PERGAMON

Accident Analysis and Prevention 32 (2000) 493–504

ACCIDENT ANALYSIS & PREVENTION

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Factors associated with falling asleep at the wheel among long-distance truck drivers

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Received 1 February 1999; received in revised form 19 May 1999; accepted 25 May 1999

Abstract

Data on the prevalence and hypothesized predictors of falling asleep while driving were gathered through face-to-face interviews with 593 long-distance truck drivers randomly selected at public and private rest areas and routine roadside truck safety inspections. Hypothesized predictor variables related to drivers' typical work and rest patterns, extent of daytime and night-time drowsiness, symptoms of sleep disorder, measures of driving exposure, and demographic characteristics. A sizeable proportion of long-distance truck drivers reported falling asleep at the wheel of the truck: 47.1% of the survey respondents had ever fallen asleep at the wheel of a truck, and 25.4% had fallen asleep at the wheel in the past year. Factor analysis reduced the large set of predictors to six underlying, independent factors: greater daytime sleepiness; more arduous schedules, with more hours of work and fewer hours off-duty; older, more experienced drivers; shorter, poorer sleep on road; symptoms of sleep disorder; and greater tendency to night-time drowsy driving. Based on multivariate logistic regression, all six factors were predictive of self-reported falling asleep at the wheel. Falling asleep was also associated with not having been alerted by driving over shoulder rumble strips. The results suggest that countermeasures that limit drivers' work hours and enable drivers to get adequate rest and that identify drivers with sleep disorders are appropriate methods to reduce sleepiness-related driving by truck drivers.

Keywords: Fatigued driving; Drowsy driving; Truck drivers; Falling asleep at wheel

1. Introduction

Until recently in the US, driving while drowsy has not been a major focus of highway safety initiatives aimed at the general public[1]. This may be attributable to studies of crash data that suggest that sleepiness-related driving is a relatively low crash risk, when compared to such other factors as alcohol-impaired driving or excessive vehicle speed. According to research conducted by the US National Highway Traffic Safety Administration, drowsiness or fatigue has been identified as a causal factor in 1.2–1.6% of all police-reported crashes and 3.6% of fatal crashes (Knipling and Wang, 1994, 1995). It is believed, however, that drowsiness is under-reported as a contributory crash factor, because there generally is little physical or other evidence that a crash-involved driver was drowsy or fell asleep, and a lack of standardization among the states in the definition and reporting of sleepiness-related crashes.

An increased interest in the role played by driver drowsiness in highway crashes is evidenced by the recent publication of reports on sleepiness and highway crashes by a national Expert Panel on Driver Fatigue and Sleepiness (1997) and by the Council on Scientific Affairs, American Medical Association

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[1] While the term 'fatigue', rather than the terms 'drowsiness' or 'sleepiness', is used most commonly with reference to commercial vehicle safety, the three terms are used interchangeably in this paper.

0001-4575/00/$ - see front matter
PII: S0001-4575(99)00067-6

1998). Both reports emphasize that certain groups of drivers, including commercial drivers, are at increased risk for sleepiness-related crashes. In this regard, government agencies, transportation professionals, researchers, the motor carrier industry, safety advocates, and others have long been concerned with the extent and causes of sleepiness-related driving among long-distance truck drivers. Research on the causes and effects of sleepiness suggests that the schedules of long-distance truck drivers may place them at higher risk for driving while drowsy and for sleepiness-related crashes. Driving is the type of task known to be fatiguing; it is both a monotonous, repetitive task and one that requires sustained attention (Monk and Folkard, 1979; Williamson et al., 1996). Not only do most truck drivers have high levels of driving exposure, many also work long, irregular hours, at times that conflict with natural circadian rhythms; they also frequently drive alone, on long, monotonous, high-speed roadways. Many truck drivers may have limited opportunities to obtain sufficient sustained, restorative sleep and thus may accumulate a sizeable sleep debt. Many may also have difficulty maintaining an otherwise healthy lifestyle, including a nutritious diet and regular exercise.

The federal hours-of-service (HOS) regulations are a primary tool used by the US Federal Highway Administration (FHWA) to promote safe travel by interstate motor carriers. Title 49, Part 392.3, of the Code of Federal Regulations stipulates that no truck driver may operate a motor vehicle while the driver's ability or alertness is impaired, or likely to become impaired, through fatigue. Title 49, Part 395 stipulates that except under limited circumstances, interstate truck drivers may not drive more than 10 consecutive h or work more than 15 h before having 8 h off-duty; a driver may split the 8 h off-duty into two rest periods if the truck has a sleeper berth. In addition, total weekly work time is limited to 60 h in 7 consecutive days or to 70 h in 8 consecutive days, depending on whether the carrier operates on a 6-day or 7-day weekly schedule. Drivers may continue to perform non-driving work-related duties past the 60/70 h limit.

In initiating rule-making in 1996 to revise the HOS regulations, the Federal Highway Administration intends to replace the current regulatory approach with one that couples regulations with a performance-based system that assesses driver alertness and fitness for duty. As outlined in the *Federal Register*, November 5, 1996, a primary consideration in the regulatory process is the extant research on the scope, causes, and effects of drowsiness among commercial vehicle drivers; the crash risks associated with different levels of drowsiness and with various scheduling, work, and compensation practices; the effectiveness of current regulations in reducing drowsiness and mitigating its effects; and the estimated effects on highway safety of proposed alternative approaches.

1.1. Research pertaining to sleepiness-related driving among truck drivers

While research on truck driver fatigue or sleepiness extends back to the 1930s, much remains unknown about the extent, causes, and effects of sleepiness-related driving among commercial drivers. Case studies of crashes conducted by the National Transportation Safety Board (NTSB, 1990, 1995) are among the most frequently cited studies of the extent of sleepiness-related crashes among truck drivers. A 1995 NTSB study of single-vehicle large-truck crashes, in which the drivers survived, found that 58% of the crashes were fatigue-related and that 19 of the 107 drivers (17%) interviewed stated that they had fallen asleep while driving (NTSB, 1995). In a self-report study of truck drivers in an Australian state without hours-of-service regulations, 5% of drivers reported having a hazardous fatigue-related event, such as nodding off, on their current trip; 14% said they had nodded off at least occasionally while at the wheel over the previous 9 months (Arnold et al., 1997). Of those drivers who had a crash in the previous 9 months, 12% cited fatigue as a contributory factor.

Most studies have examined the extent and causes of sleepiness in drivers, rather than the link between sleepiness and crash risk or between causes of sleepiness and crash risk. Synthesizing these studies is difficult, given the variety of research designs, differing outcome and predictor measures, differing sampling frames and methods, and sometimes inconsistent findings. These studies suggest, however, that sleepiness-related driving among long-distance truck drivers is associated with variables that are related to drivers' schedules, particularly their patterns of working and resting, and drivers' individual sleep needs and patterns.

First, the number and pattern of hours worked and hours off-duty have been linked to sleepiness-related driving. Studies of the general driving population and shift workers have linked sleepiness-related driving with rotating shifts and night shifts (Mitler et al., 1988; Gold et al., 1992; Marcus and Loughlin, 1996; McCartt et al., 1996; Lauber and Kayten, 1998). Researchers, using operational data from a national motor carrier, reported that total driving time had a greater effect on crash risk among truck drivers than either time of day or driving experience (Lin et al., 1994). An experimental study by Mackie and Miller (1978) found that driving performance among truck drivers declined with an irregular schedule, more than 8 h of driving for regular schedules, and more than 5 h of driving for irregular schedules. In another experimental study, Harris et al. (1972) found that driving performance, as measured by number of crashes, declined after 4 h of driving. Williamson et al. (1996) found that fatigue increased over the duration of trips, regardless of the driving regime, although the pre-trip level of fatigue was a primary factor in fatigue experienced while on the road. In a 1992 survey of over-the-road tractor-trailer drivers, violators of the hours-of-service regulation were more likely to report that they had fallen asleep at the wheel (Braver et al., 1992). Hertz (1988) identified an elevated fatal crash risk when drivers split the required 8 h off-duty into two sessions in a sleeper berth. Truck drivers' schedules may necessitate sleeping during the daytime, and daytime sleep may not achieve the restorative quality of night-time sleep (Lavie, 1986).

A second variable, the time of day, has also been identified as predictive of sleepiness-related driving among truck drivers. Based on physiologic and performance data for 80 US and Canadian long-haul truck drivers on revenue-generating trips, the US/Canadian Driver Fatigue and Alertness Study found that the strongest and most consistent factor influencing driver fatigue and alertness was time of day, rather than time on task or cumulative number of trips (Wylie et al., 1996). It might be noted that drivers participating in this study followed driving schedules that, although demanding, were permissible within current US and Canadian HOS regulations; the study did not examine the effects of schedules that violate regulations. Mackie and Miller (1978) and Harris et al. (1972) also found an association between time of day and level of fatigue, while Hertz (1988) and Jovanis et al. (1991) found night-time driving resulted in a higher crash risk for truck drivers.

Substantial research has also demonstrated a link between sleepiness-related driving and the quantity and quality of sleep. In general, a person's tendency to fall asleep during normal waking hours is increased and psychomotor performance declines with fewer hours of sleep and successive days of restricted sleep (Wilkinson et al., 1966; Carskadon and Dement, 1981; Mitler et al., 1997). The 1995 NTSB study found that predictors of sleepiness-related single-vehicle large-truck crashes were the duration of a driver's last sleep period, the total sleep obtained during the 24 h preceding the crash, and fragmented sleep patterns. The study also suggested that night driving after relatively little sleep was a better predictor of fatigue-related crashes than night driving alone. In the US/Canadian Driver Fatigue and Alertness Study (Mitler et al., 1997), researchers concluded that drivers obtained less sleep on the road than is required for alertness on the job. Although drivers vary with regard to the portion of off-duty time devoted to sleep, longer off-duty periods have been associated with longer periods of sleep (Mitler et al., 1997).

A fourth variable linked to sleepiness-related driving is obstructive sleep apnea, characterized by severely disturbed breathing during sleep. Symptoms of this disorder include obesity, snoring, sleep interrupted by intermittent gasping for breath, and excessive daytime sleepiness. Research suggests that drivers with untreated sleep apnea, snoring, or sleep-disordered breathing are at increased risk for motor vehicle crashes (Findley et al., 1988; Aldrich, 1989; Findley et al., 1989; Stoohs et al., 1993; Young et al., 1997) and that truck drivers may be at increased risk for obstructive sleep apnea (Stoohs et al., 1993, 1994).

Finally, based on studies of the general driving population, the extent of daytime sleepiness has been related to sleepiness-related driving. Based on drivers' self-report, McCartt et al. (1996) found that the frequency of drowsy driving was related to the frequency of trouble staying awake during the day and the number of hours that could be driven before the onset of drowsiness. Also using self-report data, Maycock (1997) found an association between the probability of almost falling asleep at the wheel and the Epworth Sleepiness Scale score, a measure of general daytime sleepiness (Johns, 1991).

In sum, previous studies, using a variety of methods and measures, have identified a number of variables associated with fatigue-related driving and decrements in driving performance. However, few of these studies have used multivariate analyses to establish the relative contribution of various predictors of sleepiness-related driving. Especially given the high costs and practical difficulties of conducting in situ over-the-road studies, and the considerable limitations of crash data, research methods relying on drivers' self-reports are particularly useful to gather in-depth data on drivers' experiences with sleepiness-related driving under typical circumstances and on risk factors related to drivers' typical work and rest patterns. In the study reported here, data were collected through a survey of long-distance truck drivers to determine the prevalence of sleepiness-related driving among these drivers and to identify associated risk factors and their relative predictive importance. These data represent one of the most comprehensive data sets related to drivers' typical work and rest patterns and their symptoms of sleep disorders, patterns of sleepiness, and experiences with sleepiness-related driving.

Preliminary bivariate analyses of the survey data indicated that falling asleep at the wheel in the past year was associated with a number of variables related to job characteristics and drivers' work/rest schedules (McCartt et al., 1997, 1998). However, the large set of hypothesized predictors and the significant bivariate associations between many predictors suggested that a multivariate analytical approach would provide a deeper understanding of the key driver-related and work-related constructs predictive of sleepiness-related driving. Thus, this paper reports the results of a two-stage multivariate analysis to accomplish the following: (1) condense the large set of hypothesized driver-related and work-related predictors of falling asleep at the wheel into a smaller, more useful set of constructs; and (2) measure the relative importance of these general constructs in predicting sleepiness-related driving.

2. Methods

2.1. Survey method

In-depth interviews were conducted in Spring 1997 with a sample of long-distance truck drivers selected to be representative of long-distance truck drivers traveling New York's interstate roadways. A total of 593 drivers were interviewed. Interviews were conducted with 192 drivers (32.4%) at public full-service and limited-service rest areas, with 233 drivers (39.3%) at private full-service truck stops, and with 168 drivers (28.3%) at routine truck safety inspections conducted by state and federal enforcement personnel at limited service public rest areas. Drivers were asked to participate if they had been driving a tractor-trailer for at least 6 months, made at least occasional trips of 2 or more days, and drove a minimum of 50 000 miles a year for work. As an incentive to participate, drivers were offered a $5 voucher to purchase food or beverage, or a refreshment of comparable worth. No identifying information on driver or carriers was collected; drivers were assured that their responses were completely anonymous.

A random sampling strategy was employed at all sites. At the inspection sites, interviewers approached drivers after they had been excused from inspections, and drivers were interviewed at locations removed from the inspections. Although all trucks on a roadway are required to pass through an inspection site, only a small percentage of trucks undergo inspection. Interviews at inspection sites were conducted during daytime hours when inspections were being conducted; drivers at the other rest areas were interviewed from 15:00 to 22:00 h to ensure an adequate volume of traffic for efficient data collection. The overall participation rate was 74.9%; the rate ranged from 62.1% at the public full-service rest areas to 91.4% at the private truck stops. Declinations were primarily attributed by drivers to a lack of time; interviews were not conducted with a few drivers because of language difficulties. Analyses of important driver characteristics did not vary consistently by the three types of sites.

The interview instrument was drafted consultation with staff of the FHWA's Office of Motor Carriers, state agencies involved in New York's Motor Carrier Safety Assistance Program, and the New York State Motor Truck Association. Following two pretests of the instrument, modifications were made to some questions. The final instrument consisted of 64 items, and interviews generally required 15–20 min to complete. Teams of from two to five experienced interviewers were present at each site, depending on the anticipated volume of truck traffic.

2.2. Measures

The primary criterion measure was the driver's self-report of having fallen asleep at the wheel of a truck. Predictor measures included driver demographic characteristics, years driving a commercial vehicle, annual miles driven, job characteristics, usual work schedule, and sleep/rest and sleepiness patterns, particularly while on the road. Since federal hours-of-service regulations are designed to minimize driver fatigue, four survey items addressed violations of the federal hours-of-service regulations. Several survey items addressed symptoms of obstructive sleep apnea, including snoring during sleep, cessation of breathing during sleep, and body height and weight. Items used to construct the Epworth Sleepiness Scale (Johns, 1991) were used to assess the driver's general daytime sleepiness.

A total of 21 predictor measures were derived from the questions asked during the interviews. These measures, as well as the coding system employed for this study, are fully detailed in the Appendix A.

2.3. Statistical methods

The analysis was undertaken as follows: first, an investigation of the bivariate correlations between the hypothesized predictor and criterion measures was conducted. Second, factor analysis was used to reduce the large set of driver and work/rest predictors into a smaller, more interpretable set of independent factors. Finally, a multivariate logistic regression model (Menard, 1995) was developed to assess the relative contribution of each factor to the outcome measure, self-reported falling asleep at the wheel.

Among the various multivariate methods, factor analytic techniques were selected to identify the constructs underlying the large set of predictors. Factor analysis can reduce a large set of measures to a relatively small set of dimensions, or factors, with each factor being defined by a set of graduated, or weighted, relationships with these measures. The weight, or loading, of each measure on a given factor represents the strength and direction of the relationship of the factor with the measure. The loadings range from 0 to positive or negative 1; the higher the absolute value of the weight, the stronger the relationship.

There were several reasons for using factor analysis in this study. Factor analytic approaches are particularly useful when working with a large set of measures with varying degrees and patterns of interrelationships; when a parsimonious solution is desired; and when the purpose is to generate hypotheses about the nature of interrelationships among predictors and about the relationship of these predictors to criterion measures (Gorsuch, 1974). These conditions all pertain to the current study. With factor analysis, by obtaining a smaller set of dimensions that accounts for most reliable variance in the original data set, the maximum amount of information is retained, while the number of measures is minimized for further research. An additional advantage of factor analysis is that many types of coding can be accommodated, so that continuous, ordinal, and dichotomous measures can be included.

Principal component factor analysis was employed to extract the principal factors in the present study. Initially, eight principal components with eigenvalues greater than 1.0 were examined, but two were determined to be trivial; final extraction was truncated at six principal components, consistent with Cattell's scree test. These six factors were rotated using the varimax method, a common approach that has been shown to approximate simple structure with orthogonal, or uncorrelated, factors. The construction of orthogonal factors (and factor scores) was of value in the subsequent logistic regression analysis because it facilitated the interpretation of results by eliminating multicollinearity among the predictor measures.

3. Results

3.1. Respondent characteristics

Almost all drivers interviewed were men (98.8%). Less than one-quarter of drivers (22.3%) were licensed by New York; 61.2% were licensed by another US state, and 16.5% were licensed by a Canadian province. Drivers most often worked for a private fleet (37.7%), a company that owns trucks and employs drivers, or for a for-hire fleet (35.3%), a company that leases trucks with drivers to other companies. Of the remaining drivers who described themselves as owner-operators, 22.3% worked under a lease of more than 30 days and 4.7% were independent operators. Most respondents reported that they drove more than 100 000 miles/year for work (61.3%), took trips that were usually more than 3 days in duration (79.6%), and had a work/rest schedule that changed from day to day (70.5%). Other important respondent characteristics such as age and driving experience are detailed fully in the Appendix A.

Many drivers reported that they had experienced incidents of falling asleep at the wheel of their truck, 'even for just a moment, with or without an accident.' Nearly half (47.1%) had ever fallen asleep at the wheel of their truck, and 25.4% had fallen asleep at the wheel on at least one occasion in the past year.

3.2. Bivariate correlations

Table 1 provides the bivariate correlations between the predictor and criterion measures. Listwise deletion of cases with missing information resulted in 553 respondents who answered every question used in subsequent analyses. The matrix in Table 1 contains mostly low correlations between predictors; only 13 correlations were 0.30 or larger, and only five were larger than 0.50. Correlated measures are likely to load on the same factor. For example, the relatively high correlations between (2) drive >10 h, (3) drive longer than logged, (4) <8 h off-duty, (5) unrealistic delivery schedule, and (6) hours driven/week suggested that these measures might define a single factor.

Shown in the first column of Table 1 are the correlations between all the predictor measures and the criterion (1) ever fallen asleep at the wheel of a truck. The larger correlations with the criterion were (12) nap on road, (2) drive >10 h, (3) drive longer than logged, and (10) doze resting in afternoon ($r=0.31$, 0.30, 0.26, and 0.25, respectively).

3.3. Factor analysis

Table 2 provides the results from the principal components factor analysis with varimax rotation. Six distinct and interpretable factors were identified. The factor solution was truncated at the sixth factor with an eigenvalue of 1.19. The six-factor solution extracted 52.4% of the total variance in the 21 measures included in the factor analysis. Each predictor loaded moderately or highly (above 0.40) on one and only one factor; each factor was defined by at least two predictors with moderate to high loadings. Factor eigenvalues following rotation ranged from 3.03 (27.5% of the variance extracted) to 1.46 (13.2% of the variance extracted).

The first factor — arduous work schedule — captured a driver's tendency to have a schedule involving long work hours and limited rest and, thus to violate the hours-of-service regulations. Five measures loaded heavily on this factor: drive >10 h (0.87); drive longer than logged (0.86); <8 h off-duty (0.76); unrealistic delivery schedule (0.64); and hours driven/week (0.60). None of the remaining measures produced a factor loading larger than ± 0.25.

High scores on the second factor — poor sleep on road — indicated drivers who reported that sleep of poor quality and short duration was typically received on road trips. The measures that loaded more heavily on this factor were split off-duty rest (0.83) and hours of longest sleep (-0.82), the latter loading negatively because a fewer (not greater) number of hours was connected to poor sleep on road. A direct question concerning sleep quality on road loaded moderately (0.45), while the loadings for all other measures were substantially lower.

Table 1
Bivariate correlation matrix ($n = 553$)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1. Fell asleep at wheel																					
2. Drive >10 h	0.30*																				
3. Drive longer than logged	0.26*	0.73*																			
4. <8 h off-duty	0.23*	0.64*	0.58*																		
5. Unrealistic delivery schedule	0.22*	0.53*	0.48*	0.42*																	
6. Hours driven/week	0.11*	0.44*	0.45*	0.25*	0.22*																
7. Split off-duty rest	0.10	0.04	0.00	0.21*	0.12*	0.03															
8. Hours of longest sleep	−0.17*	−0.22*	−0.24*	−0.32*	−0.20*	−0.13*	−0.60*														
9. Poor sleep on road	0.01	0.08	0.06	0.15*	0.18*	−0.02	0.16*	−0.24*													
10. Doze resting in afternoon	0.25*	0.16*	0.11*	0.05	0.10	0.05	−0.04	0.00	−0.03												
11. Doze as passenger	0.22*	0.17*	0.14*	0.04	0.18*	0.03	−0.01	−0.02	−0.13*	0.35*											
12. Nap on road	0.31*	0.25*	0.23*	0.17*	0.19*	0.15*	0.12*	−0.11*	−0.02	0.31*	0.21*										
13. Usually snore	0.08	0.04	0.01	0.01	0.01	0.00	0.00	0.01	0.04	−0.04	−0.06	0.06									
14. Body weight	0.13*	0.08	0.10	0.08	0.03	0.11*	0.06	−0.05	0.03	−0.02	0.00	0.06	0.24*								
15. Breathing stops in sleep	0.14*	0.10	0.07	0.03	0.06	0.03	0.00	−0.03	0.08	0.00	0.01	−0.01	0.17*	0.15*							
16. Poor sleep at home	−0.06	0.04	0.05	0.05	0.07	0.04	−0.02	0.02	0.18*	−0.07	−0.08	−0.02	0.12*	0.09	0.08						
17. Sleep days on road	0.01	−0.03	−0.02	−0.01	−0.06	−0.04	0.03	−0.01	−0.04	0.05	−0.05	0.07	0.02	−0.03	−0.06	0.10					
18. Drowsy midnight to dawn	0.17*	0.22*	0.21*	0.13*	0.12*	0.12*	0.04	−0.19*	0.05	0.07	0.12*	0.10	−0.05	0.04	0.01	−0.11*	−0.10				
19. Drive evenings	0.13*	0.13*	0.12*	0.04	0.15*	0.09	0.00	−0.08	0.05	0.06	0.04	0.04	0.06	0.05	0.04	−0.08	−0.16*	0.11*			
20. Multiple periods of drowsiness	0.22*	0.16*	0.18*	0.15*	0.14*	0.10	0.09	−0.20*	0.11*	0.06	0.09	0.16*	−0.07	0.04	−0.01	−0.00	−0.06	0.40*	0.04		
21. Age	0.14*	−0.08	−0.04	−0.10	−0.10	0.04	−0.05	−0.08	−0.02	0.07	0.02	0.09	0.04	0.04	0.04	−0.06	−0.08	−0.06	0.09	0.03	
22. Years driving	0.18*	0.11*	0.06	0.09	0.05	0.00	0.00	−0.07	−0.03	0.02	−0.01	0.03	0.04	0.19*	0.10	0.07	0.01	−0.04	−0.01	0.05	0.39*

* $P < 0.01$.

Three measures loaded heavily on the third factor — daytime sleepiness. Doze resting in afternoon (0.76), doze as passenger (0.69), and nap on road (0.64) all appeared to indicate a general tendency to be more or less drowsy during daylight hours; high factor scores indicated greater sleepiness. Loadings for all other measures were no larger than ± 0.20.

The fourth factor — symptoms of sleep disorder — was derived from a variety of indicators of sleeping problems. The three measures with higher loadings included usually snore (0.70), body weight[2] (0.59), and breathing stops in sleep (0.57). A direct question concerning sleep quality at home loaded moderately (0.44), while the loadings for all other measures were substantially lower.

Night-time drowsy driving was the fifth factor. Although most respondents might be expected to be at least somewhat sleepy at night, this factor helps to distinguish those drivers who reported a greater propensity to be drowsy while driving at night. The measure with the highest loading on this factor was inversely related to night-time drowsy driving: sleep days on the road (-0.64). The negative loading indicated that drivers who did not report that they usually took their longest period of sleep during the day would generate higher factor scores for night-time drowsy driving. Also loading heavily on this factor was a measure of the likelihood of driving while drowsy midnight to dawn, rather than other driving times (0.61); thus, drivers with high factor scores were those drivers who were likely to be drowsy when driving at the time of night when they might otherwise be asleep. Moderate loadings were associated with driving evenings (0.51) and reporting multiple periods of drowsiness throughout the day or night (0.47).

The sixth factor — older, long-time drivers — was the only factor defined by just two measures, but both loadings were quite high: age (0.81) and years driving (0.78). High scores on this factor were received by older, more experienced drivers and low scores by younger, less experienced drivers.

A regression approach was used to provide an exact computation of factor scores ($n = 553$). Scores for the six factors were generated in standard form (i.e. means of 0 and standard deviations of 1); because of the use of varimax rotation, the six factors were completely uncorrelated. These factor scores then were used as independent predictors of having ever fallen asleep at the wheel in a subsequent logistic regression analysis.

[2] Although an index of body mass was computed as an alternative to body weight as a predictor measure, body weight proved to be the better measure for defining this factor. Body weight and body mass were very highly correlated ($r = 0.90$).

Table 2
Results of factor analysis ($n = 553$)

Measure	Factors					
	Arduous work schedule	Poor sleep on road	Daytime sleepiness	Symptoms of sleep disorder	Night-time drowsy driving	Older, long-time driver
Drive >10 h	0.87	0.03	0.16	0.07	0.09	−0.01
Drive longer than logged	0.86	0.02	0.11	0.04	0.10	0.00
< 8 h off-duty	0.76	0.27	0.00	0.01	−0.03	−0.01
Unrealistic delivery schedule	0.64	0.14	0.13	0.09	0.08	−0.12
Hours driven/week	0.60	−0.07	0.00	−0.01	0.09	0.10
Split off-duty rest	0.00	0.83	0.12	−0.04	−0.08	0.02
Hours of longest sleep	−0.21	−0.82	−0.02	0.04	−0.09	−0.13
Poor sleep on road	0.07	0.45	−0.20	0.28	0.08	−0.18
Doze resting in afternoon	0.05	−0.06	0.76	−0.01	−0.01	0.03
Doze as passenger	0.07	−0.10	0.69	−0.05	0.14	−0.04
Nap on road	0.20	0.16	0.64	0.07	−0.05	0.08
Usually snore	−0.04	−0.02	0.04	0.70	−0.05	−0.01
Body weight	0.07	0.05	0.03	0.59	0.08	0.19
Breathing stops in sleep	0.03	−0.02	0.00	0.57	0.13	0.04
Poor sleep at home	0.12	0.05	−0.13	0.44	−0.34	−0.12
Sleep days on road	−0.01	0.12	0.19	−0.03	−0.64	−0.07
Drowsy midnight to dawn	0.14	0.20	0.18	−0.05	0.61	−0.17
Drive evenings	0.11	−0.05	0.00	0.12	0.51	0.08
Multiple periods of drowsiness	0.11	0.31	0.20	−0.04	0.47	−0.03
Age	−0.11	0.00	0.07	0.02	0.12	0.81
Years driving	0.12	0.03	−0.01	0.13	−0.07	0.78
Eigenvalues (after rotation)	3.03	1.86	1.69	1.50	1.49	1.46
Percent of variance extracted	27.5	16.9	15.3	13.6	13.5	13.2

3.4. Logistic regression analysis

A logistic regression model was calculated to identify which of the six factors were related to the probability of a driver ever having fallen asleep at the wheel of a truck, the dichotomous criterion measure. The resulting model is shown in Table 3. All six factors were found to be significant predictors of a driver ever having fallen asleep at the wheel ($P < 0.01$). Thus, risk factors included: daytime sleepiness; arduous work schedule; older, long-time driver; night-time drowsy driving; poor sleep on road; and symptoms of sleep disorder[3]. Several statistical indicators of the model's goodness of fit also are reported in Table 3. The model chi-square was significant ($G_M = 156.52$, $P < 0.01$), and both the proportional reduction in the absolute value of the log-likelihood measure (R^2_L) and the coefficient of determination between the observed and predicted criterion measures (R^2) were sizeable (0.20 and 0.21, respectively).

Daytime sleepiness and arduous work schedule produced the largest regression coefficients (0.90 and 0.59, respectively). The corresponding odds ratio for daytime sleepiness indicated that the regression coefficient for daytime sleepiness implies that the odds of reported falling asleep at the wheel (i.e. the ratio of the probability that this event occurs to the probability that it does not occur) increases approximately two-and-a-half times for every one-unit increase in the daytime sleepiness factor. In short, the odds of reported falling asleep at the wheel for a driver with a daytime sleepiness factor score of 1.00 are nearly 2.5 times greater than the odds for a driver with a daytime sleepiness factor score of 0.00. If the odds that a driver reported ever having

[3] An additional logistic regression model was calculated with the criterion having fallen asleep at the wheel of a truck *in the past year*. The factors daytime sleepiness and work long hours remained the best predictors, and night-time drowsy driving, poor sleep on road, and symptoms of sleep disorder also were significant ($P < 0.01$). However, the older, long-time driver factor was not significant in this alternate model. Its contribution to the logistic regression model reported in Table 3 may reflect the fact that older drivers who reported driving a truck more years behind the wheel of a truck have accumulated more occasions during which they might fall asleep.

Table 3
Results of logistic regression analysis with dependent variable ever fallen asleep at the wheel of a truck ($n = 553$)[a]

	Model with six factors as predictors			Model with six factors and alerted by rumble strips as predictors		
	Regression coefficient	Wald chi-square	Odds ratio	Regression coefficient	Wald chi-square	Odds ratio
Daytime sleepiness	0.90 (0.11)	63.77*	2.46	0.83 (0.12)	52.22*	2.30
Arduous work schedule	0.59 (0.10)	33.57*	1.80	0.55 (0.10)	28.98*	1.74
Older, long-time driver	0.43 (0.10)	17.43*	1.53	0.42 (0.10)	16.86*	1.53
Night-time drowsy driving	0.37 (0.10)	13.30*	1.44	0.34 (0.10)	11.15*	1.40
Poor sleep on road	0.36 (0.10)	12.26*	1.43	0.36 (0.10)	12.35*	1.44
Symptoms of sleep disorder	0.33 (0.10)	10.56*	1.39	0.36 (0.10)	11.97*	1.43
Alerted by rumble strips	–	–	–	−0.62 (.20)	9.14*	0.54
Constant	−0.21 (0.10)	4.59	–	0.68 (0.31)	4.84	–
Model Chi−Square (G_M)	156.52*			167.06*		
Degrees of Freedom	6			7		
R^2_L	0.20			0.22		
R^2	0.21			0.25		

[a] Standard errors are shown in parentheses.
* $P<0.01$.

fallen asleep at the wheel are 1.0 (i.e. about even probabilities that the event occurs or does not occur), then increasing these odds by two-and-a-half times implies a probability of 0.71 that the event does occur and a probability of 0.29 that the event does not occur.

Similarly, the odds that a driver with an arduous work schedule factor score of 1.00 reported falling asleep at the wheel are 1.8 times greater than a driver with an arduous work schedule factor score of 0.00. The least effect on odds was produced by symptoms of sleep disorder (one-unit change yields nearly 1.4 times greater odds). In interpreting these results, it may be useful to recall that the factor scores were generated in standard form; thus, the mean score for each factor was 0 and about one-third of the drivers would have scores between 0.00 and 1.00.

A second logistic regression model, also shown in Table 3, illustrated the manner in which other measures can be tested for their additional predictive significance. Here respondents answered whether 'driving over rumble strips ever alerted you that you were driving off the road due to drowsiness'; 55.5% replied 'yes'. The regression coefficient for alerted by rumble strips proved to be significant (-0.62; $P<0.01$); because the regression coefficient was negative, the probability of falling asleep at the wheel appears to be decreased by driving over rumble strips. The corresponding odds ratio for this regression coefficient indicated that the odds that a driver who answered 'yes' (i.e. was alerted by rumble strips) reported falling asleep at the wheel were almost half the odds that a driver who answered 'no' reported falling asleep. All three indicators of the first model's goodness of fit were improved by the addition of Alerted by Rumble Strips as a predictor in the second model.

An alternative view of the predictive efficiency of the logistic regression model was gained through the construction of a classification table of correct and incorrect predictions. For example, the classification of predictions derived from the second model is shown in Table 4. For three-fourths of the respondents, the model's prediction of whether a driver reported ever falling asleep at the wheel corresponded to whether a driver actually reported such an event. The model had a high level of sensitivity (71.9%): only 72 of 256 drivers who reported ever falling asleep (28.1%) were predicted incorrectly by the second model. The model also had a high level of specificity (77.8%): only 66 of 297 drivers who reported never falling asleep (22.2%) were predicted incorrectly. The correlation between predicted and observed classifications was 0.50.

4. Discussion

While prior studies of fatigue and sleepiness-related driving among truck drivers have largely focused on specific sleepiness-related driving episodes and the variables linked with those episodes, this study probed drivers with respect to self-reported prior incidents of falling asleep at the wheel and their usual 'real-world' work, sleep, and rest patterns. The study departs from other studies of sleepiness-related driving in terms of the wide range and large number of hypothesized predictors examined. This reflects the complexity of causes of sleepiness-related driving, a complexity that is impossible to replicate in experimental studies or to extract from police reports of crashes.

The study includes many of the predictors of sleepiness-related driving identified in earlier research, and it extends this research by examining the dimensions, or constructs, underlying these predictors and the relative predictive importance of these dimensions. The use of factor analysis to reduce the large set of predictors to a smaller set of meaningful latent, independent constructs not only preserves the richness of the variation in the original set of predictors, but also facilitates the use of multivariate modeling to establish the relative contribution of the constructs in explaining sleepiness-related driving. These constructs can be further refined and tested in subsequent research using a variety of approaches.

The study was undertaken for two primary reasons. First, it was viewed as an important step in developing a more comprehensive theory of the theoretical constructs predictive of sleepiness-related driving. Second, by focusing on the complex variables affecting drivers on a daily basis, the study produced results that can directly inform efforts to develop more effective strategies to manage fatigue among long-distance truck drivers.

Although the use of driver self-reported data provides a feasible and useful way to gather information on the typical daily schedules of drivers, the data should be regarded with the due caution given any self-reported data. Thus, although the survey instrument, sampling method, and protocol sought to minimize bias, the results may understate the prevalence of sleepiness-related driving and the frequency with which hours-of-service regulations are violated. In the present study, almost one-half of long-distance truck drivers (47.1%) traveling New York's roadways reported that they have fallen asleep at the wheel of their truck; furthermore, 25.4% reported falling asleep at the wheel on at least one occasion during the previous year. These estimates of the prevalence of fall-asleep incidents among truck drivers were nearly double the estimates among the general driving population in New York State (McCartt et al., 1996), and are cause for concern by government, industry, long-distance truck drivers, and other highway users.

The study successfully identified a set of latent, independent constructs underlying the large set of hypothesized predictors; these six constructs were meaningful and were closely related to predictors identified in prior studies. More importantly, these six constructs were predictive of the primary criterion measure, having ever fallen asleep at the wheel of a truck. Drivers who had fallen asleep at the wheel had higher scores on the arduous work schedule factor; these were drivers who typically drove longer than the 10 consecutive h allowed by regulation, took fewer than the 8 h off-duty required by regulation, falsified their log books, drove more hours in a typical 7-day week, and more frequently had schedules that precluded making on-time delivery without speeding or violating the hours-of-service regulations. Independent of the rigor of the work schedule, a second factor, poor sleep on road, captured a split off-duty rest period, fewer hours in the longest sleep period, and self-reported poor sleep while on the road. As would be expected, drivers reporting poor sleep on road were more likely to have fallen asleep at the wheel. The tendencies toward daytime sleepiness and toward night-time drowsy driving were also predictive of falling asleep at the wheel; the construct of night-time drowsy driving captured not only a driver's disposition to be sleepy while driving at night, but also a sleeping schedule on the road that did not involve taking the main sleep during the daytime. A driver's report of specific symptoms of obstructive sleep apnea (higher body weight, snoring, breathing stopping during sleep) and self-reported poor sleep at home comprised the factor, symptoms of sleep disorder, and were predictive of falling asleep. Finally, an older, long-time driver factor was predictive of falling asleep at the wheel; given the criterion of ever falling asleep at the wheel of a truck, this factor captured the degree of opportunity for falling asleep at the wheel by increasing the level of driving exposure.

Of these six factors, a tendency toward daytime sleepiness was most highly predictive of falling asleep at the wheel, followed by an arduous work schedule and older, long-time driver. The association between arduous work schedule and falling asleep at the wheel is especially troublesome, given that approximately two-thirds of the drivers in this study reported that they violated each of three hours-of-service regulations on at least rare occasions, and one in five drivers reported that they often or always do so. The other three factors — a tendency toward night-time drowsy driving, poor sleep on road, and symptoms of sleep disorder — were less highly predictive but still significantly associated with sleepiness-related driving. Drivers who had been alerted by driving over a roadside rumble strip were also significantly less likely to have fallen asleep.

It is useful to distinguish between those factors that would cause sleepiness-related driving and those factors

Table 4
Classification table for six-factor model including alerted by rumble strips ($n = 553$)

	As reported by drivers		
	Fallen asleep	Never fallen asleep	
As predicted by model			
Fallen asleep	184 (correct)	66 (incorrect)	
Never fallen asleep	72 (incorrect)	231 (correct)	
Total	256	297	553
Percent correct	71.9	77.8	75.0

that may be correlated with, but not causally related to, sleepiness-related driving. The former factors include arduous work schedule, poor sleep on road, and symptoms of sleep disorder, while the latter factors include night-time drowsy driving and daytime sleepiness. As a measure of driving exposure, the factor older, long-time driver is also likely to be a correlate of sleepiness-related driving rather than a cause per se, since older, more experienced drivers have had more occasions than younger drivers to be at risk.

These findings relate to discussions about the optimal approach to managing fatigue among truck drivers and proposed revisions to the hours-of-service regulations. In particular, attention has focused on approaches that do not rely exclusively on prescriptive hours-of-service rules. One proposed approach involves regulations that focus on carrier fatigue management practices and related safety outcomes (Hartley, 1996; Mahan, 1997; Knipling, 1998). Under a fatigue management program being pilot-tested in Queensland, Australia, participating carriers incorporate such practices as enlightened scheduling, education of drivers and managers about sleep hygiene, and health and fitness screening (Mahan, 1997). Hartley (1996) suggests that the driver has the ultimate responsibility for managing his/her fatigue, the carrier has the responsibility for providing an environment that allows the driver to fulfill this responsibility, and the regulatory agencies are responsible for ensuring that carriers and drivers fulfill their respective responsibilities.

Although the research reported here does not suggest specific countermeasures, it indicated that the likelihood of falling asleep at the wheel is substantially increased by work schedules that result in drivers logging long hours behind the wheel and taking limited off-duty time. The research demonstrated the importance of obtaining adequate sleep while on the road. Drivers who drove in the evening and were particularly prone to night-time drowsiness, but who did not take their longest sleep during the day, were also more prone to sleepiness-related driving. The findings suggested that sleepiness-related driving may be reduced by measures that identify drivers who have symptoms of obstructive sleep apnea or have a general tendency toward daytime sleepiness. Finally, the study provided evidence of the efficacy of roadside rumble strips in preventing fall-asleep driving incidents.

Acknowledgements

This study was funded, in part, by the New York State Department of Transportation with research funds from the Motor Carrier Safety Assistance Program, Office of Motor Carriers, Federal Highway Administration.

Appendix A. Description of predictor measures and coding scheme

	Percent
Drive >10 h: drive longer than 10 consecutive h allowed by hours-of-service regulations	
(5) Always	4.2
(4) Often	15.3
(3) Sometimes	24.5
(2) Rarely	21.9
(1) Never	34.1
Drive longer than logged: drive longer than record in log book	
(5) Always	5.2
(4) Often	16.2
(3) Sometimes	21.6
(2) Rarely	20.3
(1) Never	36.7
<8 h off-duty: take fewer than 8 h off-duty, including split periods	
(5) Always	4.2
(4) Often	14.7
(3) Sometimes	22.5
(2) Rarely	25.3
(1) Never	33.3
Unrealistic delivery schedule: schedule precludes on-time delivery without speeding or violating hours-of-service regulations	
(5) Always	2.5
(4) Often	12.8
(3) Sometimes	20.7
(2) Rarely	28.0
(1) Never	35.9
Hours driven/week[a]: hours spend driving in typical 7-day week	
Under 40 h	4.7
40–49 h	11.2
50–59 h	28.3
60–69 h	33.9
70–79 h	17.3
80 h or more	4.7
Split off-duty rest: usually split 8h off-duty into two periods	
(1) Yes	21.2
(0) No	78.8
Hours of longest sleep: hours of longest sleep period on road	
(8) 10 h or more	3.1
(7) 9 h	7.6
(6) 8 h	19.2
(5) 7 h	25.3

(4) 6 h	21.0
(3) 5 h	10.3
(2) 4 h	11.2
(1) 3 h or less	2.4

Poor sleep on road: quality of sleep while on road

(4) Poor	5.3
(3) Fair	22.0
(2) Good	53.2
(1) Excellent	19.6

Doze resting in afternoon: chance of dozing when lying down to rest in afternoon when circumstances permit

(3) High	46.0
(2) Moderate	28.4
(1) Slight	17.5
(0) Never	8.0

Doze as passenger: chance of dozing as passenger in vehicle for hour without a break

(3) High	18.1
(2) Moderate	21.0
(1) Slight	22.0
(0) Never	39.0

Nap on road: take naps in addition to main sleep while on road

(5) Always	3.4
(4) Often	15.7
(3) Sometimes	43.1
(2) Rarely	24.5
(1) Never	13.3

Usually snore: usually snore during sleep

(1) Yes	54.1
(0) No; don't know	45.9

Body weight[b]:driver body weight

Under 150 pounds	5.2
150–179 pounds	20.9
180–209 pounds	32.4
210–239 pounds	24.4
240–269 pounds	9.3
270 pounds or more	7.8

Breathing stops in sleep: ever told breathing stops during sleep

(1) Yes	11.3
(0) No; Don't Know	88.7

Poor sleep at home: quality of sleep while at home

(4) Poor	2.9
(3) Fair	12.7
(2) Good	42.4
(1) Excellent	41.9

Sleep days on road: longest period of sleep usually during daytime

(1) Yes	5.9
(0) No; don't know	94.1

Drowsy midnight to dawn: midnight to dawn is most likely time to be drowsy when driving, even if don't usually drive midnight to dawn

(1) Yes	52.5
(0) No; don't know	47.5

Drive evenings: usual driving hours include evenings

(1) Yes	92.1
(0) No	7.9

Multiple periods of drowsiness: when driving, number of times of day most likely to be drowsy [early morning (06:00–10:00 h), afternoon (14:00–16:00 h), late evening (22:00 h-midnight), midnight to dawn]

(2) 2 or more times	11.1
(1) 1 of these times	74.6
(0) None of these times	14.3

Age[c]: driver age

20–29 years	10.0
30–39 years	31.5
40–49 years	32.7
50–59 years	21.6
60 years or more	4.2

Years driving: number of years drive commercial vehicle

(7) >10 years	58.7
(6) 5–10 years	19.0
(5) 4 years	4.9
(4) 3 years	4.0
(3) 2 years	4.9
(2) 1 year	3.5
(1) 6–11 months	5.0

[a] Coded as a continuous measure from 15 to 98 h (mean = 58.4; standard deviation = 11.9)

[b] Coded as a continuous measure from 125 to 449 pounds (mean = 204.6; standard deviation = 42.1)

[c] Coded as a continuous measure from 20 to 71 years of age (mean = 42.4; standard deviation = 9.9)

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