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FURTHER CRASH EVIDENCE ON THE NIGHTTIME VISIBILITY OF TRUCKS

John M. Sullivan

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16. Abstract

As previously reported using daylight saving time crash analysis, fatal rear-end crashes between passenger vehicles and trucks show a pronounced effect of light level such that crashes involving trucks appear to be nearly nine times more likely in darkness than in light. In this report, we examine whether this effect shows any evidence of being modulated by the age of the striking driver, the travel speed or locale of the roadway, the involvement of alcohol, or by changes in regulations prescribing the use of conspicuity treatments for trucks beginning in 1993.

In general, a main effect of striking driver age was found such that younger drivers had a lower dark/light ratio in nighttime fatal rear-end crashes than older drivers. In addition, a main effect of struck vehicle suggested that the dark/light odds of a crash is about four times higher for trucks than for light vehicles. Analyses of locale, posted speed, and alcohol use by the striking driver revealed only a mild influence of locale, suggesting that the dark/light odds is 1.5 greater in rural than in urban areas. Finally, the analysis of regulatory changes in conspicuity treatment did not reveal a reliable effect specific to trucks, but did suggest that the dark/light odds of a crash has decreased by about half in recent years for both light vehicles and trucks.

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Introduction

In a previous report examining the effects of ambient light levels on fatal rear-end collisions (Sullivan & Flannagan, 2004), it was found that darkness increases the chance of such a collision between a light passenger vehicle and a medium or heavy truck by about nine times that of similar daylight crashes. The crash analysis exploited the daylight saving time (DST) technique outlined previously (Sullivan & Flannagan, 1999, 2001, 2002), controlling for many factors that are typically confounded with light level in direct day-night comparisons (e.g., fatigue level, driver demographics, alcohol use). In this report, we use the DST technique to examine these rear-end collisions in more detail to make further inferences about the role of driver vision in these collisions.

The analysis will disaggregate collisions between light vehicles and trucks on the basis of 1) the age of the striking driver, 2) the locale (rural/urban) of the crash, 3) the posted speed of the roadway, and 4) use of alcohol by the striking driver. Each of these factors might play some role in affecting driver performance. Driver age is associated with declining visual ability—as a driver ages, performance in low-light conditions declines. Consequently, older drivers may exhibit a higher crash risk in darkness than younger drivers. Because fixed roadway lighting is more likely to be present in urban as opposed to rural locales, we might expect that the nominal effect of darkness is lower in urban areas. That is, what we consider "darkness" in urban locales is actually a higher ambient light level than in rural locales. In previous analyses of pedestrian crashes (Sullivan & Flannagan, 2001), posted speed limit interacted with nighttime crash risk such that higher posted speed limits increased fatal crash risk associated with darkness. Assuming that the actual travel speed of a vehicle is closely associated with posted speed limit and that the reach of low-beam headlamps is fixed, higher speeds provide a driver with less time between perception of an object and a collision with it—less time for a successful avoidance maneuver. Alcohol use might interact with darkness if it retards recognition of visually degraded objects by diminishing contrast sensitivity (e.g., Pearson & Timney, 1998). However, alcohol impairs many central cognitive processes as well (e.g., attentional control, decision making), perhaps leaving diminished contrast sensitivity a comparatively small contribution to driving impairment.

This report also uses the DST technique to investigate whether amendments of Federal Motor Vehicle Safety Standard (FMVSS) No. 108, "Lamps, Reflective Device, and Associated Equipment," regulating conspicuity markings on trucks, has produced an observable decline in crash ratios over time. The standard was first changed in December 1992 requiring all new heavy trailers manufactured after December 1, 1993 to be marked with reflectors, reflective tape, and sheeting material to enhance conspicuity. This was further modified to require tractors to be reflectorized by July 1, 1997. In March 1999, the trailer requirement was further extended to require the entire active trailer fleet to bear conspicuity markings by June 1, 2001.

The basic FMVSS chronology is shown in Figure 1. The figure also shows how the Fatality Analysis Reporting System (FARS) crash dataset was divided in the new analysis so that a comparison could be made between pre- and post-regulation time periods.

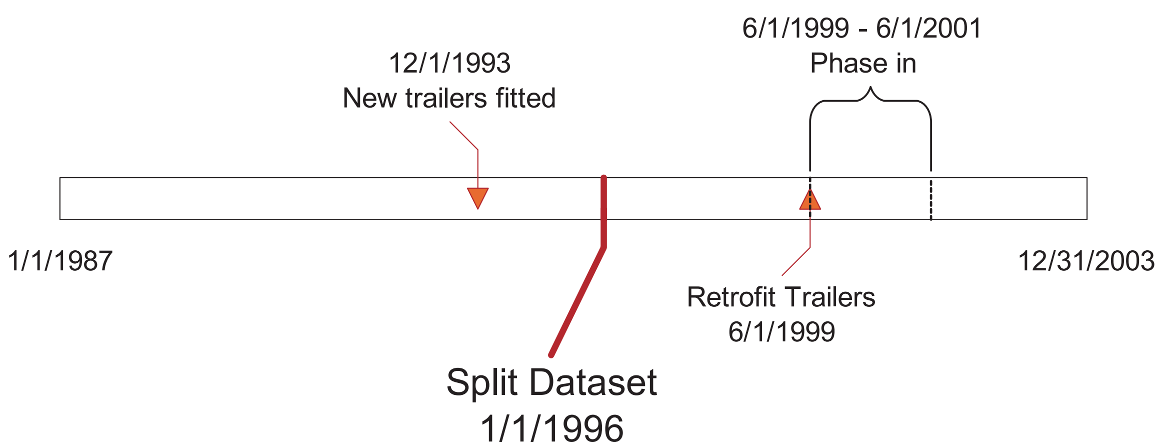

Figure 1. The timeline showing the chronology of changes to FMVSS No. 108 requiring conspicuity marking on heavy truck trailers. The timeline also shows where the FARS dataset was split to assess the possible effects of regulatory changes.

We note that, at best, the division point (January 1, 1996) is somewhat soft—prior to this date, many new trailers were likely already fitted with conspicuity markings; and following this date, many older trailers continued to have no conspicuity markings. There is no precise way of quantifying the actual mixture of marked and unmarked trailers. However, it is reasonable to assume that the trailer fleet on the road from 1996 to 2003 contained a significantly larger proportion of marked trailers than the fleet on the road from 1987 to 1995. Thus, a comparison of the two intervals might reveal some reduction in risk. We also note that a recent National Highway Traffic Safety Administration (NHTSA) study on reflective tape effectiveness reported a 43% reduction in rear-impact crashes as a result of the use of conspicuity treatments (Morgan, 2001). We might therefore expect to find evidence of this reduction in the dark/light ratios derived in the DST analyses.

Method

Crash data from the Fatality Analysis Reporting System (FARS) of the National Highway Traffic Safety Administration (NHTSA) were selected for a 17-year period from 1987 to 2003. Cases selected for analysis straddled the DST changeover periods in time-windows that abruptly changed from dark to light (or light to dark) across the time change. To perform the DST analysis, the exact start and end of civil twilight was computed for the dates of the spring and fall adjustments for DST for each county in 47 of the contiguous United States, for each of the 17 years covered in this analysis. Counties in states that do not observe DST, as well as counties split across time zones, were excluded (e.g., all counties of Arizona and 77 of Illinois).

Using the county times of the start and end of civil twilight, the clock time of reported crashes was recoded to indicate if the crash occurred in the one-hour interval just after the end of civil twilight in the evening. As shown in Figure 2, in the spring, this interval is dark before DST and light (or twilight) after the DST changeover. In the fall, the interval is light before the DST changeover and dark following it. For the present analysis, crash records were taken from five weeks before and five weeks after the evening transitions in both the spring and fall, and tagged as falling into either a light or a dark period. We note that although there is a dark/light transition in the morning the same procedure could *not* be applied directly to the morning. The five-week morning intervals straddling the DST changeover contain a mixture of both daylight and darkness (see Figure 3). As the figure illustrates, in the five-week period before the spring transition in the morning, light levels are nearly dark at the beginning and lighten as the DST transition date is reached. After the transition, the light level changes from dark to light. Inclusion of these morning crash data over the five weeks before and after the DST transition would wash out the light level difference, because crashes in the dark and light periods would not be adequately segregated. (For a more detailed analysis of crash rates and light levels in morning crash transitions, see Sullivan and Flannagan, 1999.)

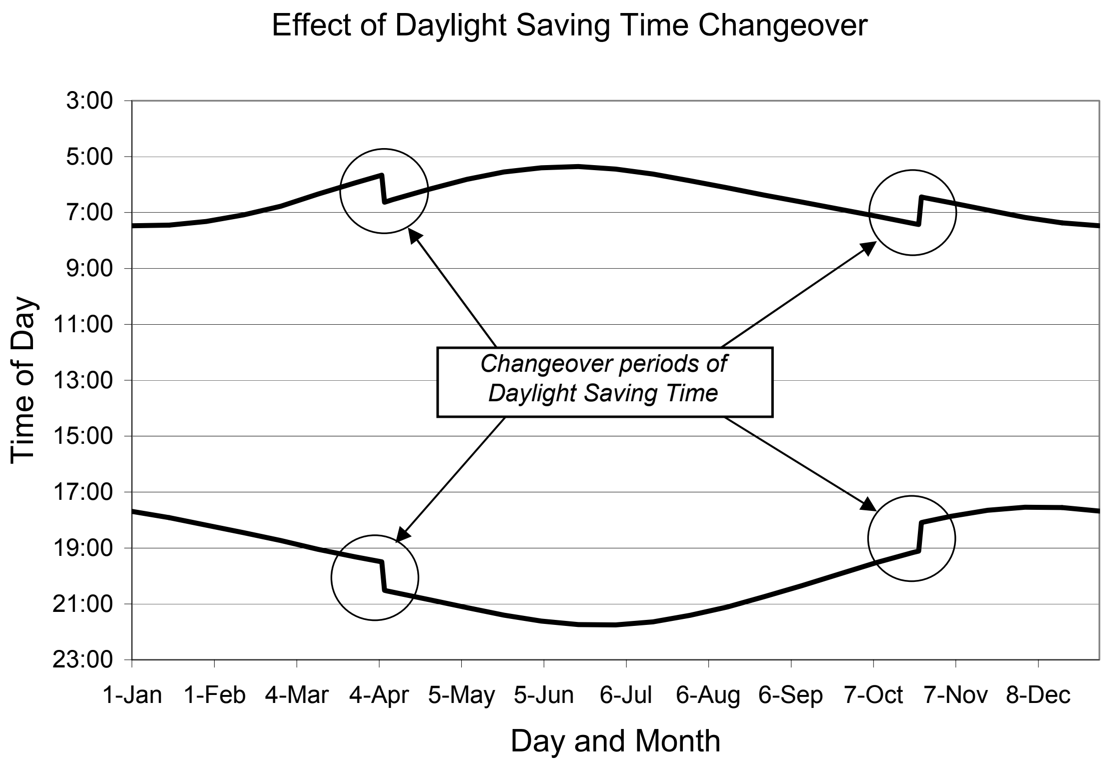

Figure 2. Daylight saving time changeover characteristics for spring and fall. The solid line is the clock time of the start (top) and end (bottom) of civil twilight throughout the year for the Ann Arbor/Detroit area (1997).

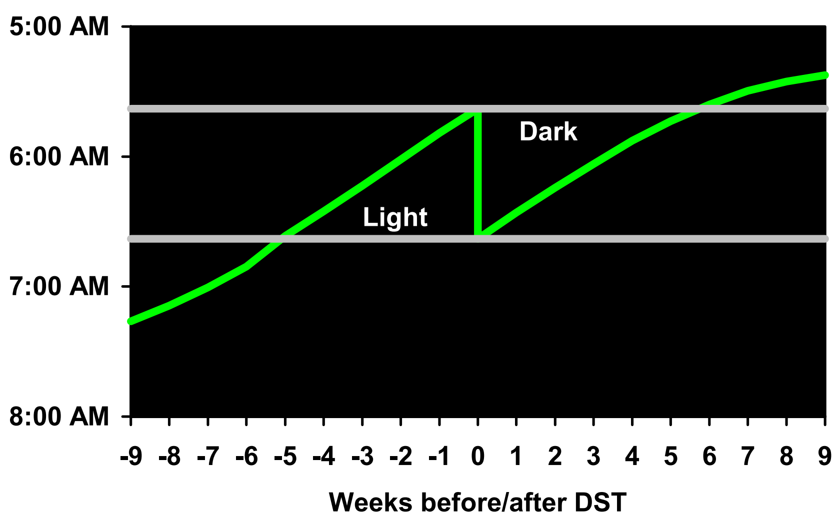

Figure 3. Spring morning transition to daylight saving time (not used). The line traces the start of civil twilight in the morning throughout the weeks before and after the transition.

The relative risk associated with a reduction in natural light was estimated by examining the proportion of crashes occurring during the dark intervals. Proportions significantly greater than 50% suggest an increased risk in darkness; below 50% suggest a reduced risk. Wherever these proportions are depicted in figures, error bars are also shown to reflect the associated 95% confidence intervals on these proportions. When these intervals do not include 50%, it may be concluded that there is a reliable difference in risk between the dark and light periods.

The present analyses focused on fatal rear-end collisions involving two vehicles during the DST interval. Vehicle types were grouped into five categories (Light Vehicle, Truck, Motorcycle, Bus, and Other), and identified as either the striking vehicle or the struck vehicle for each crash. Light vehicles included passenger cars, sport utility vehicles and light trucks. Trucks included medium and heavy single-unit trucks and tractor-trailer combination trucks. Crash records involving vehicles in each role were tabulated and are shown in Table 1.

Table 1
Counts of two-vehicle fatal rear-end crashes by vehicle type and role during the daylight saving time interval (FARS 1987-2003).

		Light Level		
Striking Vehicle	**Struck Vehicle**	**DARK**	**LIGHT**	**Total**
Light Vehicle	Bus	8	3	11
	Light Vehicle	82	44	126
	Motorcycle	7	8	15
	Other	35	8	43
	Truck	92	10	102
Light Vehicle Total		**224**	**73**	**297**
Motorcycle	Light Vehicle	12	16	28
	Motorcycle		1	1
	Other	2		2
	Truck	3	1	4
Motorcycle Total		**17**	**18**	**35**
Other	Light Vehicle	2	1	3
	Motorcycle	2		2
	Truck	1		1
Other Total		**5**	**1**	**6**
Truck	Light Vehicle	6	5	11
	Other		1	1
	Truck	3	2	5
Truck Total		**9**	**8**	**17**
Grand Total		**255**	**100**	**355**

Table 1 illustrates that the bulk of crashes involve light vehicles striking other light vehicles, trucks, or "other" vehicles (e.g., mopeds, snowmobiles, farm equipment, motor homes, or "unknown" vehicle types). For light vehicles striking other light vehicles or heavy trucks, there is a strong interaction between light condition and struck vehicle type ($\chi^2(1, 121) = 19.67$, $p < 0.001$). That is, the risk of a fatal rear-end collision involving a light vehicle striking a truck is especially high in darkness, compared to the risk of a light vehicle striking another light vehicle. This risk is shown in Figure 4, which also shows that collisions involving striking trucks fail to show an effect of darkness. In view of the relatively small number of fatal rear-end collisions involving striking trucks, and the resulting large confidence intervals, the latter result is not especially surprising. Because there are relatively few cases involving striking trucks, further analyses are directed to crashes involving light vehicles striking other light vehicles and trucks.

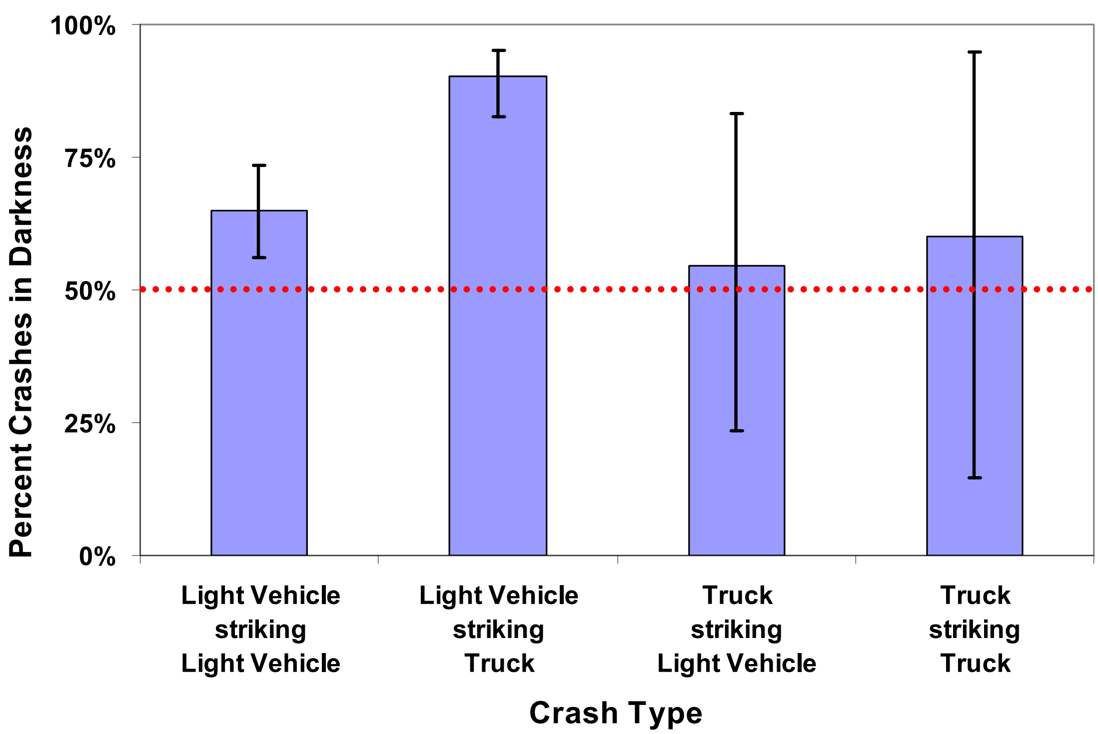

Figure 4. Percent crashes occurring during dark intervals by striking and struck vehicle types. The error bars represent 95% confidence intervals on the observed proportions of crashes in darkness.

The sample of light vehicles striking other light vehicles and trucks was further disaggregated and analyzed by driver age, crash locale, posted speed limit, and driver's use of alcohol to examine how these factors might interact with light level. The age of the striking driver was divided into six age ranges: ≤ 25 years, 26-35, 36-45, 46-55, 56-65, and ≥ 66; crash locale was classified as either rural or urban based on road function; posted speed limit was classified as high speed (greater than 45 miles per hour) or low speed (less than or equal to 45 miles per hour); and the driver's use of alcohol was determined by the driver drinking field in the FARS vehicle database table.

Results

Driver Age. To investigate the relationship between the striking driver's age and the relative risk of a fatal rear-end crash in darkness, a logistic regression was used to model percent of crashes in darkness as a function of driver age and struck vehicle type. Age was modeled as a continuous variable, using the mean driver age in each age category. A full-factorial model found no interaction between driver age and type of struck vehicle. The data (shown in Table 2) were subsequently fit to a logistic model relating age and vehicle type to crash risk. These results are shown in Table 3; the observed crash percentages and the results of the fit model are shown in Figure 5. Effects of age and vehicle type were observed such that odds of a crash in darkness—the ratio of crashes in darkness to crashes in light—increased with driver age by about 1.02 times per year of increasing age, and the odds ratio when the struck vehicle was a truck was about 4.5 times greater than when the striking vehicle was a light vehicle. (Note that odds, $\frac{p}{1-p}$, where p is the proportion of a particular outcome, is related to probability of that outcome as follows: $P = \frac{odds}{1+odds}$.)

Table 2
Counts of fatal rear-end crashes during light and dark DST time periods as a function of struck vehicle and age of the driver of the striking vehicle.

Struck Vehicle	**Mean Age**	**Light Level**		**Total**
		Dark	**Light**	
Light Vehicle	20	15	12	27
	31	19	13	32
	41	17	8	25
	51	11	5	16
	61	6	2	8
	75	11	3	14
Truck	20	19	4	23
	31	12	2	14
	41	12	0	12
	51	13	1	14
	61	12	1	13
	75	24	2	26

Table 3
Results of a logistic regression relating driver age and type of struck vehicle to relative risk of a crash in darkness. Statistically significant effects ($p < 0.05$) are identified with asterisks beside the *p* values. The estimate column represents the change in log odds associated with each factor. For example, the dark/light ratio of a struck truck is 4.5 times (exp(1.5160)) that of a struck light vehicle.

Analysis of Maximum Likelihood Estimates

Parameter		***df***	**Estimate**	**Standard Error**	**Wald Chi-Square**	***p***
Intercept		1	-0.1739	0.42	0.17	0.6777
Age		1	0.0199	0.01	4.21	0.0402*
Struck Vehicle	**Truck**	1	1.5160	0.39	15.34	<.0001*
	Light Vehicle					

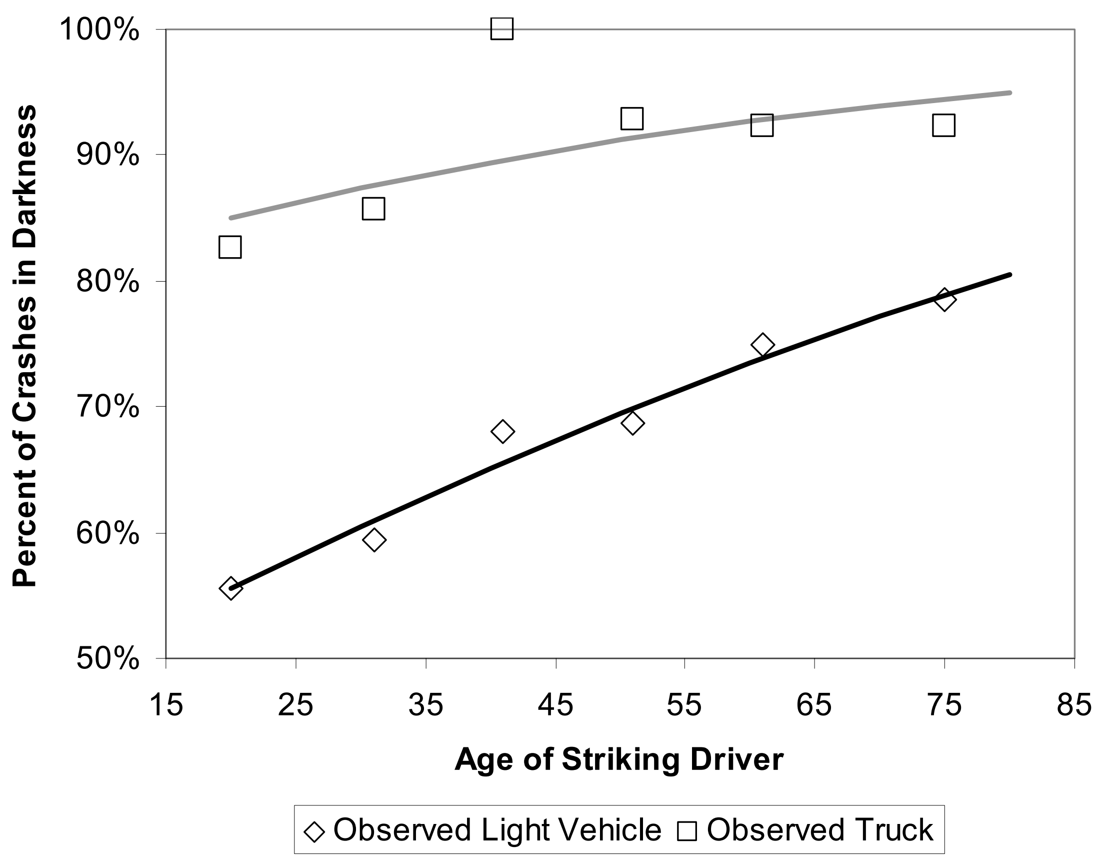

Figure 5. The observed and fit association between age of striking driver and struck vehicle type (light vehicle or truck) and the proportion of collision in darkness.

Crash Locale and Posted Speed. Figure 6 shows the percent of crashes in darkness as a function of speed, locale, and struck vehicle type. A logistic regression modeling the effects of posted speed (low/high), locale (urban/rural), and struck vehicle type on crash risk in darkness revealed a strong effect of vehicle type on crash risk (consistent with the previous analysis of driver age). The results are shown in Table 4. In this model, the odds of a fatal rear-end collision with a truck as the struck vehicle in the dark versus the light were about four times higher than the corresponding odds for collisions with light vehicles. There was also a mild suggestion in the data that the odds ratio was about 1.5 times higher in rural locales, although this result is not significant. This trend can be seen in Figure 6, where the rural proportions of dark crashes are higher than the urban proportions.

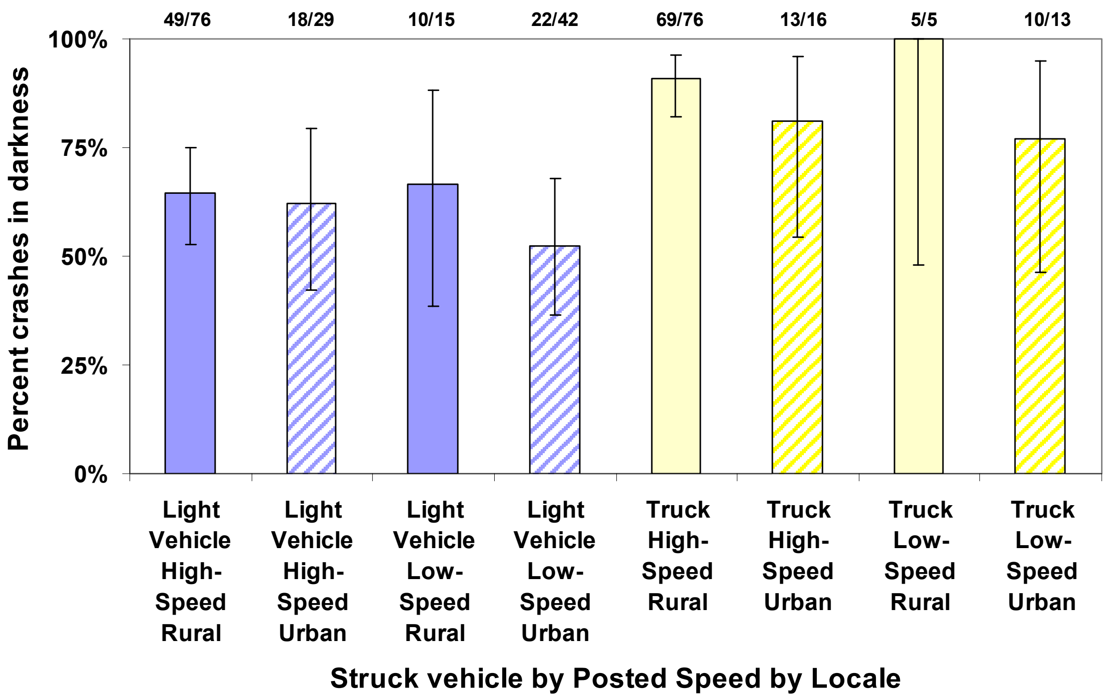

Figure 6. Proportion of crashes in darkness as a function of struck vehicle and posted speed limit. Error bars represent 95% confidence intervals on the proportions. Numbers above the bars indicate the number of crashes in darkness and the total number of observations in the sample.

Table 4
Results of a logistic regression relating type of struck vehicle (light vehicle/truck), roadway locale (rural/urban) and posted speed (high/low) to the dark/light odds. Statistically significant effects ($p < 0.05$) are identified with asterisks beside the *p* values.

Analysis of Maximum Likelihood Estimates

Parameter		***df***	**Estimate**	**Standard Error**	**Wald Chi-Square**	***p***
Intercept		1	0.7026	0.22	10.32	0.0001*
Struck Vehicle	**(Truck)** **(Light Vehicle)**	1	1.4664	0.34	18.41	<0.0001*
Locale	**(Urban)** **(Rural)**	1	-0.4418	0.32	1.88	0.1707
Speed	**(Low Speed)** **(High Speed)**	1	-0.1422	0.34	0.17	0.6772

Alcohol Use by Striking Drivers. A logistic regression modeling the effects of striking driver alcohol use (not drinking/drinking) and struck vehicle type on crash risk in darkness revealed no discernable effect of alcohol or interaction of vehicle type with alcohol. As in the previous analyses, the effect of struck vehicle dominates these results. Figure 7 shows the percent of crashes in darkness as a function of struck vehicle type and striking driver's use of alcohol. There was little evidence that a drinking driver had an elevated relative risk of a rear-end collision in darkness, or of any interaction between alcohol use and struck vehicle type (see Table 5). This should not be misunderstood to mean that alcohol has no effect on crash risk; merely that we did not find its effects on fatal rear-end collisions to be significantly greater in darkness.

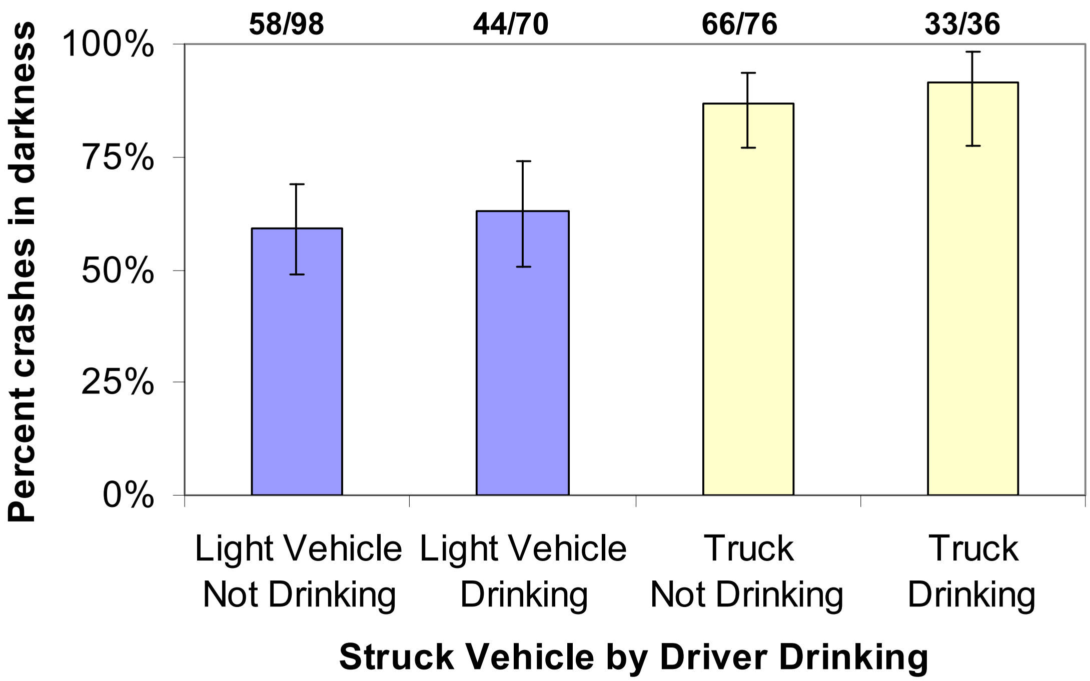

Figure 7. Risk of fatal rear-end collision in darkness as a function of struck vehicle type (light vehicle/truck) and striking driver's use of alcohol (drinking/not drinking). Numbers above the bars indicate the number of crashes in darkness and the total number of observations in the sample.

Table 5
Results of a logistic regression relating type of struck vehicle (light vehicle/truck) and striking driver's use of alcohol to odds of a crash in darkness. Statistically significant effects ($p < 0.05$) are identified with asterisks beside the *p* values.

Analysis of Maximum Likelihood Estimates

Parameter		***df***	**Estimate**	**Standard Error**	**Wald Chi-Square**	***p***
Intercept		1	0.3445	0.20	3.07	0.0800*
Struck Vehicle	**(Truck)** **(Light Vehicle)**	1	1.6184	0.34	23.11	<.0001*
Alcohol	**(Yes)** **(No)**	1	0.2211	0.29	0.59	0.4444

Effects of Conspicuity Regulations. In this analysis, all crashes involving struck heavy trucks during the DST interval were partitioned into two time periods: earlier crashes (1987 to 1995) and later crashes (1996 to 2003), in the period during which regulations regarding rear conspicuity treatments of trucks were introduced. This partitioning is illustrated in Figure 1 on page 2. Struck light vehicles were also included in the analysis as a control for changes in general nighttime visibility that may have occurred between the two time periods, but which were unrelated to the conspicuity regulations. For example, improvements in road lighting over time might reduce the nighttime crash risk for striking *both* light vehicles and trucks. The conspicuity changes in FMVSS 108 should have had a greater effect on fatal rear-end collisions into trucks at night than on collisions into light vehicles. Thus, we would expect the time period to interact with struck vehicle type.

The restriction on examining only collisions involving two vehicles applied to the preceding analyses was relaxed to increase the pool of observations included in this analysis—we included crashes involving two to four vehicles. In addition, single-unit trucks were excluded from the analysis because the regulation changes applied to tractor-trailer combination vehicles. Figure 8 shows the percent of crashes in darkness as a function of stuck vehicle type and time period. The results of a logistic regression are provided in Table 6; the best fitted model to the dark/light odds ratio suggests that the odds ratio of striking a truck in darkness is about four times that of striking a light vehicle; and the dark/light odds ratio of a fatal rear end collision in the later time period is about half of what it is in the earlier time period. A model that also included a time period by struck vehicle type interaction term did not produce a substantially better fit, suggesting that any interaction between vehicle type and time period was weak. Thus, although a decrease in the dark/light odds was observed between the two time periods for both struck vehicle types, the reduction associated with trucks does not appear to be remarkably different from the reduction observed for struck light vehicles.

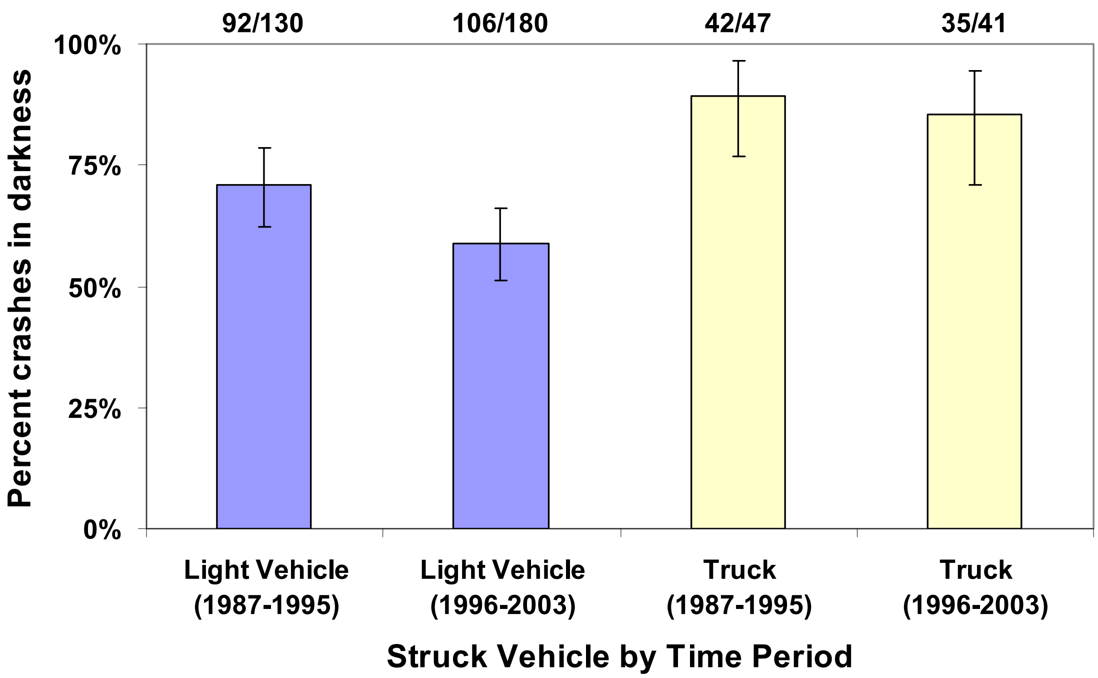

Figure 8. Proportion of fatal rear-end collision in darkness as a function of struck vehicle type (light vehicle/truck) and time interval of crash. Numbers above the bars indicate the number of crashes in darkness and the total number of observations in the sample.

Table 6
Results of a logistic regression relating type of struck vehicle (light vehicle/truck) and time period of crash to probability of a crash in darkness. Statistically significant effects ($p < 0.05$) are identified with asterisks beside the *p* values.

Analysis of Maximum Likelihood Estimates

Parameter		***df***	**Estimate**	**Standard Error**	**Wald Chi-Square**	***p***
Intercept		1	0.367	0.15	6.15	0.0131*
Struck Vehicle	**(Truck) (Light Vehicle)**	1	1.3328	0.35	14.93	<.0001*
Time Period	**(1987-1995) (1996-2003)**	1	0.5048	0.23	4.85	0.0276*

Discussion and Conclusions

These analyses indicate that the dark/light odds ratio for a fatal rear-end collision involving a light vehicle striking a truck is about four to four and a half times greater than for a light vehicle striking another light vehicle. Thus, if the dark/light odds of a fatal rear-end collision into a passenger car is about 2, the odds of a fatal rear-end collision with a truck is about 9; in percent terms this would be about 67% versus 90%. Risk of rear-end collisions into trucks is particularly high in the dark compared to daylight.

A reliable effect of age was also observed in the data, suggesting that the decline in the visual abilities of older drivers increases their dark/light crash risk. A weak effect of locale ($p = 0.17$) was also observed that suggested that dark/light crash risk in urban locales may be smaller than in rural areas. We did not observe an effect of posted speed limit or alcohol use on dark/light crash risk. Perhaps an effect of posted speed limit was not observed because the *actual* vehicle speeds involved in these rear-end crashes did not reflect the posted speed. Rear-end collisions make up about 30% of all police-reported crashes in the United States, but only 5% of all fatal crashes. For a rear-end collision to result in a fatality, relatively high speed is usually required. Because the current analysis involved only fatal rear-end collisions, the speeds may have been consistently high. The fact that alcohol did not increase relative crash risk in the dark may be due to the fact that alcohol has multiple effects, significantly impairing a driver's perceptual, cognitive, and motor capabilities. Impaired cognitive and motor capabilities may well overshadow perceptual impairment.

The analysis of the potential effects of truck conspicuity regulation suggests that the relative risk of a rear-end crash in the dark has declined in the more recent time period (1996-2003), relative to the earlier time period (1987-1995) for both struck light vehicles *and* trucks. It is unclear what the reason for this might be, but given that the effect was not restricted to trucks, it does not seem reasonable to attribute the effect to changes in truck conspicuity regulations alone. Indeed, the magnitude of the effects of the conspicuity regulations may not be observable in these data for several reasons. First, as was noted earlier, the division of the data into pre- and post-regulation partitions does not sharply divide the truck fleet into conspicuity-equipped and non-equipped trucks.

Thus, the 43% reduction in rear-impact crashes into trucks reported by NHTSA (Morgan, 2001) is unlikely to be as strong across the two time periods.

But, furthermore, suppose we assumed that all trucks in the later period were equipped with conspicuity treatments and those in the earlier period were not. If we then applied the 43% reduction to the observed DST dark/light crash ratio in data involving struck trucks before 1996, we would expect to reduce the observed 42 nighttime crashes (and five daylight crashes) to 24 nighttime crashes (and five daylight). This amounts to a change in risk from 89% (42/47) to 83% (24/29) for crashes in the dark. Such a change lies within the confidence intervals of the estimated probability for struck trucks in the later time period. The relatively small crash counts obtained using the DST dark/light ratios (particularly for daylight crashes into trucks) limits the precision of the risk estimates, making it difficult to distinguish the effect of crash reductions in the dark. Because the dark/light ratio involving rear-end collisions into trucks is very large (and involves a small denominator), our ability to distinguish differences between large crash percentages (e.g., 89% and 83%) is limited.

Despite the preceding limitations, these results provide clear evidence that darkness plays a significant role in elevating risk of fatal rear-end collisions into trucks, that driver age affects this relative risk, and that the relative risk appears to be declining.

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