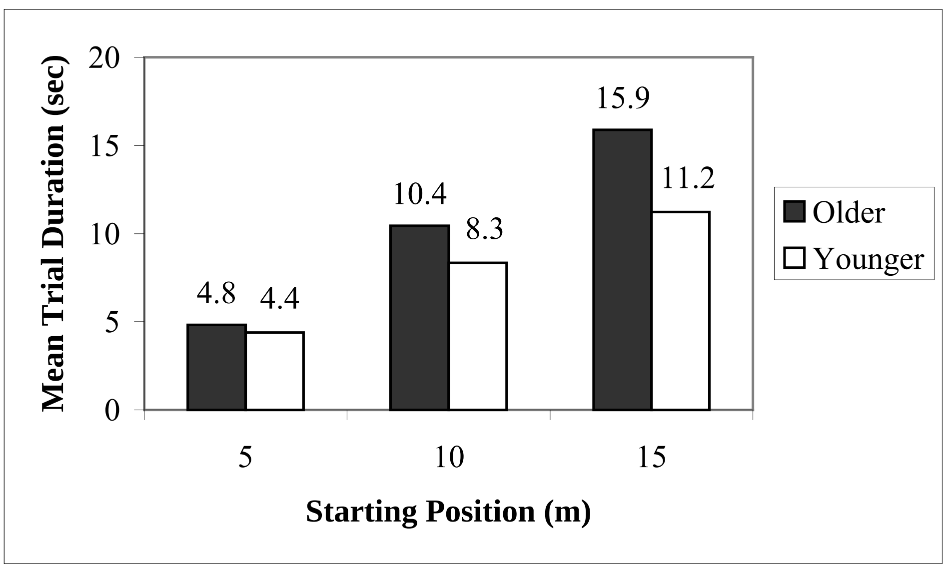

Figure 12. Daytime trial duration as a function of starting position and driver age.

Nighttime

Stopping distance. In the nighttime condition, the distance that participants stopped from the dumpster was significantly affected only by the starting position, $F(1.5,11.7) = 15.2$, $p < 0.01$. Mean stopping distances increased with increasing distance of the starting position from the dumpster (Figure 13).

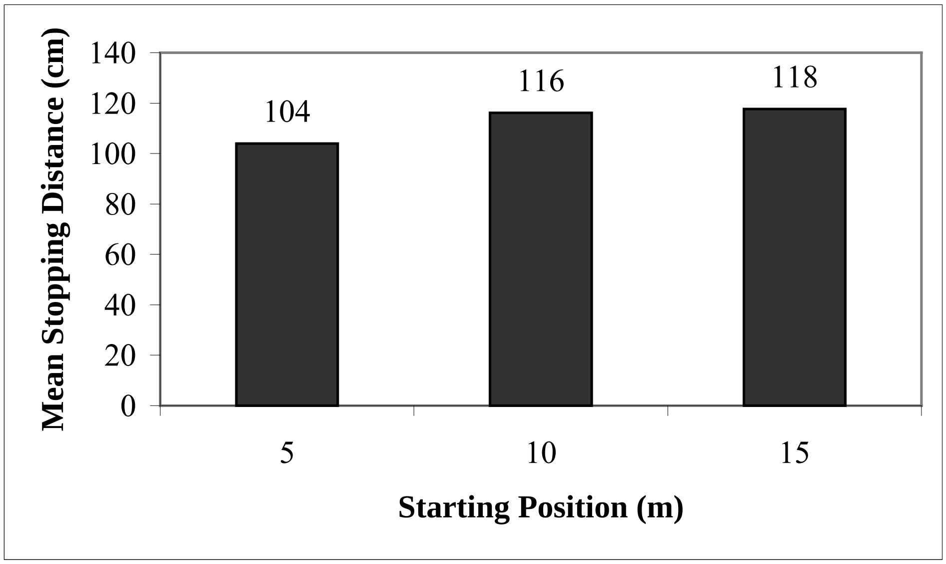

Figure 13. Nighttime stopping distance as a function of starting position.

Vehicle velocity. The velocities at which participants performed the backing maneuvers at night were significantly affected by the starting position, $F(1.2,10.0) = 201$, $p < 0.001$. Mean velocities increased with increasing distance of the starting position from the dumpster, just as they had under the daytime condition (Figure 14). Once again, driver age was significant, $F(1,8) = 15.1$, $p < 0.01$, with younger drivers having higher mean velocities than older drivers (Figure 15). Furthermore, the interaction of starting position and driver age was again significant, $F(1.2,10.0) = 11.2$, $p < 0.01$ (Figure 16), with differences between younger and older participants increasing as the starting position from the dumpster increased.

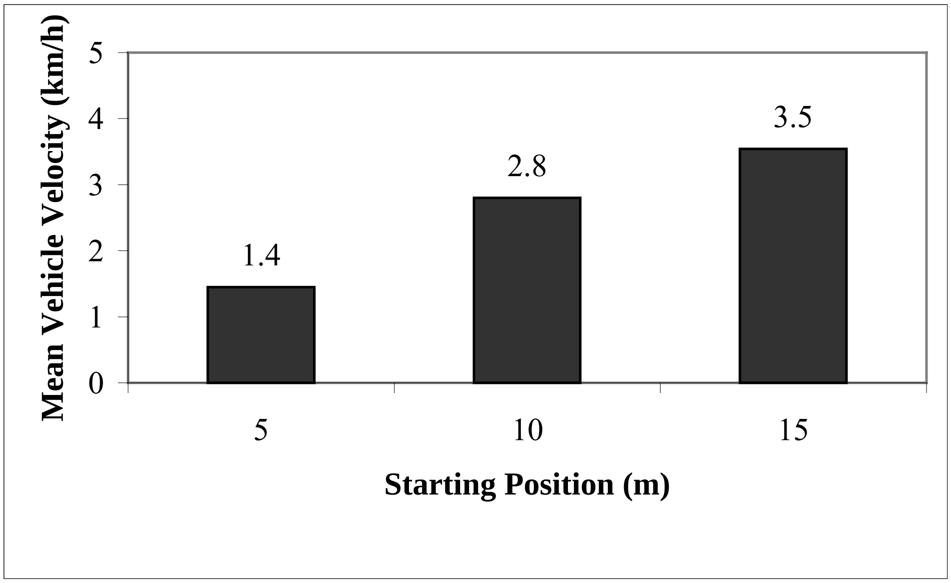

Figure 14. Nighttime velocity as a function of starting position.

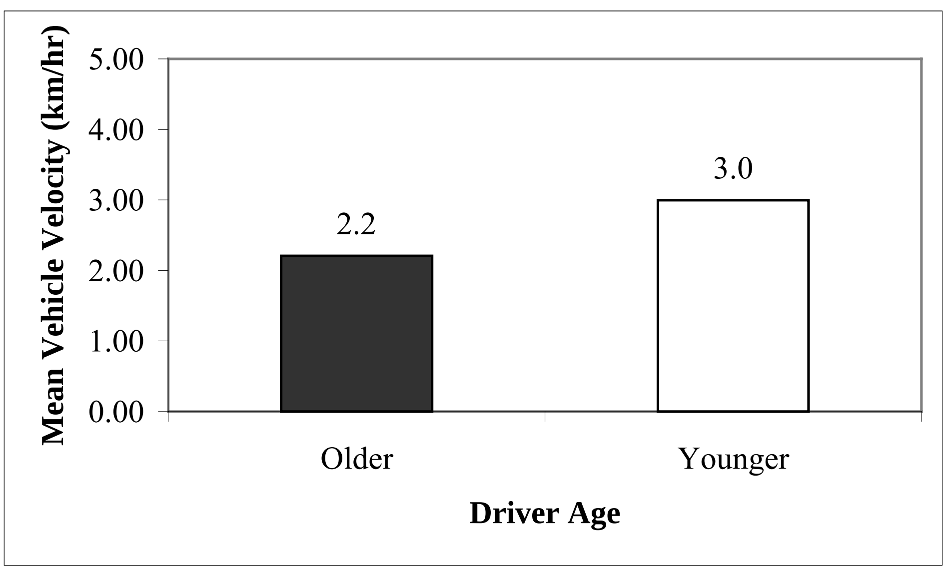

Figure 15. Nighttime velocity as a function of driver age.

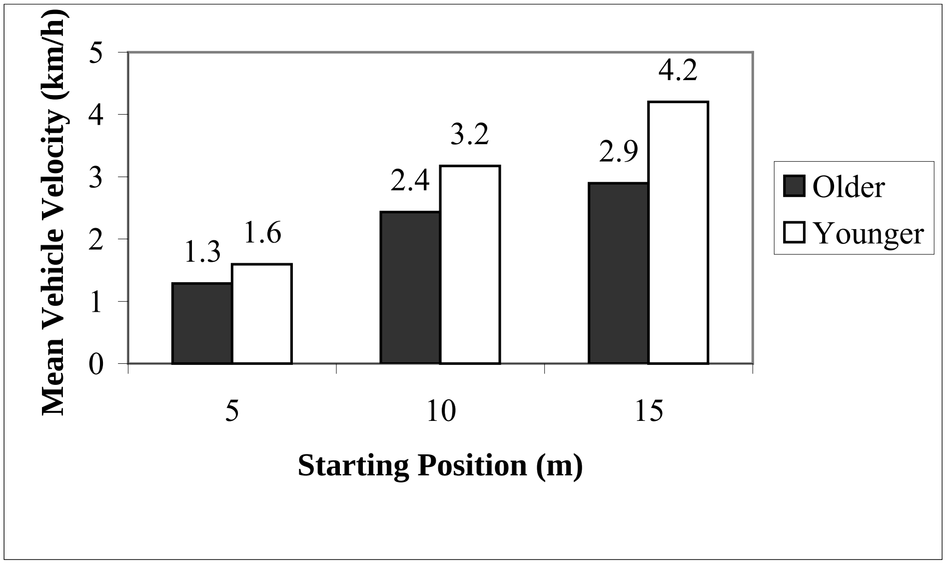

Figure 16. Nighttime velocity as a function of starting position and driver age.

Vehicle acceleration. Only the starting position of the vehicle significantly affected acceleration towards the dumpster, $F\ (1.4,11.5) = 24.8$, $p < 0.001$, with mean accelerations highest at the 5 m starting position (Figure 17).

Trial duration. Similar to the daytime results, the duration of backing maneuvers at night was significantly affected by the starting position, $F(1.1,8.4) = 132$, $p < 0.001$, driver age, $F(1,8) = 7.8$, $p < 0.05$, and the interaction of starting position and driver age, $F(1.1,8.4) = 7.7$, $p < 0.05$. Again, the shortest mean trial duration was associated with the closest starting position and the longest duration was associated with the farthest starting position (Figure 18). Older drivers had longer mean trial durations than younger drivers (Figure 19), and this difference increased as the starting position from the dumpster increased (Figure 20).

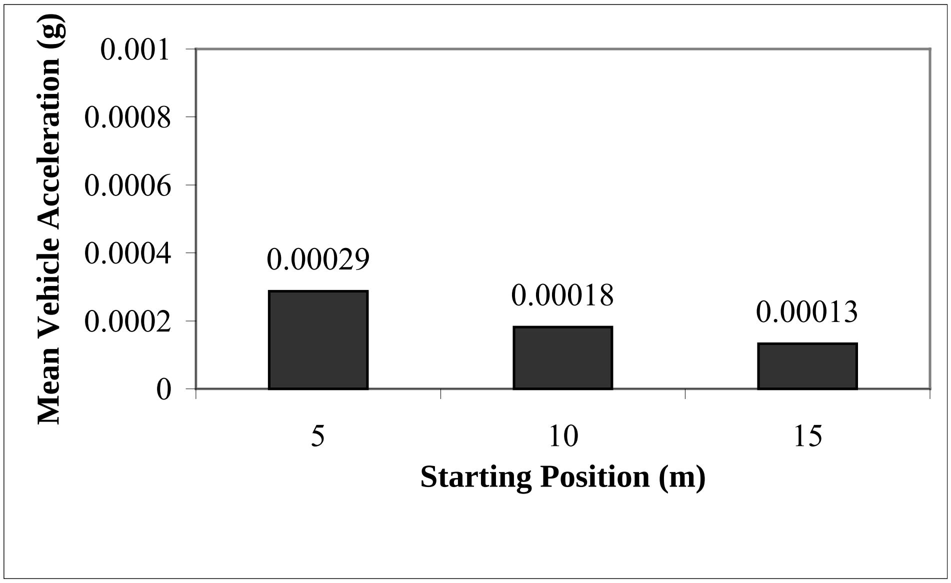

Figure 17. Nighttime acceleration as a function of starting position.

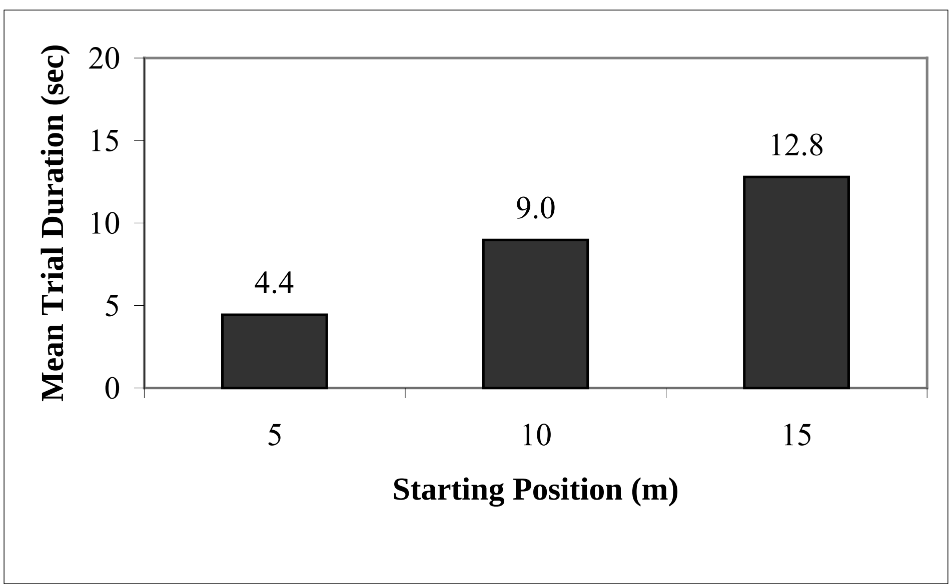

Figure 18. Nighttime trial duration as a function of starting position.

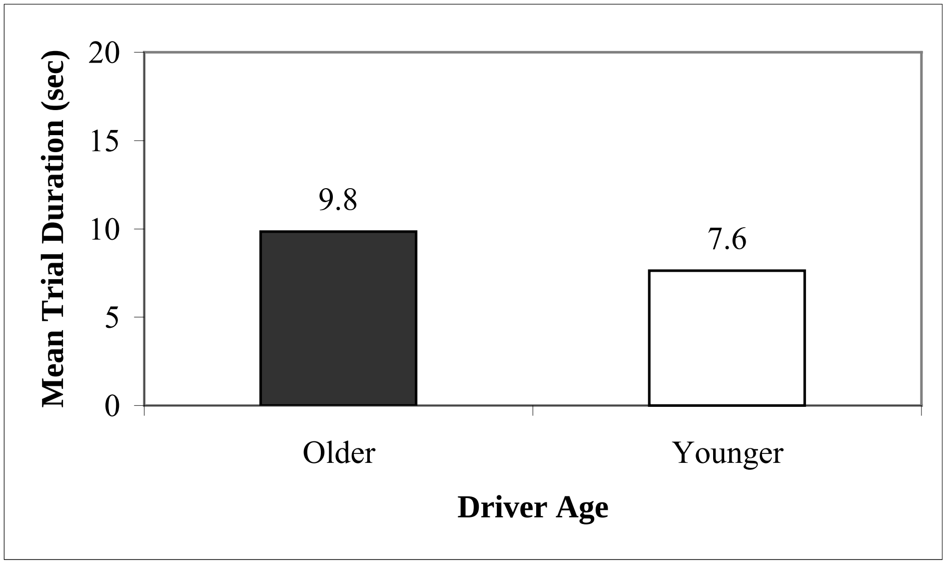

Figure 19. Nighttime trial duration as a function of driver age.

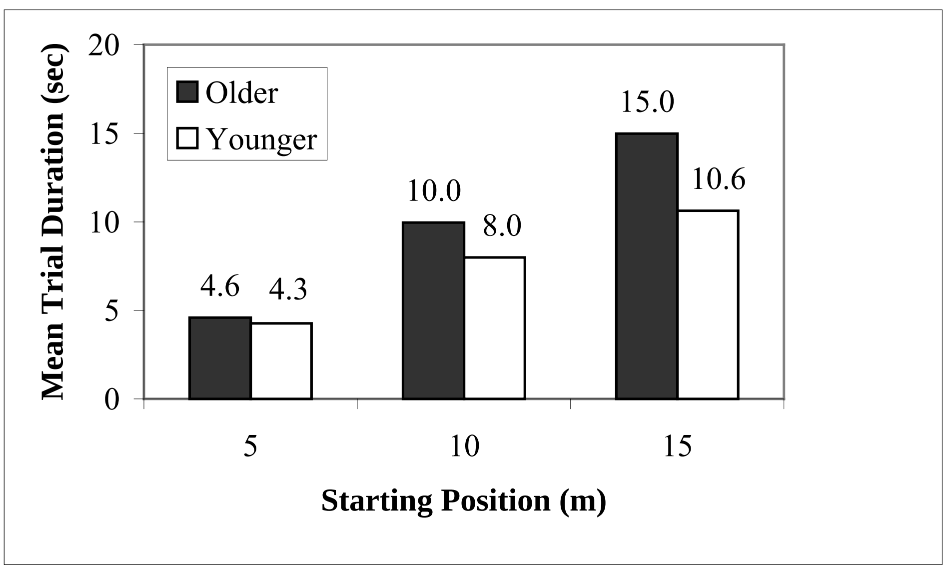

Figure 20. Nighttime trial duration as a function of starting position and driver age.

EXAMINATION OF THE BACKING CRASH DATA

Three years of crash data (1996-1998) from the General Estimates System (GES) file were examined for incidences of backing crashes. The GES data contain a nationally representative sample of police-reported crashes. Vehicles included in this analysis were passenger vehicles only: cars, minivans, and sport utility vehicles.

In this analysis, cell proportions for involvement in backing crashes were compared with the same proportions for all involvements. Statistical tests for the significance of any differences were performed. The estimates of significance reported as "p-values" are tests of whether the relevant proportion of backing involvements (backing crashes) is the same as the proportion of all accident involvements (total). Since the GES data are the products of sampling, the estimated proportions have an associated sampling error. Sampling errors for each year were estimated using procedures published in Shelton (1991). To estimate sampling errors for the aggregated three years, sampling errors of the aggregated data were calculated using the procedure for each of the years and then averaged. Since the comparisons involve the proportion of crashes (in this case, where the vehicle was backing) with the proportion of all accident involvements, the two proportions will vary together. For example, the proportion of backing involvements that occur in a dark condition is obviously related to the proportion of all involvements in a dark condition. This covariance is accounted for in the test for the difference of proportions.

All crash involvement tables that follow report data from GES on backing crash involvements (backing crash), all crashes that are not backing related (other than backing), all crashes that are undefined (unknown crash type), and all crashes (total)—the sum of the previous three columns. The top half of each table shows estimated frequencies, while the bottom half shows column percentages. The statistical significance of the differences in the proportion of backing crashes versus all crashes is calculated.

Light Condition

Table 2 shows the distribution of backing crash involvements for passenger cars only, for several light conditions using the GES variables for light condition. The GES definition of light condition is intended to describe the general light condition at the time of a crash. The condition identified as Dark/Lighted takes the presence of fixtures for roadway illumination into consideration. In addition, the GES conditions referred to as Dusk and Dawn are collapsed into a single condition (Dusk/Dawn) in all following analyses.

There is no statistically significant difference between the proportion of backing crashes that occurred in daylight (73.0%) and the proportion of the total crash involvements occurring in daylight (71.6%). However, the 6.1% of backing crashes that occurred in dark conditions is statistically different from the 8.3% of the total crashes that occurred in the dark. In other words, backing crashes were less likely to occur under dark conditions, and that difference is statistically significant. Under the dark-but-lighted (Dark/lighted) condition there is a statistically significant over-representation of the proportion of backing crashes that occurred relative to the total of all crash types.

Table 2. Backing crash involvement by lighting condition for passenger cars only, all ages.

Light condition	**Backing crash**	**Other than backing**	**Unknown crash type**	**Total**	
	Frequencies				
Daylight	241,225	16,284,276	112,998	16,638,499	
Dark	20,262	1,888,202	22,459	1,930,923	
Dark/lighted	51,689	3,413,142	35,282	3,500,113	
Dawn/dusk	12,164	849,076	10,746	871,986	
Unknown	4,968	290,199	10,880	306,047	
Total	330,309	22,724,894	192,364	23,247,567	
	Column Percentages				**Significance**
Daylight	73.0	71.7	58.7	71.6	$p > 0.05$
Dark	6.1	8.3	11.7	8.3	$p < 0.01$
Dark/lighted	15.6	15.0	18.3	15.1	$p < 0.02$
Dawn/dusk	3.7	3.7	5.6	3.8	$p > 0.05$
Unknown	1.5	1.3	5.7	1.3	
Total	100.0	100.0	100.0	100.0	

Driver Age

Additional analyses of the crash data were performed to examine the relationship of driver age to backing crashes for passenger cars only. Based on the results from the field study that showed older drivers had significantly lower mean velocities and took significantly longer to complete maneuvers, it was hypothesized that driver age could be an important factor in backing crashes. The results indicate that, in fact, backing crash involvement is significantly affected by driver age (Table 3). The analyses in Table 3 exclude crashes involving drinking drivers and include only passenger cars. Drivers between the ages of 25 and 45 were under-represented in backing crashes, accounting for 29.6% of backing crashes but 40.7% of the total crashes. In contrast, drivers older than 65 were over-represented in backing crashes, accounting for 13.4% of the backing crashes, but only 8.5% of the total crashes. Both differences are significant at the $p < 0.01$ level. The proportions of backing crashes for the other age groups (less than 25 and between 45-65 years of age) do not differ significantly from the proportions of the total crashes.

Table 3. Backing crash involvement by driver age group for passenger cars only, with drinking drivers excluded.

Driver age	Backing crash	Other than backing	Unknown crash type	Total	
	Frequencies				
≤ 24	93,702	6,572,537	56,737	6,722,976	
25-45	97,722	9,289,767	73,326	9,460,814	
46-65	54,474	3,921,210	29,082	4,004,766	
≥ 66	44,228	1,924,335	12,993	1,981,556	
Unknown	40,182	1,017,045	20,227	1,077,455	
Total	330,309	22,724,894	192,364	23,247,568	
	Column Percentages				**Significance**
≤ 24	28.4	28.9	29.5	28.9	$p > 0.70$
25-45	29.6	40.9	38.1	40.7	$p < 0.01$
46-65	16.5	17.3	15.1	17.2	$p > 0.28$
≥ 66	13.4	8.5	6.8	8.5	$p < 0.01$
Unknown	12.2	4.5	10.5	4.6	
Total	100.0	100.0	100.0	100.0	

Light Condition for Younger Drivers

Based on the finding that drivers over 65 years of age were over-represented in backing crashes, older drivers were excluded from an analysis of backing crashes by light condition in an attempt to better isolate the effects of light condition and vehicle type. In addition, the analyses in Table 4 include only passenger cars and exclude crashes involving drinking drivers. The results again show that backing crashes are not associated with dark conditions, with the proportion of backing crashes in dark conditions being lower than the proportion of total crashes in dark conditions. In comparison to Table 2, the proportion of backing crashes occurring in the dark-but-lighted condition is no longer statistically different from the total of backing crashes occurring in the dark.

Table 4. Backing crash involvement by lighting condition for passenger cars only for drivers 65 or younger, with drinking drivers excluded.

Light condition	Backing crash	Other than backing	Unknown crash type	Total	
	Frequencies				
Daylight	172,984	13,828,706	93,344	14,095,034	
Dark	15,248	1,521,295	15,284	1,551,827	
Dark/lighted	32,446	2,743,151	24,067	2,799,663	
Dawn/dusk	9,132	741,239	6,954	757,324	
Unknown	3,515	217,719	6,933	228,166	
Total	233,324	19,052,109	146,581	19,432,014	
	Column Percentages				**Significance**
Daylight	74.1	72.6	63.7	72.5	$p > 0.74$
Dark	6.5	8.0	10.4	8.0	$p < 0.01$
Dark/lighted	13.9	14.4	16.4	14.4	$p > 0.45$
Dawn/dusk	3.9	3.9	4.7	3.9	$p > 0.97$
Unknown	1.5	1.1	4.7	1.2	
Total	100.0	100.0	100.0	100.0	

Vehicle Type

Passenger vehicle type was examined because minivans and SUVs are more likely to have tinted rear windows (Sayer et al., 2000), possibly making the detection of obstacles to the rear of the vehicle more difficult. Table 5 presents the proportion of backing crashes associated with the type of passenger vehicle (passenger car versus minivan/SUV). Drivers over the age of 65 and drinking drivers are excluded. The results show that minivans/SUVs are significantly over-represented in backing crashes, having a higher proportion of backing crashes than the total of all other crash types ($p < 0.01$). Passenger cars tend to be under-represented in backing crashes, but the difference is not statistically significant.

Table 5. Backing crash involvement by type of passenger vehicle (passenger car versus minivan/SUV) for drivers 65 or younger, with drinking drivers excluded.

Vehicle type	**Backing crash**	**Other than backing**	**Unknown crash type**	**Total**	
	Frequencies				
Car	233,324	19,052,109	146,581	19,432,014	
Minivan/SUV	50,937	2,516,832	14,756	2,582,525	
Total	284,261	21,568,941	161,337	22,014,539	
	Column Percentages				**Significance**
Car	82.1	88.3	90.9	88.3	$p > 0.40$
Minivan/SUV	17.9	11.7	9.1	11.7	$p < 0.01$
Total	100.0	100.0	100.0	100.0	

Light Condition for Minivans and SUVs

Table 6 shows the difference between the proportion of backing crashes by lighting condition for minivans and SUVs (no passenger cars). Drivers older than 65 and drivers coded as drinking are also excluded. For this circumstance, the dawn/dusk lighting condition is significantly over-represented in backing crashes. Similar to the previous findings presented in Table 4, the dark-but-lighted (Dark/lighted) condition is also over-represented, but the difference does not achieve statistical significance. Daylight and dark backing crashes for minivans and SUVs are under-represented, but neither of the differences is statistically significant.

Table 6. Backing crash involvement for minivans and SUVs only by lighting condition for drivers under 66, with drinking drivers excluded.

Light condition	Backing crash	Other than backing	Unknown crash type	Total	
	Frequencies				
Daylight	33,921	1,919,934	10,584	1,964,439	
Dark	3,685	189,217	2,205	195,107	
Dark/lighted	7,819	287,767	1,480	297,066	
Dawn/dusk	4,739	90,897	395	96,031	
Unknown	773	29,016	92	29,881	
Total	50,937	2,516,832	14,756	2,582,524	
	Column Percentages				Significance
Daylight	66.6	76.3	71.7	76.1	$p > 0.14$
Dark	7.2	7.5	14.9	7.6	$p > 0.84$
Dark/lighted	15.4	11.4	10.0	11.5	$p > 0.13$
Dawn/dusk	9.3	3.6	2.7	3.7	$p < 0.01$
Unknown	1.5	1.2	0.6	1.2	
Total	100.0	100.0	100.0	100.0	

DISCUSSION

The Field Experiment

Daytime. Some of the findings from the daytime field experiment were consistent with what might have been expected a priori. Specifically, driver age affected measures of stopping distance, velocity, and trial duration; and the starting position affected measures of stopping distance, velocity, acceleration, and trial duration. The effect of driver age is consistent with results reported by Huey, Harpster, and Lerner (1995). The result from the daytime field experiment was an absence of any effects of rear-window transmittance on backing performance. Other than an interaction of starting position and window transmittance, rear-window transmittance did not affect stopping distance, velocity, acceleration, or trial duration.

Based on the results it would initially appear that a rear-window transmittance level ranging from 21% to 75% does not affect backing behavior toward a stationary object. However, it must be emphasized that participants were performing a well-learned maneuver, toward an anticipated object of high contrast under high ambient illumination. Had the dumpster been of low contrast relative to its background, or had the presence of the dumpster been unanticipated (e.g., some uncertainty added to the maneuver), the findings may have differed. Uncertainty could also be introduced through the addition of a secondary object (e.g., a pedestrian walking between the reversing car and the dumpster, or a trash can) in a small number of the trials in order to further explore the possible effects of rear-window transmittance on backing performance.

Nighttime. Similar to the results from the daytime condition, starting position affected measures of stopping distance, velocity, acceleration, and trial duration. On the other hand, driver age only had an effect on velocity and trial duration, but not on stopping distance. An unexpected result was the absence of any effects of rear-window transmittance or the intensity of the back-up lamps on backing performance. However, it must again be emphasized that participants were performing a maneuver that was well learned—particularly since they had already completed the daytime session—toward an anticipated object, with no uncertainty or concern for the presence of any other obstacles entering their path.

The Backing Crash Data

The results of examining the three years of crash data from the General Estimates System (GES) for backing crashes produced some unexpected results. First, the proportion of backing crashes that occurred in daylight was not significantly different from all crashes occurring in daylight. However, backing crashes were under-represented in dark conditions for all vehicles. This result suggests that performing backing maneuvers under dark conditions does not pose any increased crash risk. On the other hand, backing crashes under dark-but-lighted conditions were statistically over-represented for all vehicles. One possible explanation for these seemingly contrary results may be a confounding due to the characteristics of the environments in which backing is performed. Under dark-but-lighted conditions there may be more traffic, both vehicular and pedestrian, than might exist under dark, unlighted conditions. Parking lots, for example, often have fixed over-head illumination. This fixed illumination is in place specifically because parking lots are high traffic areas in which there is a greater chance of an obstacle entering a vehicle's path than in other situations, such as parallel parking or backing down one's driveway.

Analyses of the crash data also indicate that drivers over 65 are significantly over-represented in backing crashes, whereas drivers aged 25 to 45 are under-represented. Excluding older drivers, drinking drivers, and limiting the vehicle type to passenger cars, the only significant difference in the proportion of backing crashes relative to all crash types was again an under-representation for dark conditions. These combined results suggest that older drivers are those in greatest need of assistance when backing, even in passenger cars with rear-window transmittances that are typically 70% or greater. This assistance might be achieved through either an educational campaign or vehicle modifications (higher-intensity backup lamps, and rearward detection and warning devices).

Finally, an examination of backing crash involvement by vehicle type indicates that minivans and SUVs are significantly over-represented in the proportion of backing crashes, whereas passenger cars are under-represented. Furthermore, minivans and SUVs are specifically over-represented in backing crashes under both dark-but-lighted and dusk/dawn conditions where pedestrians have been shown to overestimate their own visibility (Shinar, 1984) and where drivers may very well overestimate the visibility of obstacles.

Future Research Needs

The results of this study suggest the following topics for future investigations:

a) *A wide range of ambient illumination*. Given the finding that backing accidents tend to be over-represented in dark-but-lighted and dusk/dawn conditions, field investigations under a wider variety of natural and artificial lighting conditions, in naturalistic settings, should be performed.

b) *Obstacle uncertainty and obstacle contrast*. In the current study there existed no target uncertainty when the driver was performing backing maneuvers. Had a pedestrian or other obstacle been introduced into the path of the vehicle in a few trials, the drivers' sense of uncertainty, and perhaps their attention, may have been heightened. However, the question remains whether a heightened awareness would have revealed any variations in backing performance when less light was available. Similarly, the contrast or location of the obstacle could be varied in order to introduce uncertainty regarding the distance a driver had to travel. As a result, future research should consider the effects of obstacle uncertainty and contrast.

c) *A variety of naturalistic driving conditions*. Drivers in this experiment were asked to perform simple backing maneuvers. Huey, Harpster, and Lerner (1995) examined a wider range of backing maneuvers, but only did so under daylight conditions, and there was no uncertainty component. Given the results of the crash data analyses, and the apparent effect of ambient lighting on backing crash rates, future research should include a range of backing maneuvers in naturalistic driving conditions, similar to Huey et al.

d) *Variations in vehicle class and rearward field of view*. The examination of backing crash involvement by vehicle type indicates that minivans and SUVs are over-represented in the proportion of backing crashes, whereas passenger cars are somewhat under-represented. Specifically, minivans and SUVs are over-represented in backing crashes under circumstances of dark-but-lighted and dusk/dawn conditions. Future investigations should examine the effects of varying the rearward field of view (including the height of the rear window) typical of minivans and SUVs, as well as incorporating what is, on average, a much lower level of rear-window transmittance found on these vehicles.

e) *Use of exterior rearview mirrors*. The present experiment did not examine the relative contribution of exterior rearview mirrors in performing backing maneuvers. Beyond the approach of Huey et al. to record glance locations; the need exists for future investigations to examine how mirrors and a variety of mirror properties (including mirror convexity) contribute to backing behavior. Some work in this area could be performed by examining European accident data for backing crashes, attempting to relate crash probabilities with the wider range of mirror surfaces permitted on European vehicles. Similar work has previously examined the effect of mirror convexity on lane change accidents (Luoma, Sivak, and Flannagan, 1994; Schumann, Sivak, and Flannagan, 1996).

CONCLUSIONS

The results of the present field study suggest that drivers may not adjust their backing behavior despite significant reductions in the amount of available light to the rear of a reversing vehicle. However, the conditions of the experiment were such that there was no uncertainty regarding the presence of obstacles when performing the backing maneuver. It is not known, and remains to be investigated, whether including obstacle uncertainty would affect backing performance given a reduction in the amount of light available to the driver.

The study did find that drivers adjust backing behavior with age, in that older drivers travel at lower velocities and thus take longer to perform the maneuver, under both daytime and nighttime conditions. Whether this difference in backing performance is due, in part, to their recognition of increased reaction times associated with age is not known. Another contributing factor could be that older drivers, possessing more driving experience, may simply be more attuned to the possibilities of a backing crash, and therefore proceed more cautiously. Nevertheless, as evidenced in the crash data, older drivers are over-represented in backing crashes. Therefore, as a group, older drivers may benefit most from higher-transmittance windows, higher-intensity backup lamps, and rearward detection and warning devices.

The crash data provide evidence that minivans and SUVs, relative to passenger cars, are over-represented in backing crashes under circumstances of dark-but-lighted and dusk/dawn ambient conditions. Consequently, these vehicles might benefit most from higher-transmittance windows, higher-intensity backup lamps, and rearward detection and warning devices. Future investigations should examine variation in the rearward field of view associated with minivans and SUVs, as well as incorporate what is, on average, a much lower percentage of rear-window transmittance on these vehicles.

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