Sleep Apnea Crash Risk Study

U.S. Department of Transportation
Federal Motor Carrier Safety Administration

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FOREWORD

This study assesses the risks of commercial vehicle crashes due to the presence of sleep apnea among truck drivers. The results of this study will provide the commercial motor vehicle industry, law enforcement, and the general public a better understanding of the relationship between sleep disorders and truck crashes. It will also enable corrective actions to be developed that will, in keeping with the Federal Motor Carrier Safety Administration (FMCSA) strategic safety goal: reduce the number of commercial vehicle-related fatalities and injuries.

The primary objectives of the study were:

- To obtain additional and more meaningful crash data by linking the University of Pennsylvania sleep apnea database to the FMCSA's Motor Carrier Management Information System crash database.
- To understand the impact of sleep apnea and driver impairment on crash involvement, the number of crashes, and the severity of crashes.
- To gain insight into how crash rates are impacted before and after drivers are diagnosed with sleep apnea.

The results of this study contradict those found in several previous studies; other studies found a strong positive relationship between sleep apnea and motor vehicle crashes. A possible reason for this could be attributed to limitations of the data used in our study, and these are discussed in detail in this report. This report is considered final, in that it fully documents the results of the aforementioned study.

NOTICE

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16. Abstract:
Sleep apnea is a condition in which a narrowing or closure of the upper airway during sleep causes repeated sleep disturbances, and possible complete awakenings, leading to poor sleep quality and excessive daytime sleepiness. The primary objectives of this study were to (1) obtain additional and more meaningful crash data by linking a sleep apnea database to the FMCSA's Motor Carrier Management Information System (MCMIS) crash database; (2) understand the impact of sleep apnea and driver impairment on crash involvement, the number of crashes, and the severity of crashes; and (3) gain insight into how crash rates are impacted before and after drivers are diagnosed with sleep apnea. The overall goal of the analysis is to determine the crash risks for CMV drivers with sleep apnea compared to drivers who do not have sleep apnea.

The results of this study contradict those found in several previous studies, in that other studies found a strong positive relationship between sleep apnea and motor vehicle crashes. A possible reason for this contradiction could be attributed to limitations of the data used in this study, and these are discussed in detail in this report. This study, using an analysis using logistic regression, found no association between sleep apnea, as measured by the apnea/hypopnea index, and commercial motor vehicle crashes. Patients with sleep apnea had no greater probability of having a crash than patients without sleep apnea, either before or after their diagnosis. Drivers with sleep apnea were also not found to be at an increased risk for multiple crashes, nor were crash rates impacted by the prevalence of apnea. No link between the severity of sleep apnea and traffic crashes was established in these analyses.

17. Key Words: **apnea, commercial motor vehicle, crash, crash risk, sleep, sleep disorder, truck, truck driver**		18. Distribution Statement **No restrictions**	
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SI* (MODERN METRIC) CONVERSION FACTORS

Table of APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	Inches	25.4	millimeters	mm
ft	Feet	0.305	meters	m
Yd	Yards	0.914	meters	m
Mi	Miles	1.61	kilometers	km
		AREA		
in²	square inches	645.2	square millimeters	mm²
ft²	square feet	0.093	square meters	m²
yd²	square yards	0.836	square meters	m²
Ac	Acres	0.405	hectares	ha
mi²	square miles	2.59	square kilometers	km²
		VOLUME	Note: Volumes greater than 1000 L shall be shown in m³	
fl oz	fluid ounces	29.57	milliliters	mL
Gal	Gallons	3.785	liters	L
ft³	cubic feet	0.028	cubic meters	m³
yd³	cubic yards	0.765	cubic meters	m³
		MASS		
Oz	Ounces	28.35	grams	g
Lb	Pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
		TEMPERATURE	Temperature is in exact degrees	
°F	Fahrenheit	5 × (F-32) ÷ 9 or (F-32) ÷ 1.8	Celsius	°C
		ILLUMINATION		
Fc	foot-candles	10.76	lux	lx
Fl	foot-Lamberts	3.426	candela/m²	cd/m²
		Force and Pressure or Stress		
Lbf	Poundforce	4.45	newtons	N
lbf/in²	poundforce per square inch	6.89	kilopascals	kPa

Table of APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
Mm	Millimeters	0.039	inches	in
M	Meters	3.28	feet	ft
M	Meters	1.09	yards	yd
Km	Kilometers	0.621	miles	mi
		AREA		
mm²	square millimeters	0.0016	square inches	in²
m²	square meters	10.764	square feet	ft²
m²	square meters	1.195	square yards	yd²
Ha	Hectares	2.47	acres	ac
km²	square kilometers	0.386	square miles	mi²
		VOLUME		
mL	Milliliters	0.034	fluid ounces	fl oz
L	Liters	0.264	gallons	gal
m³	cubic meters	35.314	cubic feet	ft³
m³	cubic meters	1.307	cubic yards	yd³
		MASS		
G	Grams	0.035	ounces	oz
Kg	Kilograms	2.202	pounds	lb
Mg (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2000 lb)	T
		TEMPERATURE	Temperature is in exact degrees	
°C	Celsius	1.8C + 32	Fahrenheit	°F
		ILLUMINATION		
Lx	Lux	0.0929	foot-candles	fc
cd/m²	candela/m²	0.2919	foot-Lamberts	fl
		Force & Pressure or Stress		
N	Newtons	0.225	poundforce	lbf
kPa	Kilopascals	0.145	poundforce per square inch	lbf/in²

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003, Section 508-accessible version September 2009)

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LIST OF ABBREVIATIONS

Acronym	Definition
AHI	apnea/hypopnea index
ANOVA	Analysis of Variance
BMI	body mass index
BSC	Biomedical Statistical Consulting
CDL	commercial driver's license
CI	confidence interval
CMV	commercial motor vehicle
FMCSA	Federal Motor Carrier Safety Administration
GES	General Estimates System
GLM	Generalized Linear Model
MAP	multivariable apnea prediction
MCMIS	Motor Carrier Management Information System
NGA	National Governors Association
OR	odds ratio
RDI	respiratory disturbance index
RR	relative risk
SAFETYNET	A microcomputer system used by States participating in MCSAP and by FMCSA offices. Information on safety inspections conducted by States and crashes involving motor carriers is shared with the FMCSA through this computer system.
SDB	sleep disordered breathing
UPenn	University of Pennsylvania

EXECUTIVE SUMMARY

The primary mission of the Federal Motor Carrier Safety Administration (FMCSA) is to promote the safety of commercial motor vehicle transportation and to prevent commercial vehicle-related fatalities and injuries. In support of FMCSA's mission, the Volpe National Transportation Systems Center, in collaboration with the University of Pennsylvania and Biomedical Statistical Consulting (UPenn/BSC), completed a study to assess the risks of commercial vehicle crashes due to the presence of sleep apnea among truck drivers. The results of this study will help to provide a better understanding of the relationship between sleep disorders and truck crashes and will enable corrective actions to be developed that will, in keeping with FMCSA's strategic safety goal, reduce the number of commercial vehicle-related fatalities and injuries.

The primary objectives of the study were:

- To obtain additional and more meaningful crash data by linking the UPenn sleep apnea database to the FMCSA's Motor Carrier Management Information System (MCMIS) crash database.
- To understand the impact of sleep apnea and driver impairment on crash involvement, the number of crashes, and the severity of crashes.
- To gain insight into how crash rates are impacted before and after drivers are diagnosed with sleep apnea.

From 1996 to 1998, the University of Pennsylvania Center for Sleep and Respiratory Neurobiology collected data for a study on the prevalence and consequences of obstructive sleep apnea among commercial vehicle drivers [1]. UPenn/BSC sent a multivariable apnea prediction questionnaire to a random sample of 4,826 holders of commercial driver's licenses residing in Pennsylvania. From the 1,391 responses that were returned, 406 drivers were selected to participate in the study. The overall findings from this study revealed that 28 (6.9 percent) of the 406 participants were diagnosed with severe sleep apnea, 32 (7.9 percent) had moderate sleep apnea, and 86 (21.2 percent) had mild sleep apnea. Crash histories for these 406 commercial drivers were obtained from State motor vehicle records for a period of 7 years prior to diagnosis in the UPenn sleep study and from the MCMIS crash file for a 7-year period following diagnosis.

The overall goal of the analysis is to determine the crash risks for commercial motor vehicle operators with sleep apnea compared to drivers who do not have sleep apnea. The data were analyzed using contingency tables, logistic regression, and Poisson regression models to examine the relationship between sleep apnea and the risk of crashes. Summarizing the results of the study, the following major findings were observed:

- An analysis using logistic regression found no association between sleep apnea, as measured by the apnea/hypopnea index, and commercial motor vehicle crashes. Patients with sleep apnea, as confirmed by polysomnography in overnight sleep testing, had no greater probability of having a crash than patients without sleep apnea, either before or after their diagnosis.
- Drivers with sleep apnea were also not found to be at an increased risk for multiple crashes, nor were crash rates impacted by the prevalence of apnea.

- No link between the severity of sleep apnea and the occurrence of traffic crashes—either any crash, multiple crashes, or crash rates—was established in these analyses, although a link was found between severe sleep apnea and severe crashes.
- Examining the relationship between the degree or severity of sleep apnea and crash severity, we found that drivers with severe sleep apnea were 4.6 times more likely than drivers without sleep apnea to be involved in a severe crash (defined as a tow-away crash with multiple injuries). Patients with severe sleep apnea had no higher risk of less severe crashes than patients without sleep apnea, nor were any associations found between moderate or mild sleep apnea and crash severity.

The results of this study contradict those found in several previous studies; other studies found a strong positive relationship between sleep apnea and motor vehicle crashes. A possible reason for this could be attributed to limitations of the data used in our study, and these are discussed in detail in this report.

Given the limitations in the data and the results of our analyses, some recommendations for future research are suggested. These include:

- Obtain complete and accurate crash records for every subject in the study population. To accomplish this, access to several sources of crash data would be required, including nationwide crash data files such as MCMIS, State motor vehicle records, motor carrier crash records, and self-reported driver survey data. It would also be useful to obtain information about each driver's history of traffic citations and moving violations as well as accurate and reliable estimates of exposure, i.e., actual mileage driven per month or per year.
- To the extent possible, obtain prospective information regarding treatments advised and actually administered to the study subjects for the sleep disorders diagnosed during clinical testing. These data should include the recommended treatment, if any, follow-up on whether or not treatment was actually received, the extent of treatment, and the effectiveness of treatment.
- Future studies should target long-haul commercial truck drivers who operate heavy tractor-trailer vehicles. In over-the-road highway driving, the longer distances and monotonous routine may contribute to drowsiness, and the higher speeds may increase the danger to drivers. Intuitively, it seems that the effects of sleep apnea and other sleep disorders that cause excessive daytime sleepiness would be exacerbated in long-haul truck drivers. Furthermore, our analysis showed that tractor-trailer drivers were over three times more likely to be involved in a crash during the seven years following their participation in the sleep study and nearly twice as likely to have a crash in the 14-year period before and after in-laboratory testing than other drivers, after adjusting for mileage driven.

1. INTRODUCTION

The primary mission of the Federal Motor Carrier Safety Administration (FMCSA) is to promote the safety of commercial motor vehicle transportation and to prevent commercial vehicle-related fatalities and injuries. The FMCSA has established a safety goal of reducing the number of deaths and injuries resulting from commercial vehicle-related crashes. This is achieved through a thorough understanding of crash characteristics, pre-crash scenarios, and risk factors to better identify, develop, and evaluate advanced safety technologies.

One element in meeting FMCSA's strategic safety objectives is an emphasis on the safety performance of commercial drivers to ensure they are physically qualified to operate commercial motor vehicles safely while staying mentally alert. Accordingly, the Volpe National Transportation Systems Center, in collaboration with the University of Pennsylvania and Biomedical Statistical Consulting (UPenn/BSC), completed a study to assess the risks of commercial vehicle crashes due to the presence of sleep apnea among truck drivers. The results of this study will help to provide a better understanding of the relationship between sleep disorders and truck crashes and will enable corrective actions to be developed that will, in keeping with FMCSA's strategic safety goal, reduce the number of commercial vehicle-related fatalities and injuries.

The primary objectives of the study were:

- To obtain additional and more meaningful crash data by linking the UPenn sleep apnea database to the FMCSA's Motor Carrier Management Information System (MCMIS) crash database.
- To understand the impact of sleep apnea and driver impairment on crash involvement, the number of crashes, and the severity of crashes.
- To gain insight into how crash rates are impacted before and after drivers are diagnosed with sleep apnea.

From 1996 to 1998, the University of Pennsylvania Center for Sleep and Respiratory Neurobiology collected data for a study on the prevalence and consequences of obstructive sleep apnea among commercial vehicle drivers [*1*]. This work was sponsored by FMCSA and the Trucking Research Institute of the American Trucking Association. UPenn/BSC sent a multivariable apnea prediction questionnaire to a random sample of 4,826 holders of commercial driver's licenses residing in Pennsylvania. From the 1,391 responses that were returned, 406 drivers were selected to participate in the study. The overall findings from this study revealed that 28 (6.9 percent) of the 406 participants were diagnosed with severe sleep apnea, 32 (7.9 percent) had moderate sleep apnea, and 86 (21.2 percent) had mild sleep apnea.

All 406 participants in the in-laboratory testing were assessed using multiple instruments with regard to their subjective perception of sleepiness and functional impairment, as well as objective measures of sleepiness, lack of attention, and other functional consequences of sleepiness. Methods to analyze objective measures included the Psychomotor Vigilance Test and the Divided Attention Driving Task; these tests were designed to mimic the cognitive load of driving in order to evaluate reaction times, performance lapses, and lane tracking ability. While these tests measured performance in functions related to driving tasks, the relationship between sleep apnea and increased risk of motor vehicle crashes was not specifically explored. In this study, crash histories of the 406 in-laboratory participants were obtained, and the relative crash risk of drivers diagnosed with sleep apnea was then assessed using several statistical analysis techniques.

1.1 UNIVERSITY OF PENNSYLVANIA SLEEP APNEA STUDY

Obstructive sleep apnea is a condition in which a narrowing or closure of the upper airway during sleep causes repeated sleep disturbances, possible complete awakenings, leading to poor sleep quality and excessive daytime sleepiness. Complete airway closures causing a cessation of breathing are called apneas, while repeated narrowing of the airway resulting in decrements in breathing are called hypopneas. Severity of sleep apnea is determined by counting the total number of apneas and hypopneas that occur during sleep; the average number per hour that occur during sleep is referred to as the apnea/hypopnea index (AHI). An apnea/hypopnea index of less than 5 episodes/hour is considered normal (i.e., no sleep apnea); 5-15 episodes/hour is said to be mild sleep apnea; 15-30 episodes/hour is regarded as moderate sleep apnea; and 30 or more episodes/hour is considered severe sleep apnea [2].

Since excessive sleepiness can be a consequence of sleeping disturbances, subjects with sleep apnea are at risk to fall asleep inappropriately and have impaired performance on tasks such as driving that require sustained vigilance and attention. As a result, drivers with sleep apnea have an increased risk of motor vehicle crashes [1].

The research study conducted by the University of Pennsylvania Center for Sleep and Respiratory Neurobiology, which involved overnight laboratory testing of 406 subjects, was one of the largest and most comprehensive sleep apnea studies ever performed on any population [1]. The population selected for the study was a random sample of commercial driver license (CDL) holders living in Pennsylvania within 50 miles of the University of Pennsylvania. The UPenn research study had three objectives:

- To estimate the prevalence of sleep apnea among a sample of commercial truck drivers living in Pennsylvania within 50 miles of the University of Pennsylvania.
- To examine the relationship in commercial truck drivers between severity of sleep apnea and decreased function related to driving performance.
- To develop a profile of an overall sample of commercial truck drivers with regard to their sleep apnea-related characteristics and risks.

The results of the study showed that the prevalence rates of sleep apnea among commercial truck drivers are similar to sleep apnea rates found in other general populations. Specifically, it was found that 6.9 percent of the 406 subjects were diagnosed with severe sleep apnea (i.e., $AHI \geq 30$ episodes/hour), 7.9 percent had moderate sleep apnea ($15 \leq AHI < 30$ episodes/hour), and 21.2 percent had mild sleep apnea ($5 \leq AHI < 15$ episodes/hour). The study also revealed that the prevalence of sleep apnea depends on the relationship between two major factors, age and degree of obesity as measured by body mass index (BMI), with the prevalence of sleep apnea increasing with increasing age and BMI. This relationship is important because it provides the commercial driving industry with equations that are useful in estimating the prevalence of sleep apnea, based on the distribution of age and BMI, in any target population of drivers.

Another meaningful study finding showed that the prevalence of sleep apnea depends on the average duration of sleep over consecutive nights at home. Short sleep duration, six hours or less per night, results in an increase in the prevalence of sleep apnea. It was found that sleep duration is affected by the time at which drivers awake in the morning; since more that 35 percent of commercial truck drivers terminate their sleep before 6:00 a.m. and approximately 12 percent before 5:00 a.m., they have significantly shorter sleep durations and higher chances of daytime sleepiness. All measures of sleepiness showed that the effects of daytime performance depend, not only on the severity of sleep apnea, but also on the average sleep duration of the driver. Average sleep duration less than 6 hours per night was found to be associated with impaired performance in laboratory tests.

Nearly one-third of the drivers in the UPenn sleep apnea study indicated self-reported sleepiness on the subjective tests. However, no association was found between measures of self-reported sleepiness and the presence and severity of sleep apnea. The basis for the lack of this relationship is unclear, but it indicates that self-reports of sleepiness are not a reliable source in identifying drivers who are likely to have sleep apnea. No clear relationship was found between sleep duration at home and all tests of performance that were conducted. On the other hand, all objective tests of performance such as assessment of reaction times, performance lapses, lane tracking ability, and objectively measured sleepiness did show a clear relationship with severity of sleep apnea. Degraded performance was particularly observed in drivers with severe sleep apnea (i.e., 30 or more breathing abnormalities per hour of sleep).

1.2 PREVIOUS RESEARCH ON MOTOR VEHICLE CRASHES AND SLEEP APNEA

Since excessive daytime sleepiness is a consequence of sleep apnea, a number of previous research studies have addressed the question of whether patients with sleep apnea have a higher incidence and increased risk of motor vehicle crashes. Connor et al. [3] conducted a review of the international literature to identify all epidemiological studies that examined the association between driver sleepiness/fatigue and the occurrence of crashes or crash injury. Studies were included in the review and subsequently critiqued if they met three criteria: a fatigue or fatigue-related (e.g., sleepiness, sleep deprivation) exposure measure, an outcome measure of crashes or injuries due to crashes, and the inclusion of a comparison group. Nineteen studies fulfilled the inclusion criteria. Fourteen of these studies are based on a small case series of patients with sleep apnea who were evaluated in sleep disorder centers; crash rates in sleep apnea patients are compared with those in a control group. These studies are summarized in Table 1 based on Connor et al., [3] who criticized many of these studies on the following methodological grounds:

- Given the small size of the samples due to low response rates in many of the studies, there are concerns about selection bias. Moreover, the comparison groups often did not represent the same population from which the cases came.

- Self-reported exposures or outcomes were commonly used, raising the possibility of recall bias. In addition, official driving records, which were the sole source of outcome data in some studies, are typically incomplete.
- The potential confounding effects of age, gender, driving mileage, and alcohol or drug use on the relationship between fatigue/sleepiness and crashes were often not adequately considered.
- The small sample size in many studies limits the precision by which estimates of the increase in crash risk can be determined.

Table 1. Sleep Apnea and the Risk of Motor Vehicle Crashes: Summary of Previous Epidemiological Research

Study	Participants	Exposure	Confounders Considered	Crash Outcomes	Results	Comments
Aldrich [7], United States, cross-sectional design	424 Consecutive adult sleep clinic patients, 279 men, 145 women, non-drivers excluded, 70 "healthy" adult controls.	Type of sleep disorder, by polysomnography in clinic patients only. Questionnaire in all participants.	Gender (analyzed separately), approximate age matching.	Self-reported number of automobile accidents.	No patient group had a higher rate of crashes (from any cause) than controls.	No polysomnography in controls; uncontrolled confounding by age, mileage, drug and alcohol use; outcome measured over variable period; no effect estimates reported.
Alpert et al. [8], United States, cross-sectional design	200 Men over 65 years of age recruited for a previous sleep study from in-patients of a VA hospital between 1985 and 1990.	Respiratory disturbance index (RDI), from sleep recording, obtained from clinic records.	Gender (restricted), age (restricted).	Number of accidents as driver in past 5 years, from official records of motor vehicle moving violations.	23% of patients with RDI$\geq$10 had at least one accident compared with 11% with RDI<10 ($p=0.02$). Relative risk (RR) for crash (95% Confidence Interval [CI]) for RDI>10 compared with RDI<10 = 2.1 (1.1-4.1).	Selection criteria not given, restricted to patients with driving records. Possible biased underreporting of crashes. Uncontrolled confounding by mileage, alcohol, and drug use. No effect estimates reported.

Study	Participants	Exposure	Confounders Considered	Crash Outcomes	Results	Comments
Barbe et al. [9], Spain, cross-sectional design	60 Sleep clinic patients, 60 "healthy" controls (hospital workers). Exclusion for: no drivers license, non-residents, drug abuse, shift-work, psychiatric disorders, epilepsy, narcolepsy, and periodic limb movements (1 out of 61 cases declined to participate).	Sleep apnea status, by polysomnography in patients and by clinical history in controls (confirmatory polysomnography in two). Epworth Score for usual daytime sleepiness.	Gender (matched), age (matched), mileage (adjusted), alcohol (stratified), drug use.	Number of automobile accidents in past 3 years, from self-report and insurance records.	Odds Ratio (OR) for at least one crash (95% CI) for apneics compared with controls = 2.3 (0.97-5.33). Adjusted for mileage OR = 2.6 (1.06-6.43). OR for more than one crash = 5.2 (1.07-25.29). Other potential confounders reported not to have affected the estimates. No association between Epworth Score and risk of crash in apnea patients.	Response rate high (one refusal). Control group may not be representative of driving population. All major confounders considered. Association between Epworth Score and risk of crash not examined in controls.
Bearpark et al. [10], Australia, cross-sectional design	135 Male sleep clinic patients, 289 male volunteer controls from an Easter Show.	Apnea Index by polysomnography in patients. BMI and 7-item mini sleep questionnaire in all groups.	Gender (restricted), age (matched), mileage: no difference between groups.	Self-reported accidents in the last 2 years (as driver).	Number of crashes in last 2 years, controls 0.4, snorers 0.3, apneics 0.3. OR for crash (95% CI) compared with controls for snorers = 0.62 (0.27-1.42), for apneics = 0.63 (0.38-1.05).	No response rates reported; no polysomnography in controls; uncontrolled confounding by drug and alcohol use; no effect estimates reported.

Study	Participants	Exposure	Confounders Considered	Crash Outcomes	Results	Comments
Findley et al. [11], United States, cross-sectional design	64 Selected from 77 sleep clinic patients. Also compared with all drivers in Virginia (records) n = 3.7 million.	Sleep apnea status, by polysomnography in patients. No exposure measurement in general population.	None.	Crashes per driver in 5-year period from State driving records.	% Subjects having a crash, apneic patients: 31%; non-apneics: 6% (P=0.01). Mean number of crashes: apneic patients 0.41; non-apneics: 0.06 (P<0.01); Virginia drivers: 0.16 (P<0.02). RR for crash (95% CI) for apneics compared with non-apneics = 7.2 (1.8-30). RR for crash (95% CI) for severe apneics compared to Virginia = 2.6.	Response rate not reported; selection criteria not stated; restricted to patients with driving records (90% of apneics, 76% of non-apneics). Possible biased underreporting of crashes. Uncontrolled confounding by age, gender, mileage, alcohol and drug use. Very small sample. No effect estimates reported. Non-apneic group not representative controls.
Findley et al. [12], United States, cross-sectional design	46 Patients diagnosed with obstructive sleep apnea at a sleep clinic. Controls: all licensed drivers in Virginia.	Sleep apnea status by polysomnography in patients. No exposure measurement in comparison group.	None.	Crashes per driver in 5-year period from State driving records.	Mean number of crashes, mild apnea: 0.13; moderate apnea: 0.24; severe apnea: 0.46; Virginia drivers: 0.16. RR for crash (95% CI) for severe apneics compared with Virginia drivers = 3.4 (1.9-6.0).	Relationship to sample in previous study [11] not clear. Same comments apply.

Study	Participants	Exposure	Confounders Considered	Crash Outcomes	Results	Comments
Findley et al. [13], United States, cross-sectional design	62 Sleep apnea patients. 12 age- and sex-matched sleep clinic patients. 10 age- and sex-matched volunteers. 10 Narcolepsy patients. 10 age- and sex-matched patients. 10 age- and sex-matched volunteers.	Sleep apnea severity by polysomnography. Presence of narcolepsy by multiple sleep latency test. No sleep testing for volunteer controls.	Age (matching), gender (matching)	"Steer clear" computerized driving vigilance test. Crashes per driver in 5-year period from State driving records.	Simulator performance negatively associated with presence and severity of sleep apnea. Simulator performance negatively associated with presence (but not severity) of narcolepsy. Crash rates in performance groups: normal performance, 0.05; poor performance, 0.20; very poor performance, 0.38.	No analysis of crash rates by diagnostic group. Uncontrolled confounding by mileage and drug and alcohol use. Possible biased underreporting of crashes.
George et al. [14], Canada, cross-sectional design	27 Male sleep clinic patients, 270 male controls (10 age-matched controls for each patient) from driving records.	Presence of obstructive sleep apnea in patients by polysomnography (20), or clinical diagnosis (7). No exposure measurement in controls.	Age (matching), gender (restriction).	Number of car accidents as driver, from State records.	% of subjects ever had a crash: apneics, 97%; non-apneics, 54%. Mean number of crashes: apneics, 2.63; non-apneics, 1.28. OR for at least one crash in apneics vs. non-apneics = 10.9.	Very small exposed sample; selection criteria not stated; possible biased underreporting of crashes. Uncontrolled confounding by mileage and drug and alcohol use; outcome measured over variable period.

Study	Participants	Exposure	Confounders Considered	Crash Outcomes	Results	Comments
Gonzalez-Rothi et al. [15], United States, cross-sectional design	126 of 140 consecutive sleep clinic patients.	Sleep apnea status by polysomnography from record review.	None.	Self-reported vehicular mishaps, including "near miss", actual crashes, or subjects who no longer operated a motor vehicle for fear of falling asleep.	Treated apnea group: 34% (19 events); untreated apnea group: 27% (6 events; control group: 7% (2 events).	Selection criteria unclear. Uncontrolled confounding by age, gender, mileage, and alcohol and drug use. Mean age and gender distribution varied between groups. Objective and subjective outcome measures grouped together, and not analyzed separately. No effect estimates reported.
Haraldsson et al. [16], Sweden, cross-sectional design	282 Male ENT-department patients who were regular car drivers, 140 with sleep apnea symptoms (response rate 97%), 142 with nasal obstruction (response rate 89%).	Clinical diagnosis of sleep apnea (n=73), habitual snoring (n=67) or no sleep disorder (n=142), by self report.	Age, gender (restricted), mileage.	Self-reported single-car and combined-car accidents in the past 5 years.	OR for involvement in crashes compared with controls, adjusted for mileage. All crashes: snorers OR = 1.4 (P>0.05); apneics OR = 1.5 (P<0.05). Single vehicle crashes: snorers OR = 1.2 (P>0.05); apneics OR = 6.8 (P<0.05).	Uncontrolled confounding by age and alcohol and drug use.

Study	Participants	Exposure	Confounders Considered	Crash Outcomes	Results	Comments
Ohayon et al. [17], United Kingdom, cross-sectional design	4,972 Adults randomly sampled from the non-institutionalized UK population aged over 15 years. Response rate 80%.	Snoring, breathing pauses during sleep, sleep apnea, self-reported daytime sleepiness, by computer-assisted telephone interview.	None.	Driving accidents in the previous year by self report.	Crashes in the previous year: all drivers, 5.3%; snorers, 4.6%; breathing pauses, 6.1%; all others 5.9%. Not reported for sleep apnea. No differences on chi-square test.	Representative sample of adult UK population with 80% response. No effect estimates reported or able to be calculated from data. Uncontrolled confounding by age, gender, mileage, alcohol and drug use.
Teran-Santos et al. [5], Spain, case-control design	102 Drivers treated at Emergency Departments (response rate 71%), 152 age- and sex-matched controls from primary healthcare centers (response rate 89%).	Sleep apnea status by respiratory polysomnography. Epworth Sleepiness Scale, symptoms of sleep apnea by questionnaire.	Age, gender (matched), illicit drug use (restricted), alcohol, mileage.	Crash resulting in treatment of driver at Emergency Department.	Adjusted odds ratio (95% CI) for crash with sleep apnea (AHI>10) = 7.2 (2.4-21.8).	Sensitivity analysis for non-responders supported positive association. Control group may not be representative of driving population. Exclusion from cases of most severely injured and drivers of cars where only passengers were injured.

Study	Participants	Exposure	Confounders Considered	Crash Outcomes	Results	Comments
Wu and Yan-Go [18], United States, cross-sectional design.	253 Sleep clinic patients with a driver's license. Response rate 86%.	Sleep apnea status on polysomnography, falling asleep at inappropriate times by self report.	Age, gender, alcohol use.	Self-reported car crashes.	Adjusted OR (95% CI) for association of crashes with: sleep apnea = 2.58 (1.06-6.31); falling asleep at inappropriate times = 5.72 (2.39-9.21).	Uncontrolled confounding by mileage, outcome measured over variable period, outcome measure not clearly defined. References to "driving accidents or near accidents due to sleepiness", "having an accident", self-reported MVAs".
Young et al. [4], United States, cross-sectional design.	913 Employed adults enrolled in an ongoing study of the natural history of sleep disordered breathing. Licensed driving > 1,000 miles per year.	Sleep disordered breathing (SDB) status measured by polysomnography and self-reported snoring frequency.	Age, gender, mileage, alcohol.	Crash history over 5-year study period, by record matching with motor vehicle accident data from Wisconsin State records.	Adjusted OR (95% CI) for at least one crash in men: no SDB = 1.0 (reference); snorers = 3.4 (1.8-6.9); mild SDB = 4.2 (1.6-11.3); severe SDB = 3.4 (1.4-8.0). In women: snorers = 0.9 (0.5-1.6); mild SDB = 0.8 (0.3-2.0); severe SDB = 0.6 (0.2-2.5).	Response rates not stated. From a previous description, 82% responded to initial questionnaire and 43% responded to recruitment for polysomnography. Outcome measure may be affected by biased underreporting. Controlled for all major confounders. Small number of events in subgroups, resulting in poor precision.

Despite these limitations and shortcomings, these studies provide evidence of an increased risk of motor vehicle crashes in subjects with sleep apnea. Almost all of these studies, including those judged by a critical review [3] to have at least a moderately robust design, show that individuals with sleep apnea have anywhere from a 3 to 7 times greater risk of crashes than individuals with no sleep apnea.

Three recent major research studies listed in Table 1, employing different designs and strategies to estimate crash risk associated with sleep apnea in different populations, are particularly noteworthy and will be discussed in further detail. First, Young et al. [4] determined the risk of motor vehicle accidents with unrecognized sleep disordered breathing (SDB) in a random sample of 913 licensed motor vehicle drivers, ages 30 to 60, who had completed an overnight sleep study as part of the Wisconsin Sleep Cohort Study. Crash records for this group were obtained from State records for a 5-year period, and the increased relative risk of crashes was determined for different levels of sleep apnea severity (AHI<5, 5≤AHI≤15, and AHI>15). One hundred sixty five participants were involved in 227 motor vehicle crashes over the 5-year period. Logistic regression analyses of the total sample as well as samples stratified by gender were conducted, and odds ratios for having a positive crash history (i.e., single or multiple crashes) over the 5-year study period were estimated for drivers with SDB compared to those without SDB.

The results of the study [4] are summarized in Table 2. Gender-specific odds ratios were adjusted for age and self-reported average miles driven per year; odds ratios for the total sample were also adjusted for gender. Men with SDB, compared to those without SDB, were found to be 3 to 4 times more likely to be involved in a crash in 5 years; however, no crash risk association with SDB was found in women. The increased risk of crashes was not related to severity of sleep apnea. In contrast, the odds ratios for SDB and *multiple* crashes were positive for both men and women with SDB, as shown in Table 2. Overall, drivers with AHI > 5 (vs. no SDB) were 4.6 times more likely to have multiple crashes in a 5-year period.

Table 2. Increased Relative Risk of Crashes (Odds Ratio), for Different Levels of Sleep Disordered Breathing in Men and Women [*4*]*

SDB Category	Any Crash in 5 Years Men OR *(95% CI)*	Any Crash in 5 Years Women OR *(95% CI)*	Any Crash in 5 Years Total OR *(95% CI)*	Multiple Crashes in 5 Years Men OR *(95% CI)*	Multiple Crashes in 5 Years Women OR *(95% CI)*	Multiple Crashes in 5 Years Total OR *(95% CI)*
No SDB	(Reference Category)					
AHI < 5	3.4 *(1.8, 6.9)*	0.9 *(0.5, 1.6)*	1.5 *(1.0, 2.4)*	2.2 *(0.7, 7.0)*	3.3 *(0.9, 12.0)*	2.9 *(1.0, 8.6)*
AHI 5–15	4.2 *(1.6, 11.3)*	0.8 *(0.3, 2.0)*	1.9 *(0.9, 3.8)*	1.8 *(0.2, 14.0)*	4.5 *(0.8, 25.0)*	3.1 *(0.8, 12.7)*
AHI > 15	3.4 *(1.4, 8.0)*	0.6 *(0.2, 2.5)*	1.6 *(0.8, 3.1)*	11.9 *(1.1, >25)*	2.4 *(0.2, 25.0)*	7.3 *(1.8, >25)*

* Gender-specific Odds Ratios adjusted for age and miles driven per year; OR for total sample adjusted for age, miles driven per year, and gender.

The researchers also investigated the role of sleepiness as an explanatory factor by creating continuous variables from the Epworth Sleepiness Scale and the multiple sleep latency test. Addition of the individual sleepiness variables did not substantially change the magnitude or the statistical significance of any of the odds ratios for SDB and accident history. In addition, the possibility that drivers with a combination of sleepiness and SDB had the greatest likelihood of crashes was investigated. None of the interactions of SDB and sleepiness measures, however, was significant in predicting crash risk.

Using a different methodological approach, Teran-Santos et al. [5] conducted a case-control study of the relationship between sleep apnea and the risk of traffic crashes. The case patients were 102 drivers who received emergency treatment in Burgos or Santander, Spain after highway traffic crashes. Drivers charged with violation of alcohol laws were excluded. Controls were 152 patients randomly selected from primary care centers in the same cities and were matched with cases for age and gender but not for annual miles driven. Patients with known chronic illnesses and those who had been involved in a traffic accident in the previous two months were excluded from the control group. Logistic regression models were used to estimate the relationship between the dependent variable, whether a crash had occurred (yes or no), and the independent variable, apnea/hypopnea index (AHI values of ≥ 5, ≥10, and ≥ 15 were used as cutoff points to create three categories or subgroups of apnea severity). Odds ratios were adjusted by entering potential confounders as independent variables; these included use or non-use of alcohol, visual refraction disorders, body mass index, years of driving, age, involvement in previous accidents, use of medication causing drowsiness, smoking, work and sleep schedule, kilometers driven per year, and coexisting conditions (including psychiatric disorders and arterial hypertension).

Table 3 shows the major findings from the Teran-Santos et al. study [5]. A large increased relative risk (odds ratio) of crashes in subjects with sleep apnea can be clearly seen. This risk does not appear to change with severity of the illness, although it must be noted that the three AHI categories are not mutually exclusive, because the number of cases in each category was not high enough to make a proper analysis. While the odds ratios are indicative of a strong association between sleep apnea and traffic crashes, a potential limitation of the study was that the control group may not have been representative of the general population. The prevalence of AHI ≥ 5 episodes/hour in this group (4.6 percent) is considerably lower than those reported in previous prevalence studies. As suggested by Pack et al. [1], it may be that excluding controls with poorly defined chronic illness, which might have included hypertension, a known consequence of sleep apnea, removed a number of controls with sleep apnea. Thus, the high odds ratios reported in this study may be a by-product of the selection of the control group.

Table 3. Relationship Between Sleep Apnea and Traffic Crashes [5]

Apnea/Hypopnea Index	Case Patients (N = 102)	Controls (N = 152)	Unadjusted Odds Ratio *(95% CI)*	Adjusted Odds Ratio *(95% CI)*
≥ 5	29 (28.4%)	7 (4.6%)	8.2 *(3.4–19.6)*	11.1 *(4.0–30.5)*
≥ 10	21 (20.6%)	6 (3.9%)	6.3 *(2.4–16.2)*	7.2 *(2.4–21.8)*
≥ 15	17 (16.7%)	5 (3.3%)	5.8 *(2.1–16.5)*	8.1 *(2.4–26.5)*

In a third study, George and Smiley [6] reviewed overnight sleep studies performed in the Health Sciences Center sleep laboratory in Ontario, Canada between 1990 and 1994. Driving records were obtained from the Ministry of Transportation of Ontario on 460 holders of general driver's licenses who were diagnosed as having sleep apnea. A group of 581 control subjects, matched to apnea patients by age and sex, were extracted from the Ministry of Transportation database. Confirmed cases of sleep apnea were arbitrarily divided into three groups based on AHI: AHI 10–25, AHI 26–40, and AHI > 40. Poisson regression models were developed to assess differences in crash rates (i.e., crashes per year) between drivers with sleep apnea and control subjects; separate analyses were performed for male and female drivers. Overall, a significant difference was found in crash rates between sleep apnea patients and control subjects. In the five years preceding diagnosis, 155 of 460 (33.7 percent) sleep apnea patients had one or more crashes compared with 150 of 581 (25.8 percent) controls. However, this difference was entirely accounted for by higher crash rates in patients with the most severe sleep apnea (AHI > 40); no significant differences in crash rates were found among subjects with AHI 10–25, subjects with AHI 26–40, and the control group. Therefore, an increased risk of motor vehicle crashes was found only in patients with severe sleep apnea.

The results of the studies just discussed, together with the critical review by Connor et al. [3] of the previous work listed in Table 1, highlight the methodological difficulties in estimating elevated crash risk among drivers with sleep disorders. Since crashes are relatively rare events, the probability of a crash occurring in drivers impaired by sleepiness is relatively low. Nevertheless, research in this area generally supports the view that sleep apnea is a risk factor for increased motor vehicle crashes.

2. STUDY DESIGN AND METHODOLOGY

2.1 UNIVERSITY OF PENNSYLVANIA SLEEP STUDY POPULATION

From 1996 to 1998, the University of Pennsylvania Center for Sleep and Respiratory Neurobiology collected data for a study on the prevalence and consequences of obstructive sleep apnea among commercial vehicle drivers [1]. The study design was based on a two-stage sampling strategy. In the first stage, the population of interest was determined. Information was obtained from the population to allow classification of the population into groups at higher risk and lower risk for the presence of sleep apnea. In the second stage, weighted samples of subjects were selected from the higher risk and lower risk groups to participate in laboratory testing to establish the presence and degree of sleep-disordered breathing. In this weighted sampling scheme, the ratio of the number of higher risk subjects to lower risk subjects was larger in the selected sample compared to the same ratio in the population. This design enriched the sample in terms of the number of subjects with apnea that were available for assessment of functional consequences while allowing a population-based estimate of prevalence.

UPenn chose as their sampling frame the population of CDL holders in Pennsylvania who lived within 50 miles of the UPenn sleep center. The advantage of this approach is that the sampling frame is precisely defined, permitting a true random sample of drivers in a well-defined population [1]. Thus, UPenn sent a Multivariable Apnea Prediction (MAP) questionnaire to a random sample of 4,826 Pennsylvania CDL holders residing within 50 miles of UPenn. MAP is an instrument that allows calculation of the relative likelihood of sleep apnea, on a scale between zero and one, based on age, gender, body mass index (a measure of degree of obesity), and responses to questions about the frequency of symptoms of sleep apnea [19]. Survey respondents were rank ordered from highest to lowest values of MAP, that is, from highest to lowest relative likelihood of sleep apnea. It must be noted that the MAP instrument is not precise enough to determine definitively whether an individual subject has apnea or not, but it is a valuable tool that can be used in population studies to stratify subjects into groups with different relative risk or likelihood of sleep apnea. From the survey of 4,826 CDL holders, 1,391 usable responses were returned; among these, 62 did not have sufficient data to compute a value of MAP that was necessary for stratifying the subjects according to their risk of having sleep apnea. From the final total of 1,329 survey responses, UPenn found the top 551 MAP scores to be greater than 0.4356. This group was defined as the higher risk group, and 44.8 percent of these subjects ($n = 247$) were enlisted for overnight sleep testing in the laboratory. The remaining 778 respondents, with MAP scores below 0.4356, constituted the lower risk group, and 20.4 percent were enrolled in a random order for in-laboratory studies ($n = 159$). Therefore, a total of 406 commercial drivers were selected to participate in the UPenn sleep apnea study. The overall study design and selection of the study population is shown schematically in Figure 1.

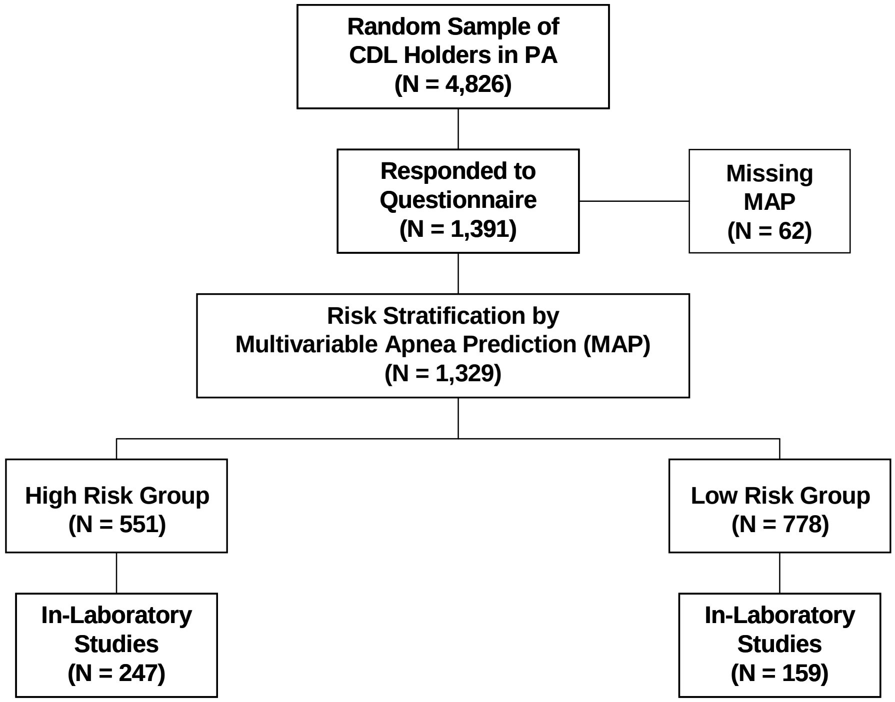

Figure 1. Commercial Driver Population Selected for UPenn Sleep Apnea Study

The MAP scores of the 247 subjects in the higher risk group enrolled for in-laboratory studies ranged from 0.44 to 0.94 with a mean of 0.64 and a median of 0.62. The mean age of this group was 49.3 years, and the mean body mass index (BMI) was 33.0 kg/m^2. For the 159 subjects in the lower risk group, MAP scores ranged from 0.03 to 0.43 with a mean value of 0.26 and a median of 0.30. The mean age of the lower risk group was 42.6 years, and the mean BMI was 27.6 kg/m^2. Thus, as expected based on risk stratification, the lower risk group was younger and less obese than the higher risk group. [1].

Independently of their study of the prevalence of sleep apnea in commercial drivers, UPenn also collected crash data for the drivers who responded to the MAP questionnaire. Crash histories for respondents were obtained through examination of State motor vehicle records for a period of seven years preceding their participation in the sleep apnea study. Crash information included crash date, the number and types of vehicles involved, geographic location, and major contributing factors. The retrospective crash data obtained were for periods prior to the drivers being diagnosed with sleep apnea.

2.2 MOTOR CARRIER MANAGEMENT INFORMATION SYSTEM (MCMIS) CRASH DATABASE

Under the Motor Carrier Safety Assistance Program, FMCSA has implemented a crash reporting system based on State police crash reports which are electronically transmitted from the States to FMCSA. The MCMIS crash file is maintained by FMCSA and contains data on trucks and buses in crashes that meet the uniform crash data standards developed through the National Governors Association (NGA). An NGA reportable crash involves a truck (a vehicle that is designed, used, or maintained primarily for carrying property and has at least two axles and six tires) or a bus (a vehicle with a seating capacity of at least nine people, including the driver). The crash must result in either at least one fatality, at least one injury for which the injured person was taken to a medical facility for immediate medical attention, or at least one vehicle that was towed from the crash scene as a result disabling crash damage. The crashes are reported by the individual States and transmitted to FMCSA through a computer-based software system called SAFETYNET.

The MCMIS crash file is intended to be a census of trucks and buses involved in fatal, injury, and tow away crashes; however, some States do not report all NGA-eligible crashes. As a result, MCMIS does not provide a complete representation of all commercial motor vehicle crashes that occur annually in the United States. For example, the States reported 91,027 trucks involved in crashes through SAFETYNET to the MCMIS crash file in the year 2001. Based on the 2001 General Estimates System (GES) data, which is a nationally representative probability sample of all police-reported crashes that occur each year in the U.S., an estimated 147,000 trucks were involved in crashes that should have been reported. Thus, FMCSA received reports on about 62 percent of the trucks involved in NGA-reportable crashes [20]. Similarly, the 2000 MCMIS crash file captured approximately 62 percent of all truck crashes, and 1999 MCMIS crash data included about 60 percent of all NGA-reportable crashes. It should be noted that Pennsylvania, the State in which the majority of crashes occurred involving the drivers used in this study, reported about 96 percent of all truck crashes to MCMIS between 1998 and 2000. Both the MCMIS and GES databases describe the events and details of motor vehicle crashes, but they do not include data on crash causation or fault.

Despite the fact that truck crashes are under-reported in the MCMIS database, we selected MCMIS as the source of crash data for a 7-year period following sleep apnea diagnosis in our study for two reasons. First, MCMIS is centrally managed and updated by FMCSA and is, therefore, easily accessible. Second, and more importantly, MCMIS contains CDL information for each driver involved in a crash. This allowed us to link the crash data to the patient data for each of the 406 subject who underwent in-laboratory testing during the UPenn sleep apnea study. GES is a more complete dataset and contains more details on pre-crash scenarios, environmental conditions, and possible contributing factors; however, GES does not include any driver identifying information that is needed to match the crash information to the UPenn sleep study participants. We obtained MCMIS crash data for the period covering January 1996 through March 2003, thus providing crash histories of drivers after they were (or were not) diagnosed with sleep apnea.

2.3 DATA ANALYSIS METHODOLOGY

The first task in our analysis of crash risk due to sleep apnea in commercial drivers was to define the data requirements and create a new database to support the analysis. This involved merging selected data elements collected by UPenn during the sleep apnea study with crash information contained in the MCMIS crash file. Constructing the new crash database to establish the crash records of the drivers following their participation in the UPenn sleep laboratory testing (i.e., post-diagnosis) was a three-step process. First, FMCSA compiled MCMIS crash data for the period from January 1996 to March 2003 and sent it to the Volpe Center in delimited text file format. Next, since all the CDL holders who participated in the sleep apnea study were licensed in the State of Pennsylvania, Volpe extracted from the MCMIS data only those crashes in which the driver held a Pennsylvania-issued CDL. In addition, MCMIS data elements that were not necessary to support the analysis were deleted. Volpe then sent the data in SAS format to UPenn/BSC. And finally, UPenn/BSC linked the MCMIS crash data with their data from the sleep apnea study, using CDL number as the matching variable, to create a crash archive for all 406 commercial drivers who were evaluated for sleep disorders. To maintain confidentiality and protect the identities of the drivers, UPenn/BSC stripped out any information that would permit driver identification and sent the final database to Volpe for analysis.

Driver demographic information, job-related driving data (i.e., monthly/yearly miles driven, years of commercial driving experience, driving schedule, and types of vehicles driven), medical histories, information about sleeping habits, alcohol and drug use, and subjective measures of self-reported sleepiness were collected for each subject using survey questionnaires as part of the UPenn overnight sleep study. Table 4 lists the data elements that were provided by UPenn and used in our study. The majority of these data elements are self-reported responses to survey questions; the number of respondents, N, varies since not all sleep study participants responded to every questionnaire item. The effects of these variables, which all could have a relationship with both the presence of sleep apnea and the risk of a crash occurring, may bias or distort the estimate of crash risk due to sleep apnea. Therefore, we investigated the potential confounding effects of all these variables on the relationship between sleep apnea and motor vehicle crashes in our analysis.

Table 4. List of UPenn Sleep Study Data Elements

Variable	Description	Type	N
AGE	Driver's age on date of visit	Numeric	406
SEX	Driver's gender	Categorical	406
RACE	Driver's race	Categorical	406
MARSTAT	Driver's marital status	Categorical	403
WEI_LBS	Weight (pounds)	Numeric	393
HEI_INCH	Height (inches)	Numeric	398
BMIPHYS	Body Mass Index (kg/m^2)	Numeric	390
AHICAT	Severity of sleep apnea (i.e., AHI category)	Categorical	406
TRDI3	Respiratory Disturbance Index	Numeric	406
PSQI4	Hours of sleep per night	Numeric	398
ESSTOTAL	Total Epworth Sleepiness Scale	Numeric	386
I1	Apnea, snoring, snorting	Numeric	406
I2	Difficulty sleeping	Numeric	399
I3	Daytime sleepiness	Numeric	399
PROBSL	Problem with daytime sleepiness	Yes/No	404
PROBRS	Problem with restless sleep	Yes/No	404
PROBINS	Problem falling asleep at night	Yes/No	404
PSQI6	Overall sleep quality rating	Categorical	398
SCOR15	Frequency of falling asleep at work	Categorical	395
SCOR18	Frequency of excessive sleepiness	Categorical	391
PSQI8	Use of sleep medicine during previous month	Categorical	390
SCOR36WI	Alcohol use per week—wine	Numeric	166
SCOR36BE	Alcohol use per week—beer	Numeric	245
SCOR36SP	Alcohol use per week—spirits	Numeric	164

Variable	Description	Type	N
SCOR36TO	Alcohol use per week—total	Numeric	284
SCOR37	Days per week at least 1 drink	Numeric	271
SCOR38G2	Still taking sleeping pills?	Yes/No	316
SCOR38H2	Still taking antihistamine/decongestant?	Yes/No	342
PROBHBP	Problem with high blood pressure	Yes/No	404
PROBOHD	Problem with other heart disease	Yes/No	404
HBP	History of high blood pressure	Yes/No	400
PH	History of pulmonary hypertension	Yes/No	403
OTHHD	History of other heart disease	Yes/No	400
TXSLPAP	Ever treated for sleep apnea?	Yes/No	374
T6	Years of commercial driving experience	Numeric	398
DRVDYWK	Days per week of commercial driving	Numeric	319
DRVHRDY	Hours per day of commercial driving	Numeric	319
ROTSHIFT	Works rotating shift	Yes/No	382
NITSHIFT	Works steady night shift	Yes/No	369
T2	Currently employed as truck driver?	Categorical	406
T3_A	Type of driving (local vs. long-haul)	Categorical	342
T4_A	Current driving schedule	Categorical	334
CVTYP1	Drives a local truck	Yes/No	326
CVTYP2	Drives a van	Yes/No	324
CVTYP3	Drives a bus	Yes/No	323
CVTYP4	Drives a construction vehicle	Yes/No	323
CVTYP5	Drives a tractor-trailer	Yes/No	322
MILES	Monthly miles driven	Numeric	320
MILESY_A	Adjusted miles per year driven	Numeric	379

Each record in the MCMIS crash file contains approximately 90 data elements pertaining to the motor carrier, driver, vehicles, and circumstances of the crash. Many of these data elements were not needed for our study and were not included in the final database. Table 5 lists the MCMIS variables that were merged with the sleep apnea data shown in Table 4 to construct the new crash database. Two additional variables not shown in Table 4 or Table 5 were defined. *CRASHEVENT* is a variable that indicates whether or not a driver was involved in a commercial motor vehicle crash from 1996 to March 2003 according to MCMIS data. The second additional variable, *CRASH_SEVERITY*, uses three variables from the MCMIS crash file to classify each crash by severity. With the exception of fatal crashes, MCMIS contains no information about crash or injury severity. Thus, *CRASH_SEVERITY* was derived as follows using the variables *FATALITY*, *INJURY*, and *TOWAWAY* from the MCMIS crash file:

- If *FATALITY* > 0, then *CRASH_SEVERITY* = "Fatal".
- If *TOWAWAY* = "Yes" and *INJURY* > 0, then *CRASH_SEVERITY* = "Severe".
- If TOWAWAY = "Yes" and INJURY = 0, then CRASH_SEVERITY = "Moderate".
- If *TOWAWAY* = "No" and *INJURY* > 0, then *CRASH_SEVERITY* = "Minor".

It is interesting to note that none of the 406 drivers in our study population were involved in a fatal crash between 1996 and March 2003.

Table 5. List of MCMIS Crash File Data Elements (N = 56)

Variable	Description	Type
RPT_ST	Crash report State	Character
RPTNUM	Police crash report number	Numeric
ACDT-DATE	Date of crash	Numeric
ACDT_TIME	Time of crash	Numeric
SEQ_NUM	Crash sequence number	Numeric
INTERSTATE	Crash occurred on interstate highway	Yes/No
FATALITY	Number of fatalities	Numeric
INJURY	Number of injuries	Numeric
TOWAWAY	Vehicle towed from crash scene	Yes/No
TRUCKBUS	Crash involved truck or bus	Categorical
RD_TWAY	Road traffic way	Categorical
RD_ACCESS	Road access control	Categorical
RD_SURF	Road surface condition	Categorical
WEATHER	Weather condition	Categorical
LIGHT	Light condition	Categorical
SEQ_ONE	Crash sequence of events, first	Categorical
SEQ_TWO	Crash sequence of events, second	Categorical
SEQ_THRE	Crash sequence of events, third	Categorical
SEQ_FOUR	Crash sequence of events, fourth	Categorical
ACDT_JURIS	State in which crash occurred	Character
ACDTVEHICS	Number of vehicles involved in crash	Numeric
VEHIC_CONF	Configuration of motor vehicle	Categorical
VEHICCARGO	Vehicle cargo body type	Categorical
VEHIC_GVWR	Gross vehicle weight range	Categorical

The overall goal of the analysis is to determine the crash risks for commercial motor vehicle operators with sleep apnea compared to drivers who do not have sleep apnea. More specifically, the analysis will determine the relative crash risks as a function of both the presence and the severity of sleep apnea (i.e., none, mild, moderate, and severe). To accomplish these analyses, relevant variables from the UPenn sleep apnea database were linked with crash data from the MCMIS crash file, as discussed above, and a special database was created to support the analysis. The data were analyzed using Contingency Tables and a Generalized Linear Model (GLM) to examine the risk associated with the operation of commercial motor vehicles by drivers with sleep apnea. The GLM refers to a family of regression models in which some function of the values of an outcome factor are linked to a linear combination of predictor variables. A commonly used GLM in biostatistical and epidemiological applications, and one that was employed in this research study, is logistic regression. The hypothesis to be tested by this modeling approach is that a driver diagnosed with sleep apnea is more likely to be involved in a motor vehicle crash than a driver with no history or symptoms of sleep apnea, after controlling for differences in the other predictor variables included in the model.

Contingency table analysis is a statistical method used for exploring multivariate but discrete data distributed into tables. In general, the rows of a contingency table represent alternate outcomes, and the columns denote exposure (or lack of exposure) to a treatment or risk factor. Several contingency tables will be compiled to explore the relationships between crash variables, sleep apnea variables, and other variables of interest. As an example, consider Table 6, a 2-by-2 contingency table that describes the relationship between driver impairment and commercial motor vehicle crashes:

Table 6. Contingency Table Describing the Relationship between Driver Impairment and Commercial Motor Vehicle Crashes

Outcome	Sleep Apnea	No Sleep Apnea	Total
Crash	a	b	a + b
No Crash	c	d	c + d
Total	a + c	b + d	406

In a 2-by-2 contingency table in which no other confounding variables are included as predictors, the Odds Ratio measure of association can be calculated as:

$$Odds\ Ratio = \frac{Odds(Crash\ with\ SA)}{Odds(Crash\ with\ No\ SA)} = \frac{a/c}{b/d} = \frac{ad}{bc}$$

In the example above, the calculation gives the estimated odds, or likelihood, of a crash occurring for drivers with sleep apnea. Thus, the odds ratio in this study will provide a reasonable approximation for the relative risk of crashes for those drivers who are diagnosed with sleep apnea.

The data in this study were also analyzed using logistic regression. Logistic regression is a mathematical modeling approach that can be used to describe the relationship of several independent or predictor variables to a binary or dichotomous dependent variable (e.g., crash or no crash). Logistic regression models identify factors that affect the likelihood of an outcome and can be used to predict the outcome of an event. The outcome of interest for this study is a heavy-truck related crash. Thus, logistic regression models were used to predict the occurrence of a crash event based on a set of predictor variables. The predictor (or independent) variables may be either binary or continuous quantitative variables. In this study, the predictor variables included such driver characteristics as the presence and severity of sleep apnea, age, gender, marital status, years of commercial driving experience, alcohol and drug use, and annual miles driven.

The logistic regression model has the following form:

$$\Pr(Crash) = \frac{1}{1 + e^{-z}}$$

where $z = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots + \beta_n X_n$
(n = number of independent or predictor variables)
and β is the coefficient of the predictor variable X.

The estimated model was used to predict the probability of a particular response, in this case a heavy truck-related crash, for the values of the predictor variables. As in any regression model the regression coefficients β_i in the logistic model play an important role in providing information about the relationships of the predictor variables in the model to the dependent variable. For the logistic model, quantification of these relationships involves a parameter called the odds ratio. Applied to our study, the odds ratio is a measure that compares two groups, subjects with and without sleep apnea, in predicting the outcome (dependent) variable, involvement in a motor vehicle crash. The odds of a crash occurring are defined as

$$\frac{\Pr(Crash)}{\Pr(No\ Crash)} = e^{\beta_0+\beta_1 X_1+\beta_2 X_2+\ldots+\beta_n X_n} = e^{\beta_0} e^{\beta_1 X_1} \ldots . e^{\beta_n X_n}$$

An equivalent way of expressing the logistic regression model, called the "logit form" of the model, is given by the formula

$$\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots . + \beta_n X_n$$

Logistic regression determines the β coefficients that make the observed outcome (crash or no crash) most "likely" using the maximum likelihood method. Maximum likelihood estimates are estimates, which, generally speaking, ascribe the highest likelihood to the observed data. Thus, the application of the logistic regression model yields a set of estimated odds ratios, determined from the β coefficients, that are useful and readily interpretable measures of association. The results of a logistic regression model yield a set of p-values for each β coefficient. Each p-value tests the null hypothesis that the adjusted odds ratio for that X variable equals 1.0 in the overall population. In other words, the null hypothesis being tested is that there is no association between the X variable and the occurrence of a crash, after adjusting for all other X variables.

In addition to using binary logistic regression to predict crash involvement (i.e., crash or no crash), multinomial logistic regression models were estimated to determine the relationship between the presence and severity of sleep apnea and crash severity. In a multinomial logistic regression model, the response assumes more than two values; in this case the crash severity dependent variable would have the values "severe," "moderate," and "mild." In addition, we explored the increased relative risk for drivers with sleep apnea being involved in *multiple* crashes.

And finally, crash rates were normalized by the number of miles driven annually for each driver, and a Poisson regression model was estimated. Poisson regression analysis is a regression technique used for modeling dependent variables that describe count (i.e., discrete) data. Whereas linear regression analysis is based on a continuous dependent variable with a normal distribution and logistic regression analysis employs a binary dependent variable with a binomial distribution, the methodology of Poisson regression analysis assumes that the underlying distribution of the dependent variable under consideration is Poisson. In each instance, the analysis goal is the same—namely, to fit to the data a regression equation that will accurately model the dependent variable as a function of a set of predictor variables. The Poisson distribution is often used to model the occurrence of rare events, such as the number of motor vehicle crashes occurring either over time or as a function of the number of miles driven. Thus, Poisson regression is an appropriate statistical technique for analyzing crash *rates*.

3. RESULTS

Data on 406 commercial truck drivers were analyzed in this study. These subjects were evaluated for the presence and degree of obstructive sleep apnea in overnight laboratory testing at the University of Pennsylvania Center for Sleep and Respiratory Neurobiology. Three hundred eighty two (94.6 percent) of the subjects were male and 22 (5.4 percent) were female. The mean age of the 406 drivers was 46.7 years (SD = 11.4 years), and the subjects had, on average, 16.7 years (SD = 11.4 years) of commercial driving experience. Nearly two-thirds of the drivers (64.6 percent) were exclusively local/short drivers whose workday involved trips of 100 miles or less from their home base, as compared to 8.6 percent long haul-only drivers and 28.7 percent who said they operated both local and over-the-road routes. One hundred forty six (36 percent) of the 406 subjects were found to have some degree of sleep apnea (i.e., apnea/hypopnea index ≥ 5 episodes/hour); of the 146 subjects diagnosed with sleep apnea, 28 had severe (AHI ≥ 30), 32 had moderate (15 ≤ AHI < 30), and 86 had mild (5 ≤ AHI < 15) sleep apnea.

Crash data were obtained from State motor vehicle records covering the period from 1989 to 1996, that is, prior to in-laboratory testing to determine the prevalence of sleep apnea in these 406 drivers. In addition, crash records from the MCMIS crash file were obtained from 1996 to 2003, following sleep apnea diagnosis. Prior to diagnosis in the overnight studies, 101 of the 406 participants were involved in a total of 135 commercial motor vehicle crashes. After diagnosis, 50 participants were involved in a total of 56 crashes. As shown in Figure 2, 39 drivers (9.6 percent) had more than one crash over the entire 14-year period.

Figure 3 shows the breakdown of crash involvement by severity of sleep apnea for the drivers who had crashes.

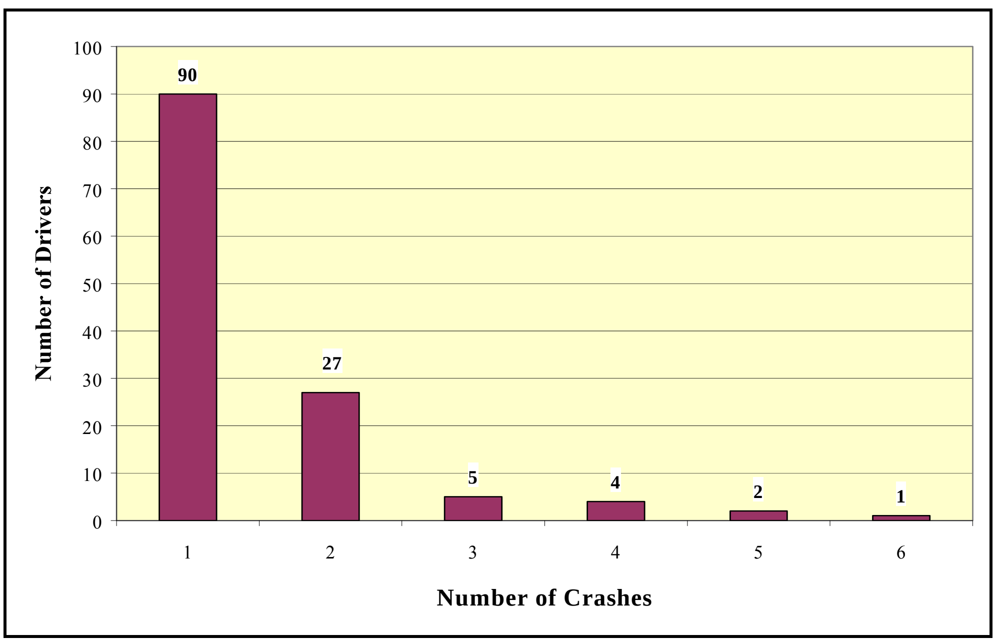

Figure 2. Crash Involvement for the 406 UPenn Sleep Study Subjects

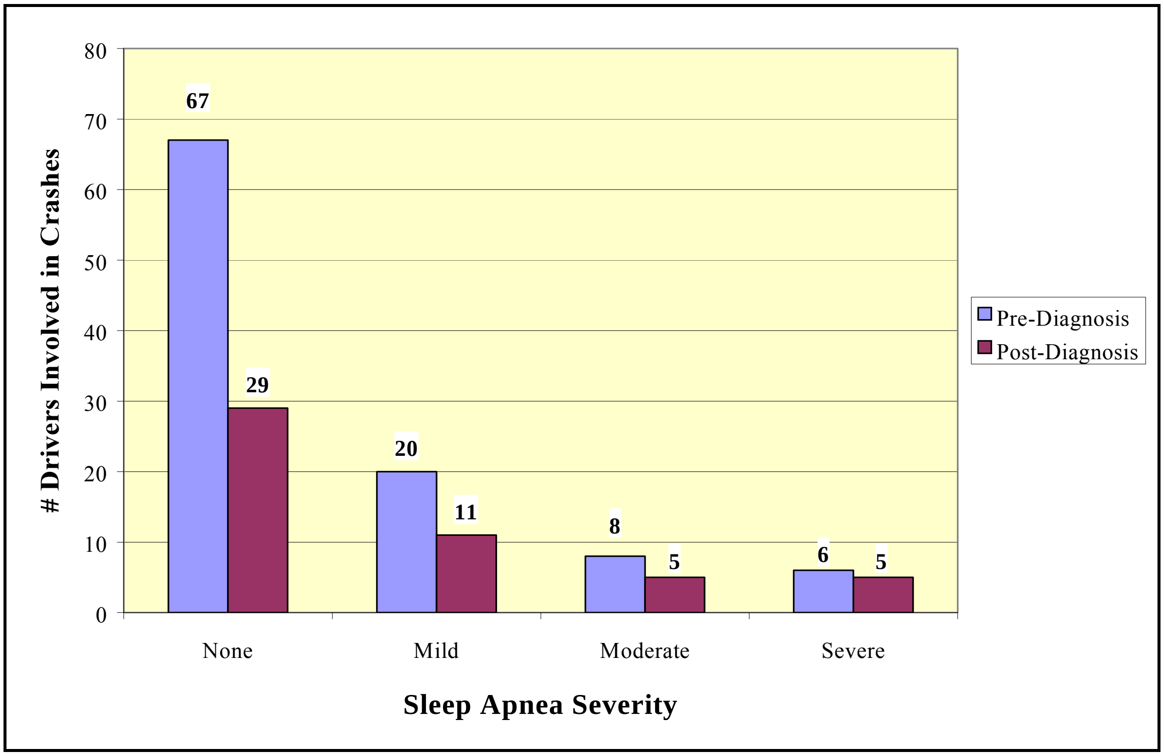

Figure 3. Breakdown of Crash Involvement by Severity of Sleep Apnea

Table 7 shows the distributions of the various data elements collected during the UPenn sleep study for drivers diagnosed with sleep apnea (AHI ≥ 5) versus the comparison group of drivers who were found to have no sleep disordered breathing (AHI < 5). In a similar manner, the distribution of the UPenn sleep study variables by crash involvement, both before and after diagnosis with sleep apnea, is summarized in. It should be noted that many of the data elements were based on drivers' responses to survey questions, and, as a result, several variables contain missing values. The estimate of crash risk due to the presence of sleep apnea could be influenced by the potential confounding effects of these variables on the relationship between sleep apnea and commercial motor vehicle crashes. Therefore, exploratory data analysis was conducted to identify variables that are related both to the outcome (pre- and post-diagnosis crash involvement) and to the exposure (the presence of sleep apnea).

Table 7. Distribution of UPenn Sleep Study Variables for Drivers With and Without Sleep Apnea

Variable	Sleep Apnea (n = 146)	No Sleep Apnea (n = 260)
Sleep Apnea Severity		
Severe (AHI ≥ 30)	28 (19.2%)	NA
Moderate (AHI 15-30)	32 (21.9%)	NA
Mild (AHI 5-15)	86 (58.9%)	NA
None (AHI < 5)	NA	260 (100.0%)
Gender		
Male	140 (95.9%)	244 (93.8%)
Female	6 (4.1%)	16 (6.2%)
Age Group		
24–30	5 (3.4%)	22 (8.5%)
31–40	37 (25.3%)	74 (28.5%)
41–50	43 (29.5%)	82 (31.5%)
51–60	39 (26.7%)	49 (18.8%)
61–70	18 (12.3%)	27 (10.4%)
71–77	4 (2.7%)	6 (2.3%)
Marital Status		
Married	110 (75.9%)	187 (72.5%)
Single	17 (11.7%)	36 (14.0%)
Divorced/Separated/Widowed	18 (12.4%)	35 (13.5%)
Commercial Driving Experience (years)		
0–5	17 (12.0%)	52 (20.3%)
6–10	28 (19.7%)	61 (23.8%)
11–20	44 (31.0%)	64 (25.0%)
21–30	35 (24.6%)	56 (21.9%)
> 30	18 (12.7%)	23 (9.0%)
Body Mass Index (kg/m^2)		
20–<25	3 (2.2%)	43 (17.0%)
25–<30	37 (27.0%)	111 (43.9%)
30–<35	42 (30.7%)	74 (29.2%)
≥ 35	55 (40.1%)	25 (9.9%)
Alcohol Use (drinks/week)		
0–5	65 (60.7%)	99 (55.9%)
6–10	17 (15.9%)	35 (19.8%)
> 10	25 (23.4%)	43 (24.3%)
Currently Employed As Truck Driver		
Yes, Full Time	88 (60.3%)	164 (63.1%)
Yes, Part Time	27 (18.5%)	51 (19.6%)
No	31 (21.2%)	45 (17.3%)
Type of Driving		
Over the Road	7 (5.8%)	21 (9.4%)
Local	77 (64.2%)	144 (64.9%)
Both	36 (30.0%)	57 (25.7%)
Current Driving Schedule		
Days Only	53 (44.9%)	94 (43.5%)
Nights Only	5 (4.2%)	11 (5.1%)
Both	60 (50.9%)	111 (51.4%)

Variable	Sleep Apnea (n = 146)	No Sleep Apnea (n = 260)
Drives a Local Truck		
Yes	42 (37.2%)	92 (43.2%)
No	71 (62.8%)	121 (56.8%)
Drives a Tractor-Trailer		
Yes	53 (47.3%)	78 (37.1%)
No	59 (52.7%)	132 (62.9%)
Works Rotating Shift		
Yes	20 (14.6%)	38 (15.5%)
No	117 (85.4%)	207 (84.5%)
Works Steady Night Shift		
Yes	20 (15.2%)	28 (11.8%)
No	112 (84.8%)	209 (88.2%)
Adjusted Miles/Year Driven		
< 10,000	17 (12.5%)	44 (18.1%)
10,000–25,000	37 (27.2%)	63 (25.9%)
25,001–50,000	31 (22.8%)	54 (22.2%)
50,001–75,000	22 (16.2%)	22 (9.1%)
> 75,000	29 (21.3%)	60 (24.7%)
Average Sleep During Past Month		
≤ 6 Hours	70 (49.6%)	118 (45.9%)
> 6 Hours	71 (50.4%)	139 (54.1%)
Total Epworth Sleepiness Scale		
< 6	44 (32.1%)	65 (26.1%)
6–10	65 (47.4%)	101 (40.6%)
>10	28 (20.4%)	83 (33.3%)
Overall Sleep Quality		
Very Good	33 (22.9%)	59 (23.2%)
Fairly Good	80 (55.6%)	146 (57.5%)
Fairly Bad	27 (18.7%)	46 (18.1%)
Very Bad	4 (2.8%)	3 (1.2%)
Problem with Daytime Sleepiness		
Yes	20 (13.7%)	39 (15.1%)
No	126 (86.3%)	219 (84.9%)
Problem with Restless Sleep		
Yes	52 (35.6%)	54 (20.9%)
No	94 (64.4%)	204 (79.1%)
Problem Falling Asleep		
Yes	10 (6.8%)	29 (11.2%)
No	136 (93.2%)	229 (88.8%)
Sleep Medication Use During Previous Month		
None	110 (76.9%)	210 (85.0%)
< Once/Week	9 (6.3%)	12 (4.9%)
1-2 Times/Week	6 (4.2%)	7 (2.8%)
> 3 Times/Week	18 (12.6%)	18 (7.3%)
Currently Taking Sleep Medication		
Yes	5 (5.0%)	6 (2.8%)
No	95 (95.0%)	210 (97.2%)

Variable	Sleep Apnea (n = 146)	No Sleep Apnea (n = 260)
Currently Taking Antihistamine/Decongestant		
Yes	22 (19.3%)	24 (10.5%)
No	92 (80.7%)	204 (89.5%)
History of High Blood Pressure		
Yes	50 (34.7%)	42 (16.4%)
No	94 (65.3%)	214 (83.6%)

Table 8. Distribution of UPenn Sleep Study Variables for Drivers Involved in Crashes and Drivers Not Involved in Crashes*

Variable	Pre-Diagnosis Crash (n=101)	Pre-Diagnosis No Crash (n=305)	Post-Diagnosis Crash (n=50)	Post-Diagnosis No Crash (n=356)
Sleep Apnea Severity				
Severe (AHI ≥ 30)	6 (5.9)	22 (7.2)	5 (10.0)	23 (6.5)
Moderate (AHI 15-30)	8 (7.9)	24 (7.9)	5 (10.0)	27 (7.6)
Mild (AHI 5-15)	20 (19.8)	66 (21.6)	11 (22.0)	75 (21.1)
None (AHI < 5)	67 (66.4)	193 (63.3)	29 (58.0)	231 (64.9)
Gender				
Male	98 (97.0)	286 (93.8)	46 (92.0)	338 (94.9)
Female	3 (3.0)	19 (6.2)	4 (8.0)	18 (5.1)
Age Group				
24–30	14 (13.9)	13 (4.3)	2 (4.0)	25 (7.0)
31–40	34 (33.7)	77 (25.2)	16 (32.0)	95 (26.7)
41–50	27 (26.7)	98 (32.1)	16 (32.0)	109 (30.6)
51–60	19 (18.8)	69 (22.6)	12 (24.0)	76 (21.3)
61–70	5 (5.0)	40 (13.1)	4 (8.0)	41 (11.5)
71–77	2 (2.0)	8 (2.6)	0 (0.0)	10 (2.8)
Marital Status				
Married	73 (73.7)	224 (73.7)	36 (73.5)	261 (73.7)
Single	17 (17.2)	36 (11.8)	6 (12.2)	47 (13.3)
Divorced/Separated/Widowed	9 (9.1)	44 (14.5)	7 (14.3)	46 (13.0)
Commercial Driving Experience (years)				
0–5	23 (23.2)	46 (15.4)	12 (24.0)	57 (16.4)
6–10	25 (25.3)	64 (21.4)	7 (14.0)	82 (23.6)
11–20	23 (23.2)	85 (28.4)	15 (30.0)	93 (26.7)
21–30	21 (21.1)	70 (23.4)	12 (24.0)	79 (22.7)
> 30	7 (7.1)	34 (11.4)	4 (8.0)	37 (10.6)
Body Mass Index (kg/m^2)				
20– <25	10 (10.2)	36 (12.3)	8 (17.0)	38 (11.1)
25– <30	39 (39.8)	109 (37.3)	14 (29.8)	134 (39.1)
30– <35	28 (28.6)	88 (30.1)	16 (34.0)	100 (29.1)
≥ 35	21 (21.4)	59 (20.2)	9 (19.2)	71 (20.7)

Variable	Pre-Diagnosis Crash (n=101)	Pre-Diagnosis No Crash (n=305)	Post-Diagnosis Crash (n=50)	Post-Diagnosis No Crash (n=356)
Alcohol Use (drinks/week)				
0–5	45 (60.8)	119 (56.7)	21 (61.8)	143 (57.2)
6–10	18 (24.3)	34 (16.2)	5 (14.7)	47 (18.8)
> 10	11 (14.9)	57 (27.1)	8 (23.5)	60 (24.0)
Currently Employed As Truck Driver				
Yes, Full Time	85 (84.2)	167 (54.8)	40 (80.0)	212 (59.6)
Yes, Part Time	15 (14.8)	63 (20.6)	5 (10.0)	73 (20.5)
No	1 (1.0)	75 (24.6)	5 (10.0)	71 (19.9)
Type of Driving				
Over the Road	9 (9.1)	19 (7.8)	4 (8.9)	24 (8.1)
Local	62 (62.6)	159 (65.4)	27 (60.0)	194 (65.3)
Both	28 (28.3)	65 (26.7)	14 (31.1)	79 (26.6)
Current Driving Schedule				
Days Only	41 (41.4)	106 (45.1)	17 (36.2)	130 (45.3)
Nights Only	5 (5.1)	11 (4.7)	3 (6.4)	13 (4.5)
Both	53 (53.5)	118 (50.2)	27 (57.4)	144 (50.2)
Drives a Local Truck				
Yes	47 (51.6)	87 (37.0)	12 (27.3)	122 (43.3)
No	44 (48.4)	148 (63.0)	32 (72.7)	160 (56.7)
Drives a Tractor-Trailer				
Yes	40 (45.5)	91 (38.9)	28 (66.7)	103 (36.8)
No	48 (54.5)	143 (61.1)	14 (33.3)	177 (63.2)
Works Rotating Shift				
Yes	15 (15.8)	43 (15.0)	6 (12.5)	52 (15.6)
No	80 (84.2)	244 (85.0)	42 (87.5)	282 (84.4)
Works Steady Night Shift				
Yes	14 (15.6)	34 (12.2)	7 (15.6)	41 (12.7)
No	76 (84.4)	245 (87.8)	38 (84.4)	283 (87.3)
Adjusted Miles/Year Driven				
< 10,000	10 (10.3)	51 (18.1)	3 (6.1)	58 (17.6)
10,000–25,000	23 (23.7)	77 (27.3)	9 (18.4)	91 (27.6)
25,001–50,000	27 (27.8)	58 (20.6)	10 (20.4)	75 (22.7)
50,001–75,000	12 (12.4)	32 (11.3)	9 (18.4)	35 (10.6)
> 75,000	25 (25.8)	64 (22.7)	18 (36.7)	71 (21.5)
Average Sleep During Past Month				
≤ 6 Hours	52 (52.5)	136 (45.5)	27 (56.2)	161 (46.0)
> 6 Hours	47 (47.5)	163 (54.5)	21 (43.8)	189 (54.0)
Total Epworth Sleepiness Scale				
< 6	19 (19.6)	74 (25.6)	8 (16.7)	85 (25.1)
6–10	39 (40.2)	127 (43.9)	25 (52.1)	141 (41.7)
>10	39 (40.2)	88 (30.5)	15 (31.2)	112 (33.1)

Variable	Pre-Diagnosis Crash (n=101)	Pre-Diagnosis No Crash (n=305)	Post-Diagnosis Crash (n=50)	Post-Diagnosis No Crash (n=356)
Overall Sleep Quality				
Very Good	18 (18.4)	74 (24.7)	10 (20.8)	82 (23.4)
Fairly Good	58 (59.2)	168 (56.0)	30 (62.5)	196 (56.0)
Fairly Bad	20 (20.4)	53 (17.7)	8 (16.7)	65 (18.6)
Very Bad	2 (2.0)	5 (1.7)	0 (0.0)	7 (2.0)
Problem with Daytime Sleepiness				
Yes	22 (22.0)	37 (12.2)	1 (2.0)	58 (16.3)
No	78 (78.0)	267 (87.8)	48 (98.0)	297 (83.7)
Problem with Restless Sleep				
Yes	25 (25.0)	81 (26.6)	10 (20.4)	96 (27.0)
No	75 (75.0)	223 (73.4)	39 (79.6)	259 (73.0)
Problem Falling Asleep				
Yes	8 (8.0)	31 (10.2)	1 (2.0)	38 (10.7)
No	92 (92.0)	273 (89.8)	48 (98.0)	317 (89.3)
Sleep Medication Use During Previous Month				
None	77 (79.4)	243 (82.9)	31 (64.6)	289 (84.5)
< Once/Week	8 (8.2)	13 (4.4)	3 (6.3)	18 (5.3)
1-2 Times/Week	4 (4.1)	9 (3.1)	7 (14.6)	6 (1.8)
> 3 Times/Week	8 (8.2)	28 (9.6)	7 (14.6)	29 (8.5)
Currently Taking Sleep Medication				
Yes	3 (4.1)	8 (3.3)	1 (2.9)	10 (3.6)
No	71 (95.9)	234 (96.7)	34 (97.1)	271 (96.4)
Currently Taking Antihistamine/Decongestant				
Yes	16 (19.3)	30 (11.6)	9 (21.4)	37 (12.3)
No	67 (80.7)	229 (88.4)	33 (78.6)	263 (87.7)
History of High Blood Pressure				
Yes	20 (20.0)	72 (24.0)	14 (28.6)	78 (22.2)
No	80 (80.0)	228 (76.0)	35 (71.4)	273 (77.8)

Note: Percentages shown in parentheses.

Quantitative or continuous variables (e.g., age, BMI, hours of sleep per night) were assessed using Analysis of Variance to compare the mean values between the crash vs. no crash groups and between the drivers with sleep apnea vs. drivers with no sleep apnea. Means were compared using the Student's *t*-test, and a *p*-value of 0.05 or less was used to establish statistical significance. In other words, a *p*-value of 0.05 or less for a particular variable would lead to rejection of the null hypothesis of no difference in mean values for the two groups, thereby indicating a statistically significant relationship between the variable and crash involvement of sleep apnea status. Qualitative (i.e., categorical and dichotomous yes/no) variables were analyzed using contingency tables, and the chi-square test was employed to test for association between two factors (for example, are drivers who reported having problems with restless sleep or who have trouble falling asleep at night more likely to be involved in a crash?). Again, a *p*-value of 0.05 or less is considered to indicate statistically significance evidence of an association between the two factors. Complete results of the exploratory data analysis are presented in Appendix A. The major findings are summarized in the following paragraphs.

From the list of sleep study data elements shown in Table 4, the following were found to be risk factors for sleep apnea:

- Age.
- Weight.
- Body Mass Index (weight/height^2).
- Apnea, snoring, and snorting during sleep.
- Race.
- Problem with restless sleep.
- High blood pressure.
- Other heart disease.

As discussed previously, age and body mass index have particularly strong relationships to the prevalence of sleep apnea. The mean age of subjects with some degree of sleep apnea was 48.7 years compared to an average age of 45.5 years for those who were not diagnosed with sleep apnea. Similarly, the mean BMI for sleep apnea patients was 34.2 kg/m^2 versus 29.1 kg/m^2 for the comparison group of drivers without sleep apnea.

The driver's current employment status, whether or not he or she drives a local truck, and whether or not the driver suffers from daytime sleepiness were all found to have a statistically significant association with commercial vehicle crashes, both before and after the driver underwent in-laboratory sleep testing at UPenn. It is interesting to note that drivers who suffer from daytime sleepiness were more likely to have a crash in the pre-diagnosis period but less likely to have a crash following diagnosis than drivers who do not suffer from daytime sleepiness. In addition, during the 7-year period prior to diagnosis in the sleep laboratory, age, years of commercial driving experience, and Epworth Sleepiness Scale score had a positive association with crash involvement. That is, the mean values of the crash group compared to the no-crash group for age (43.0 vs. 47.9 years), years of driving experience (14.5 vs. 17.4 years), and ESS score (9.7 vs. 8.6) were significantly different from each other at a 0.05 significance level. Furthermore, the variables that were significantly related to an increased crash risk for the 7-year period following sleep apnea diagnosis were miles per year driven, use of sleep medication, whether or not the driver operates a tractor-trailer, and whether or not the driver reported having difficulty falling asleep at night. The association between crash involvement and difficulty falling asleep was found to be negative, indicating that drivers who cannot fall asleep easily at night have a lower likelihood of crashes.

Summarizing the results of the exploratory data analysis, several sleep study variables were positively related to either crash involvement or the prevalence of sleep apnea. However, only age was found to be associated with both sleep apnea and the occurrence of crashes during the pre-diagnosis period. It is interesting to note that, whereas older drivers are at higher risk for sleep apnea, younger drivers with fewer years of commercial driving experience have an increased likelihood of motor vehicle crashes.

Contingency tables were developed to determine the relationship between crash involvement (i.e., was the driver involved in a crash, yes or no) and the presence of sleep apnea. Results for the 7-year period (1989–1996) prior to diagnosis of sleep apnea are shown in Table 9. Crash involvement for the sleep apnea patients (AHI ≥ 5) versus the comparison group of subjects without sleep apnea (AHI < 5) is nearly the same; that is, 23.3 percent of drivers who had sleep apnea as compared to 25.8 percent of drivers without apnea were involved in a commercial vehicle crash during the 7-year period prior to diagnosis. Of all drivers who had been in a crash, 33.7 percent were diagnosed with sleep apnea, and 36.7 percent of drivers in the no-crash group had sleep apnea. Thus, these similar outcomes seem to suggest a lack of association between crash involvement and sleep apnea, and this is confirmed by an insignificant chi-square test ($p = 0.578$).

Table 9. 2 × 2 Contingency Table: Presence of Sleep Apnea vs. Crash Involvement (Pre-Diagnosis)

Crash Involvement	**Sleep Apnea: Count,** Column %, Row %	**No Sleep Apnea: Count,** Column %, Row %	**TOTAL**
Crash	**34** 23.29 33.66	**67** 25.77 66.34	**101**
No Crash	**112** 76.71 36.72	**193** 74.23 63.28	**305**
TOTAL	**146**	**260**	**406**

Looking at the 7-year period following participation in the UPenn sleep study (1996–2003) in Table 10, we can see that crash involvement among sleep apnea patients is higher than in the comparison group—14.4 percent vs. 11.2 percent. But again, the chi-square statistics are not significant ($p = 0.346$). The results for all crashes over the entire 14-year period shown in Table 11 can be similarly interpreted. Therefore, there is no statistical evidence in these data to suggest that the presence of sleep apnea significantly increases the likelihood or the risk of motor vehicle crashes.

Table 10. 2 × 2 Contingency Table: Presence of Sleep Apnea vs. Crash Involvement (Post-Diagnosis)

Crash Involvement	**Sleep Apnea: Count,** Column %, Row %	**No Sleep Apnea: Count,** Column %, Row %	**TOTAL**
Crash	**21** 14.38 42.00	**29** 11.15 58.00	**50**
No Crash	**125** 85.62 35.11	**231** 88.85 64.89	**356**
TOTAL	**146**	**260**	**406**

Table 11. 2 × 2 Contingency Table: Presence of Sleep Apnea vs. Crash Involvement (All Crashes)

Crash Involvement	Sleep Apnea: Count, Column %, Row %	No Sleep Apnea: Count, Column %, Row %	TOTAL
Crash	**44** 30.14 34.11	**85** 32.69 65.89	**129**
No Crash	**102** 69.86 36.82	**175** 67.31 63.18	**277**
TOTAL	**146**	**260**	**406**

If the *presence* of sleep apnea in commercial drivers does not significantly influence the crash risk, the question arises as to whether the *severity* of sleep disturbances contributes to crashes. Hence, we investigated the relationship between crash involvement and the degree or severity of sleep apnea, as measured by the apnea/hypopnea index. Table 12, Table 13, and Table 14 show contingency tables of crash incidence distributed by sleep apnea severity for the pre-diagnosis period (1989–1996), post-diagnosis (1996–2003), and the entire 14-year period from 1989 to 2003, respectively. Looking first at the post-diagnosis crash involvement on Table 13, we see that crash incidence is higher for all three apnea severity categories than for the comparison group of drivers with no sleep apnea. Examination of the column percentages reveals that about 11 percent of drivers with no sleep apnea were involved in a crash as compared to approximately 18 percent of drivers with severe sleep apnea, 16 percent of drivers with moderate sleep apnea, and 13 percent of drivers with mild sleep apnea. Thus, it would appear that drivers with sleep apnea, particularly severe and moderate degrees of apnea, have a higher likelihood of crashes. However, once again, the data lack statistical evidence of a positive association between sleep apnea severity and post-diagnosis crash involvement, as indicated by an insignificant chi-square test ($p = 0.71$). Similar findings of no association of sleep apnea severity were obtained for pre-diagnosis crashes and all crashes shown in Table 12 and Table 13, respectively.

Table 12. Contingency Table of Sleep Apnea Severity by Crash Involvement (Pre-Diagnosis)

Crash Involvement	Sleep Apnea Severity Severe $AHI \geq 30$: Count, Column %, Row %	Sleep Apnea Severity Moderate $15 \leq AHI < 30$: Count, Column %, Row %	Sleep Apnea Severity Mild $5 \leq AHI < 15$: Count, Column %, Row %	Sleep Apnea Severity None $AHI < 5$: Count, Column %, Row %	TOTAL
Crash	**6** 21.43 5.94	**8** 25.00 7.92	**20** 23.26 19.80	**67** 25.77 66.34	**101**
No Crash	**22** 78.57 7.21	**24** 75.00 7.87	**66** 76.74 21.64	**193** 74.23 63.28	**305**
TOTAL	**28**	**32**	**86**	**260**	**406**

Table 13. Contingency Table of Sleep Apnea Severity by Crash Involvement (Post-Diagnosis)

Crash Involvement	Sleep Apnea Severity Severe AHI ≥ 30: Count, Column %, Row %	Sleep Apnea Severity Moderate 15 ≤ AHI < 30: Count, Column %, Row %	Sleep Apnea Severity Mild 5 ≤ AHI < 15: Count, Column %, Row %	Sleep Apnea Severity None AHI < 5: Count, Column %, Row %	TOTAL
Crash	**5** 17.86 10.00	**5** 15.63 10.00	**11** 12.79 22.00	**29** 11.15 58.00	**50**
No Crash	**23** 82.14 6.46	**27** 84.38 7.58	**75** 87.21 21.07	**231** 88.85 64.89	**356**
TOTAL	**28**	**32**	**86**	**260**	**406**

Table 14. Contingency Table of Sleep Apnea Severity by Crash Involvement (All Crashes)

Crash Involvement	Sleep Apnea Severity Severe AHI ≥ 30: Count, Column %, Row %	Sleep Apnea Severity Moderate 15 ≤ AHI < 30: Count, Column %, Row %	Sleep Apnea Severity Mild 5 ≤ AHI < 15: Count, Column %, Row %	Sleep Apnea Severity None AHI < 5: Count, Column %, Row %	TOTAL
Crash	**8** 28.57 6.20	**10** 31.25 7.75	**26** 30.23 20.16	**85** 32.69 65.89	**129**
No Crash	**20** 71.43 7.22	**22** 68.75 7.94	**60** 69.77 21.66	**175** 67.31 63.18	**277**
TOTAL	**28**	**32**	**86**	**260**	**406**

These results are summarized in Table 15, which presents the unadjusted and adjusted odds ratios for having a crash comparing drivers in each AHI category to those with no sleep apnea (AHI < 5 episodes/hour). Odds ratios were adjusted for potential confounding effects of the following factors by including them as independent variables in the logistic regression model: age, gender, alcohol use, body mass index, self-reported daytime sleepiness, presence or absence of high blood pressure, use or nonuse of medications causing drowsiness (i.e., sleep medicine, antihistamine, or decongestant), unusual work/sleep schedule (i.e., steady night shift work), and miles driven per year. The 95-percent confidence intervals on the odds ratios, shown in parentheses on Table 15, indicates that the relationship between sleep apnea severity and motor vehicle crashes is not statistically significant. The null hypothesis being tested in the logistic regression analysis is that the two possible outcomes, crash or no crash, are equally likely (i.e., Odds Ratio = 1). Since the value of 1 is contained in every confidence interval at a 95 percent level of significance, the null hypothesis of no association cannot be rejected, and we therefore conclude that there is no statistical evidence in the data to suggest that drivers with sleep apnea are more likely than drivers without sleep apnea to have a commercial vehicle crash.

Table 15. Relative Risk (Odds Ratio) of Crashes for Different Levels of Sleep Apnea Severity

Sleep Apnea Severity	Pre-Diagnosis Crashes: Unadjusted Odds Ratio *(95% CI)*	Pre-Diagnosis Crashes: Adjusted Odds Ratio *(95% CI)*	Post-Diagnosis Crashes: Unadjusted Odds Ratio *(95% CI)*	Post-Diagnosis Crashes: Adjusted Odds Ratio *(95% CI)*	All Crashes: Unadjusted Odds Ratio *(95% CI)*	All Crashes: Adjusted Odds Ratio *(95% CI)*
None (AHI<5)			Reference Category			
Any (AHI≥5)	0.87 *(0.54–1.40)*	0.84 *(0.36–1.88)*	1.34 *(0.73–2.43)*	0.87 *(0.25–2.85)*	0.89 *(0.57–1.37)*	0.71 *(0.33–1.51)*
Severe (AHI≥30)	0.79 *(0.28–1.91)*	0.92 *(0.11–5.50)*	1.73 *(0.55–4.59)*	1.74 *(0.07–23.82)*	0.82 *(0.33–1.88)*	0.61 *(0.07–3.55)*
Moderate (AHI 15-30)	0.96 *(0.39–2.16)*	0.84 *(0.16–3.51)*	1.48 *(0.47–3.85)*	0.87 *(0.04–8.01)*	0.94 *(0.41–2.02)*	0.54 *(0.11–2.18)*
Mild (AHI 5-15)	0.87 *(0.48–1.53)*	0.84 *(0.32–2.10)*	1.17 *(0.54–2.39)*	0.77 *(0.19–2.86)*	0.89 *(0.52–1.50)*	0.77 *(0.32–1.80)*

Next, we investigated whether or not drivers with various degrees of sleep apnea had a greater likelihood of being involved in multiple crashes over the 14-year period than drivers who did not have sleep apnea. In this case, the binary dependent variable in the logit model was given a value of 1 if the driver had more than one crash between 1989 and 2003 and a value of 0 for one or zero crashes. A contingency table showing the distribution of multiple-crash subjects by AHI category is shown in Table 16. Unadjusted and adjusted odds ratios for multiple crashes by AHI category are presented in Table 17. No association was found between sleep apnea presence or severity and multiple crashes. This suggests that the commercial drivers in this study who were diagnosed with sleep apnea were not at increased risk for having more than one crash over the 14-year period prior to and following diagnosis.

Table 16. Relationship of Sleep Apnea Severity to Multiple Crash Involvement (All Crashes)

Crash Involvement	Sleep Apnea Severity Severe AHI ≥ 30: **Count,** Column %, Row %	Sleep Apnea Severity Moderate 15 ≤ AHI < 30: **Count,** Column %, Row %	Sleep Apnea Severity Mild 5 ≤ AHI < 15: **Count,** Column %, Row %	Sleep Apnea Severity None AHI < 5: **Count,** Column %, Row %	TOTAL
More than 1 Crash	**3** 10.71 7.69	**4** 12.50 10.26	**10** 11.63 25.64	**22** 8.46 56.41	**39**
0 or 1 Crash	**25** 89.29 6.81	**28** 87.50 7.63	**76** 88.37 20.71	**238** 91.54 64.85	**367**
TOTAL	**28**	**32**	**86**	**260**	**406**

Table 17. Relative Risk of Multiple Crashes for Drivers with Sleep Apnea (All Crashes)

Sleep Apnea Severity	Unadjusted Odds Ratio *(95% CI)*	Adjusted Odds Ratio *(95% CI)*
None (AHI<5)	Reference	Category
Any (AHI≥5)	1.43 *(0.72-2.77)*	2.53 *(0.70-9.33)*
Severe (AHI≥30)	1.30 *(0.29-4.10)*	2.05 *(0.07-28.69)*
Moderate (AHI 15-30)	1.54 *(0.43-4.40)*	1.80 *(0.06-24.17)*
Mild (AHI 5-15)	1.42 *(0.62-3.07)*	2.97 *(0.78-11.64)*

In the final logistic regression analysis, we assessed the relationship between sleep apnea severity and the *severity* of motor vehicle crashes. For this analysis, only MCMIS crash data for the 7-year period after diagnosis in the UPenn sleep laboratory was used. The crash data collected for the pre-diagnosis period did not include any data elements that specified the severity of the crash or of the injuries sustained by the occupants of the vehicles involved. Table 18 shows the relationship between sleep apnea severity and crash severity. Because of several low cell frequencies seen in Table 18 (two cells are, in fact, empty), the "moderate" and "minor" crash severity categories were collapsed into a single group. A multinomial logit model was then estimated with crash severity as the response and sleep apnea severity as the predictor variable. In this analysis, a significant relationship was found between severe sleep apnea (AHI ≥ 30 episodes/hour) and severe crashes (i.e., multiple injuries and vehicle towed from accident scene). Drivers with severe sleep apnea were 4.6 times more likely (95 percent CI = 1.34–13.77) to be involved in a severe crash in the 7-year period than drivers with no sleep apnea. It was also found that drivers with severe sleep apnea were no more likely to be involved in moderate/minor crashes than those without sleep apnea. Moreover, no statistically significant relationship was found between either moderate or mild sleep apnea and crash severity.

Table 18. Relationship of Sleep Apnea Severity to Crash Severity (Post-Diagnosis)

Crash Severity	**Severe** **AHI ≥ 30:** **Count,** Column %, Row %	**Moderate** **15 < AHI < 30:** **Count,** Column %, Row %	**Mild** **5 < AHI < 15:** **Count,** Column %, Row %	**None** **AHI < 5:** **Count,** Column %, Row %	**TOTAL**
Severe	**5** 17.24 21.74	**1** 3.13 4.35	**6** 6.90 26.09	**11** 4.17 47.83	**23**
Moderate	**0** 0.00 0.00	**4** 12.50 20.00	**5** 5.75 25.00	**11** 4.17 55.00	**20**
Minor	**1** 3.45 7.69	**0** 0.00 0.00	**1** 1.15 7.69	**11** 4.17 84.62	**13**
No Crash	**23** 79.31 6.46	**27** 84.38 7.58	**75** 86.21 21.07	**231** 87.50 64.89	**356**
TOTAL	**29**	**32**	**87**	**264**	**412**

Several additional models were investigated to determine the best model for predicting the likelihood of crash involvement by truck drivers with and without sleep apnea in the University of Pennsylvania study. Given that the initial logistic regression found no significant relationships between sleep related variables and crashes, it was necessary to look at crashes as a function of the number of miles driven since the probability of a person being involved in a crash depends on how many miles a person drives in a given period of time. To accomplish this, a Poisson regression analysis was conducted. A Poisson regression equation relates a count or a rate, such as the number of crashes per miles driven, to a series of independent variables providing a structure for statistical analysis.

In our study, the number of miles driven per year reported by each driver was used in the analysis since this information was collected in the initial UPenn sleep apnea study period. It is important to recognize that these miles were very subjective and also that two surveys spanning several months needed to be used by the UPenn researchers since the initial response requested "miles driven in a truck," and many drivers reported that they were not currently employed as truck drivers (n = 76 or 19 percent). A subsequent survey conducted several months later indicated that 59 drivers reported that they were currently unemployed. Interestingly, these were not all the same unemployed drivers from the initial survey, suggesting that some drivers were able to find employment while others lost employment. It was discovered that 27 of the 406 drivers (6.6 percent) were unemployed at the time of both surveys, and this could be a potential source of error in the analysis that should be noted. Although one would expect that those unemployed during both surveys would not report any miles driven, 24 drivers surprisingly reported annual mileage driven ranging from 100 miles to 130,000 miles per year (mean = 20,997.13 and *SD* = 31,857.92). It should be noted that the data were adjusted to maximize the mileage driven at 130,000 miles per year. In other words, some drivers indicated they drove more than 130,000 miles per year; however, given the infeasibility of a predominantly short-haul driver population to do this, the miles were capped at 130,000 by analysts at UPenn.

There were also 30 missing observations in this latter survey. Discussions with analysts at the University of Pennsylvania revealed that these missing observations were most likely the subjects with the most severe sleep apnea since they were tested early in the study and did not have the benefit of responding to this latter survey. Given these differences in the two surveys, the analysts adjusted the miles driven per year to reflect the survey with the higher number of miles reported regardless of whether or not they were unemployed at the time both surveys were taken.

We then investigated whether the 27 drivers that were unemployed at the time of both survey should be excluded from the model. Of the 27 drivers that were unemployed, only one had a crash and it is highly unlikely that it was a work-related crash since the driver was not working. To further determine how much of an impact these 27 drivers had on the study, a comparison of the proportion unemployed in each sleep apnea group was investigated. From below Table 19, one can observe that they were fairly equally distributed among the severity type. Thus, the impact of including the unemployed drivers in the analysis was judged to be minimal, whereas the effect of excluding them from an already limited sample size of 406 would substantially weaken the statistical power of the analysis. For these reasons, it was decided to include the 27 unemployed drivers in the analysis.

Table 19. Comparison of Sleep Apnea Severity for Non-Employed Drivers to Total Sample

Sleep Apnea Severity	Non-Employed	Total Sample	Percent
Severe (AHICAT_1)	2	28	7.14%
Moderate (AHICAT_2)	2	32	6.25%
Mild (AHICAT_3)	7	86	8.14%
None (AHICAT_4)	16	260	6.15%
TOTAL	27	406	6.65%

As discussed previously, a simple logistic regression model was used to investigate the effect of sleep apnea on the likelihood of crash involvement and crash severity. However, this model does not take into account that crashes can be impacted over time and by miles driven. Therefore, a Poisson regression model was estimated to explore the impact of sleep apnea on crash rates (i.e., crashes as a function of miles driven). The results, shown in Table 20, indicate that none of the sleep apnea severity categories (AHICAT) had a significant impact on whether or not a driver had a high crash rate (probability – $P > |z|$ – was greater than 0.05), after adjusting for gender, age, use of sleep medication, use of antihistamine/decongestant, whether or not the driver operated a tractor-trailer, and full-time employment status. The variables that were significantly related to crashes per mile driven were age and antihistamine/decongestant use; the negative coefficients for these variables indicate that older drivers and drivers who were using antihistamine and/or decongestant medication were less likely to be involved in a crash.

Table 20. Results of Poisson Regression Analysis

Variable	Coefficient	95% Confidence Interval—Lower Limit	95% Confidence Interval—Upper Limit	Std. Error	Z	P > |z|
Constant	-11.099	-12.339	-9.859	0.633	-17.54	0.000
AHICAT_2	0.053	-0.712	0.818	0.390	0.14	0.892
AHICAT_3	0.235	-0.389	0.858	0.318	0.74	0.461
AHICAT_4	0.070	-0.506	0.646	0.294	0.24	0.812
Sex	0.345	-0.285	0.976	0.322	1.07	0.283
Age	-0.021	-0.035	-0.007	0.007	-2.87	0.004
Sleepmed	0.294	-0.024	0.613	0.163	1.81	0.070
Antihis	-0.383	-0.691	-0.075	0.157	-2.43	0.015
Cvtyp5	-0.111	-0.356	0.134	0.125	-0.89	0.376
Fulltruck	0.418	-0.008	0.843	0.217	1.92	0.054

Diagnostic evaluation of the Poisson regression model revealed that the mean (0.47) and variance (0.75) of the crash counts used as the dependent variable were not equal. This violates an important property of the Poisson distribution (i.e., that the mean must equal the variance). When the variance is larger than the mean, there is an indication of over dispersion in the data. Over dispersion, a common problem in Poisson regression, can produce severe underestimates of the standard errors and overestimates of test statistics. To correct for the problem of over dispersion, a negative binomial regression model was estimated. The results of this analysis are presented in Table 21. Again, no association was found between sleep apnea and crash rates; age and antihistamine/decongestant use were still significant factors.

Table 21. Results of Negative Binomial Regression Analysis

Variable	Coefficient	95% Confidence Interval—Lower Limit	95% Confidence Interval—Upper Limit	Std. Error	z	P > |z|
Constant	-10.199	-12.239	-8.160	1.040	-9.80	0.000
AHICAT_2	0.176	-1.024	1.375	0.612	0.29	0.774
AHICAT_3	0.407	-0.617	1.432	0.523	0.78	0.436
AHICAT_4	0.148	-0.806	1.101	0.487	0.30	0.762
Sex	0.157	-0.948	1.262	0.564	0.28	0.781
Age	-0.026	-0.048	-0.005	0.011	-2.40	0.017
Sleepmed	0.235	-0.287	0.757	0.266	0.88	0.377
Antihis	-0.629	-1.151	-0.108	0.266	-2.36	0.018
Cvtyp5	-0.128	-0.491	0.234	0.185	-0.69	0.487
Fulltruck	0.378	-0.187	0.943	0.288	1.31	0.190

It was shown earlier on Table 7 that of the 406 drivers used in this study, 277 (68.2 percent) were not involved in a crash over the 14-year study period. In other words, over two-thirds of the crash samples used in the analysis were zeros. This is a problem that is frequently encountered when analyzing crash or injury data. Therefore, in our final analysis we used a zero-inflated negative binomial model that takes into account both over dispersion and the large number of zeros in the crash counts. As observed in Table 22, the same results persisted and sleep-related variables did not have an impact on crash risk.

Table 22. Results of Zero-Inflated Negative Binomial Regression Analysis

Variable	Coefficient	95% Confidence Interval—Lower Limit	95% Confidence Interval—Upper Limit	Std. Error	z	P > |z|
Constant	-8.796	-10.534	-7.058	0.887	-9.92	0.000
AHICAT_2	-0.210	-1.255	0.835	0.533	-0.39	0.694
AHICAT_3	-0.242	-1.138	0.653	0.457	-0.53	0.596
AHICAT_4	-0.471	-1.308	0.366	0.427	-1.10	0.270
Sex	-0.264	-1.159	0.632	0.457	-0.58	0.564
Age	-0.002	-0.020	0.015	0.009	-0.27	0.788
Sleepmed	-0.017	-0.431	0.396	0.211	-0.08	0.934
Antihis	-0.222	-0.630	0.187	0.208	-1.06	0.287
Cvtyp5	-0.371	-0.694	-0.048	0.165	-2.25	0.024
Fulltruck	-0.481	-1.029	0.067	0.279	-1.72	0.085

It is important to note that separate analyses were performed using overall crash counts (shown in Table 20, Table 21, and Table 22), pre-diagnosis crash counts, and post-diagnosis crash counts as the dependent variables. However, even when the data were separated by pre- and post-diagnosis crash counts, there was still no impact on crash rates due to the prevalence of sleep apnea.

In summary, the presence and severity of obstructive sleep apnea among a population of 406 commercial truck drivers was analyzed as a risk factor for motor vehicle crashes. Logistic regression models were developed to determine the likelihood of crash involvement (i.e., having at least one crash), crash severity, and multiple crashes among commercial drivers before and after being diagnosed with sleep apnea. In addition, crashes were normalized by mileage driven, and Poisson regression and negative binomial regression models were developed to determine the effect of sleep apnea on crash rates. With the exception of a significant positive relationship between severe sleep apnea and severe crashes, results from this study showed that the presence and severity of sleep apnea in commercial truck drivers are not good predictors of motor vehicle crash involvement. In other words, we found no compelling statistical evidence that sleep apnea in general increases crash risk among commercial drivers, although it was found that severe sleep apnea increases the risk of severe crashes. Furthermore, there was no evidence from the data used in this study to suggest that crash risk is impacted before and after drivers are diagnosed with sleep apnea.

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4. CONCLUSIONS

A study was completed to assess the risks of commercial vehicle crashes based on the presence and severity of sleep apnea in a sample of 406 drivers in Pennsylvania. An analysis using logistic regression found no association between sleep apnea, as measured by the apnea/hypopnea index, and commercial motor vehicle crashes for unadjusted and adjusted estimates of relative risks. Patients with sleep apnea, as confirmed by polysomnography in overnight sleep testing, had no greater probability of having a crash than patients without sleep apnea, either before or after their diagnosis. Drivers with sleep apnea were also not found to be at an increased risk for multiple crashes. In the sleep study conducted by UPenn, sleep apnea patients with the most severe form of the condition (i.e., AHI ≥ 30 episodes/hour) exhibited degraded performance in tests sensitive to the effects of sleep loss such as the psychomotor vigilance reaction time test and the divided attention driving task [1]. However, no such link between the degree of sleep apnea and traffic crashes—either any crash or multiple crashes—was established in these analyses.

When we investigated the relationship between the degree or severity of sleep apnea and crash severity, we found that drivers with severe sleep apnea were 4.6 times more likely than drivers without sleep apnea to be involved in a severe crash (defined as a tow-away crash with multiple injuries). Patients with severe sleep apnea had no higher risk of less severe crashes than patients without sleep apnea, nor were any associations found between moderate or mild sleep apnea and crash severity.

Crashes were normalized by the amount of mileage driven per year for each driver to explore the effect of sleep apnea on crash rates. Crash rates for the 7-year periods prior to and following sleep apnea diagnosis, as well as overall crash rates for the entire 14-year study period were used as dependent variables in the analyses. No significant relationships between any of the sleep apnea severity categories and crash rates were found, thus providing further evidence that the presence of sleep apnea in commercial drivers does not lead to a higher likelihood of crashes.

The Epworth Sleepiness Scale, a self-reported measure of sleepiness based on the respondent's stated likelihood to doze in eight typical situations, was also investigated as an independent predictor of crash risk. Consistent with previous studies [4, 5], the Epworth scale failed to identify subjects with a higher risk of crashes. A possible reason for this absence of association could be the lack of adequate sensitivity and specificity with regard to driving performance in the questions from which the Epworth scale is derived [4]. Other subjective measures of sleepiness, namely the Karolinska Sleepiness Scale and the Stanford Sleepiness Scale, were also evaluated in this study and similar results were obtained; that is, no relationship between these two subjective measures of sleepiness and increased crash risk was found for the 406 subjects who participated in the UPenn sleep study.

The results of this study contradict those found in several previous studies, discussed in Section 1.2 of this report. Other studies found a strong positive relationship between sleep apnea and motor vehicle crashes. While it appears that sleep apnea is not a risk factor for vehicular crashes among a sample of 406 commercial motor vehicle operators, we must acknowledge the limitations of the data and warn that these results must be interpreted with caution. Odds ratios were adjusted for potential confounding variables. However, many of these confounding variables were based on self-reported information and many drivers may have misinterpreted some of the questions. For example, an initial survey was provided to drivers that asked for the number of monthly miles driven in a truck. Many of the drivers, however, were not primarily truck drivers but were actually bus drivers, construction vehicle operators, van drivers, or a combination of the above. Therefore, the number of miles driven as a commercial operator was actually underrepresented in many cases and, in other cases, was missing altogether. Consequently, adjusted odds ratios were based on fewer observations than the entire study population of 406 drivers, resulting in a loss of analytical power and less precise point estimates for the odds ratios. Furthermore, missing variables were biased toward patients with severe sleep apnea since these patients were recruited and tested first, before other subjects (with moderate, mild, or no sleep apnea) were tested and before additional questionnaires were developed. This may have led to the non-significant findings for the relationship between sleep apnea severity and crashes.

Another limitation of the study relates to the incomplete crash and driving records that were available. Information about pre-diagnosis crashes (1989─1996) was obtained through examination of State motor vehicle records. These records did not include out-of-State crashes or in-State minor "fender-bender" crashes, for which a State report may not be mandatory. Therefore, the pre-diagnosis crash rates may be underestimated. Also, the MCMIS crash file, which was used for post-diagnosis crashes, is known to include only about 60 percent of the commercial vehicle crashes that should be reported. Hence, crashes in the post-diagnosis period (1996─2003) are similarly underreported. The effect of underreported crashes on our results is mitigated somewhat by the fact that Pennsylvania typically reports a significantly higher percentage of commercial vehicle crashes (approximately 96 percent between 1998 and 2000) to MCMIS than the nation as a whole. Nevertheless, with these limited number of crash data, our analysis would most likely underestimate the association between sleep apnea and motor vehicle crashes.

The large majority of subjects analyzed in this study were short-haul drivers who operated local routes, typically within a 100-mile radius of their home base. These drivers generally drive more often in dense urban environments requiring a high level of alertness than long-haul truckers, who drive long stretches on interstate highways under monotonous driving conditions and who are more susceptible to fatigue and daytime sleepiness. In addition, not all subjects who participated in the study were employed on a full-time basis. According to questionnaire responses, 78 of the 406 subjects (19.2 percent) were employed only part-time, and 76 subjects (18.7 percent) were unemployed at the time of their participation in the sleep study. Although employment status is a dynamic variable subject to rapid and frequent change, the fact that 38 percent of the drivers were either unemployed or worked only part-time could underestimate the crash risk due to sleep apnea.

One final limitation in our dataset was that the mileage driven was not accurately reported by some drivers as discussed above, and other drivers failed to respond at all to the question regarding monthly mileage driven. Thus, normalizing crash rates by mileage driven and controlling for driving exposure, which is a very important factor in determining motor vehicle crashes, was very difficult in our analysis. However, using information provided by follow-up questionnaires that were given to drivers after the initial survey responses had been obtained, the monthly mileage driven by all drivers in the study was corrected. These data were used to estimate a Poisson regression model. Poisson regression analysis takes into account the number of crashes an individual has based on the number of miles he or she typically drives, or the crash rate. Therefore, a more comprehensive depiction of crash likelihood was provided based on the data available. Further, to allow for possible over dispersion that might violate the restrictive assumptions of the Poisson distribution (i.e., the mean must equal the variance), the data were also analyzed using negative binomial regression. Both regression modeling techniques failed to show a significant association between sleep apnea and crash rates. Nevertheless, the problem of inaccurate measures of driving exposure (i.e., mileage driven) should be addressed in any future research efforts.

Given the limitations in the data and the results of our analyses, some recommendations for future research can be suggested. With regard to study design and subject population, a major strength of this study was that every subject was clinically evaluated in a sleep laboratory and given an overnight polysomnography test. As a result, the presence and degree of obstructive sleep apnea was accurately diagnosed in the sleep apnea patient group, and the comparison group had no clinical evidence of a sleep disorder. Future studies to determine the crash risks associated with sleepiness or sleep disorders should therefore also include overnight sleep test results in addition to detailed crash histories in a comprehensive database. Recognizing the limitations of available crash information, self-reported crash data could also be collected for each driver to validate the information being obtained at the State level. Additionally, future studies should make every attempt to obtain prospective information regarding treatments advised and actually administered for the sleep disorders diagnosed during clinical testing. These data should include the recommended treatment, if any, follow-up on whether or not treatment was actually received, the extent of treatment (e.g., number of or length of treatments), and the effectiveness of treatment (e.g., driver's assessment of treatment effectiveness). This information is relevant because studies have shown that those who receive treatment for their condition over a long period of time are less likely to be involved in a motor vehicle crash. However, treatments are typically intrusive and expensive (e.g., continuous positive airway pressure [CPAP]), thereby reducing the likelihood that a driver would follow the recommended treatment for an extended period.

Future studies should also target long-haul commercial truck drivers who operate heavy tractor-trailer vehicles. In over-the-road highway driving, the longer distances and monotonous routine may contribute to drowsiness, and the higher speeds may increase the danger to drivers. Intuitively, it seems that the effects of sleep apnea and other sleep disorders that cause excessive daytime sleepiness would be exacerbated in long-haul truck drivers. It should be noted that only 28 subjects in our study population were exclusively long-haul drivers; this number was insufficient to evaluate the crash risk due to sleep apnea. As indicated earlier, the 406 drivers who participated in the UPenn sleep study operated various types of commercial vehicles, including tractor-trailers, buses, vans, and construction vehicles. Tractor-trailer drivers consisted of only 40 percent of the subjects, yet our analysis showed that tractor-trailer drivers were over three times more likely to be involved in a crash during the seven years following their participation in the sleep study and nearly twice as likely to have a crash in the 14-year period before and after in-laboratory testing than other drivers, after adjusting for mileage driven. Although sleep apnea was not found to be a significant factor in these crashes, the positive association with crash involvement suggests that tractor-trailer drivers should be investigated further in future research studies.

One final recommendation for future research pertains to crash data collection. In future studies, every possible effort should be made to obtain complete and accurate crash records for every subject in the study population. To accomplish this, access to several sources of crash data would be required, including nationwide crash data files such as MCMIS, State motor vehicle records, motor carrier crash records, and self-reported driver survey data. It would also be useful to obtain information about each driver's history of traffic citations and moving violations as well as accurate and reliable estimates of exposure, i.e., actual mileage driven per month or per year. And finally, data regarding crash causation in sufficient detail to allow the at-fault driver/vehicle to be determined would be helpful for future research studies. However, it is important to recognize that many drivers with sleep disorders have impaired cognitive abilities such as decreased reaction time, decision-making ability, and vigilance performance [*13, 21, 22, 23, 24, 25,* 26*, 27, 28*] which are difficult to determine at the scene of an incident. To some extent, at-fault judgment is made in police accident reports (e.g., indications of alcohol or drug use, or speeding). However, law enforcement officials are not adequately trained to attribute fault to sleepy drivers who crash, and key clues (on driver inattentiveness, distraction, and fatigue) are often lacking. There are no objective laboratory tests to determine pre-crash sleepiness, as there are to establish blood levels of alcohol, thus complicating investigations, especially where no capable, unbiased, or living witnesses exist [*29, 30, 31, 32*]. Therefore, the need for additional research to investigate these concerns further is necessary.

APPENDIX A—EXPLORATORY ANALYSIS RESULTS

Table 23. Analysis of Variance (ANOVA) Results for Continuous Variables Comparison of Mean Values for Patients with Sleep Apnea vs. Comparison Group of Patients with No Sleep Apnea

Dependent Variable	Mean Sleep Apnea	Mean No Sleep Apnea	F-Ratio	Pr > F
AGE*	48.70*	45.54*	7.296*	0.007*
WEI_LBS*	237.35*	203.27*	65.872*	<0.0001*
HEI_INCH	70.03	69.91	0.137	0.711
BMIPHYS*	34.18*	29.13*	88.652*	<0.0001*
TRDI3*	19.49*	1.32*	303.27*	<0.0001*
PSQI4	6.29	6.37	0.400	0.527
ESSTOTAL	9.15	8.74	0.718	0.397
I1*	1.21*	0.77*	19.729*	<0.0001*
I2	1.12	1.03	0.974	0.324
I3	0.66	0.58	1.113	0.292
SCOR36WI	1.36	2.30	2.503	0.116
SCOR36BE	5.69	6.52	0.560	0.455
SCOR36SP	1.76	2.68	1.047	0.308
SCOR36TO	7.32	8.23	0.562	0.454
SCOR37	2.90	3.08	0.105	0.748
T6	17.96	15.96	2.842	0.093
DRVDYWK	8.12	8.23	0.010	0.922
DRVHRDY	12.73	17.30	1.612	0.205
MILES	3,998	3,179	3.197	0.075
MILESY_A	47,222	47,157	0.000	0.988

Asterisks indicate variables are statistically significant at $\alpha = 0.05$

Table 24. ANOVA Results for Continuous Variables Comparison of Mean Values for Crash Drivers vs. No-Crash Drivers (Pre-Diagnosis Crashes)

Dependent Variable	Mean Crash	Mean No Crash	F-Ratio	Pr > F
AGE*	42.95*	47.91*	14.897*	0.0001*
WEI_LBS	217.95	214.57	0.453	0.501
HEI_INCH	70.12	69.89	0.395	0.530
BMIPHYS	31.14	30.82	0.239	0.625
TRDI3	6.68	8.24	1.040	0.308
PSQI4	6.18	6.39	2.184	0.140
ESSTOTAL*	9.65*	8.63*	3.814*	0.052*
I1	0.93	0.93	0.000	0.996
I2	1.13	1.04	0.819	0.366
I3*	0.74*	0.57*	4.485*	0.035*
SCOR36WI	1.21	2.09	1.623	0.204
SCOR36BE	5.41	6.47	0.741	0.390
SCOR36SP	2.04	2.41	0.136	0.713
SCOR36TO	6.69	8.31	1.454	0.229
SCOR37	2.22	3.31	3.248	0.073
T6*	14.48*	17.40*	4.897*	0.028*
DRVDYWK	7.48	8.47	0.758	0.385
DRVHRDY	16.33	15.45	0.052	0.819
MILES	3,407	3,482	0.023	0.878
MILESY_A	51,087	45,586	1.367	0.243

Asterisks indicate variables are statistically significant at $\alpha = 0.05$

Table 25. ANOVA Results for Continuous Variables Comparison of Mean Values for Crash Drivers vs. No-Crash Drivers (Post-Diagnosis Crashes)

Dependent Variable	Mean Crash	Mean No Crash	F-Ratio	Pr > F
AGE	45.80	46.80	0.338	0.561
WEI_LBS	217.56	215.11	0.135	0.713
HEI_INCH	70.23	69.91	0.468	0.494
BMIPHYS	31.08	30.88	0.053	0.819
TRDI3	8.91	7.70	0.358	0.550
PSQI4	6.34	6.34	0.000	1.000
ESSTOTAL	8.90	8.89	0.000	0.988
I1	0.90	0.93	0.044	0.834
I2	1.00	1.07	0.362	0.548
I3	0.67	0.60	0.367	0.545
SCOR36WI	1.75	1.90	0.028	0.866
SCOR36BE	7.42	6.00	0.796	0.373
SCOR36SP	1.17	2.45	0.818	0.367
SCOR36TO	9.26	7.70	0.740	0.390
SCOR37	2.40	3.09	0.660	0.417
T6	15.48	16.84	0.625	0.430
DRVDYWK	6.77	8.40	1.175	0.279
DRVHRDY	10.56	16.48	1.352	0.246
MILES	3,407	3,350	1.755	0.878
MILESY_A	64,476	44,612	10.847	0.243

Asterisks indicate variables are statistically significant at $\alpha = 0.05$

Table 26. Crash Involvement by Gender (Pre-Diagnosis Crashes)

Crash Involvement	Male: Count, Column %, Row %	Female: Count, Column %, Row %	TOTAL
Crash	98 25.52 97.03	3 13.64 2.97	101
No Crash	286 74.48 93.77	19 86.36 6.23	305
TOTAL	384	22	406

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	1.776	0.1826
Pearson	1.573	0.2098

Table 27. Crash Involvement by Gender (Post-Diagnosis Crashes)

Crash Involvement	Male: Count, Column %, Row %	Female: Count, Column %, Row %	TOTAL
Crash	46 11.98 92.00	4 18.18 8.00	50
No Crash	338 88.02 94.94	18 81.82 5.06	356
TOTAL	384	22	406

Test	**Chi Square**	**Prob > ChiSq**
Likelihood Ratio	0.664	0.4151
Pearson	0.741	0.3892

Table 28. Sleep Apnea Severity by Gender

Sleep Apnea Severity	Male: Count, Column %, Row %	Female: Count, Column %, Row %	TOTAL
Severe SA	26 6.77 92.86	2 9.09 7.14	28
Moderate SA	30 7.81 93.75	2 9.09 6.25	32
Mild SA	84 21.88 97.67	2 9.09 2.33	86
No SA	244 63.54 93.85	16 72.73 6.15	260
TOTAL	384	22	406

Test	**Chi Square**	**Prob > ChiSq**
Likelihood Ratio	2.475	0.4797
Pearson	2.085	0.5549

Table 29. Crash Involvement by Race (Pre-Diagnosis Crashes)

Crash Involvement	White: Count, Column %, Row %	Black: Count, Column %, Row %	Hispanic: Count, Column %, Row %	American Indian: Count, Column %, Row %	TOTAL
Crash	79 23.03 78.22	17 32.08 16.83	4 50.00 3.96	1 50.00 0.99	101
No Crash	264 76.97 86.56	36 67.92 11.80	4 50.00 1.31	1 50.00 0.33	305
TOTAL	343	53	8	2	406

Test	**Chi Square**	**Prob > ChiSq**
Likelihood Ratio	4.934	0.1767
Pearson	5.472	0.1403

Table 30. Crash Involvement by Race (Post-Diagnosis Crashes)

Crash Involvement	White: Count, Column %, Row %	Black: Count, Column %, Row %	Hispanic: Count, Column %, Row %	American Indian: Count, Column %, Row %	TOTAL
Crash	39 11.37 78.00	11 20.75 22.00	0 0.00 0.00	0 0.00 0.00	50
No Crash	304 88.63 85.39	42 79.25 11.80	8 100.00 2.25	2 100.00 0.56	356
TOTAL	343	53	8	2	406

Test	**Chi Square**	**Prob > ChiSq**
Likelihood Ratio	5.900	0.1166
Pearson	5.184	0.1588

Table 31. Sleep Apnea Severity by Race

Sleep Apnea Severity	White: Count, Column %, Row %	Black: Count, Column %, Row %	Hispanic: Count, Column %, Row %	American Indian: Count, Column %, Row %	TOTAL
Severe SA	18 5.25 64.29	8 15.09 28.57	2 25.00 7.14	0 0.00 0.00	28
Moderate SA	24 7.00 75.00	8 15.09 25.00	0 0.00 0.00	0 0.00 0.00	32
Mild SA	76 22.16 88.37	9 16.98 10.47	0 0.00 0.00	1 50.00 1.16	86
No SA	225 65.60 86.54	28 52.83 10.77	6 75.00 2.31	1 50.00 0.38	260
TOTAL	343	53	8	2	406

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	18.554	0.0293
Pearson	19.539	0.0210

Table 32. Crash Involvement by Marital Status (Pre-Diagnosis Crashes)

Crash Involvement	Married: Count, Column %, Row %	Single: Count, Column %, Row %	Separated/ Divorced: Count, Column %, Row %	Widow(er): Count, Column %, Row %	TOTAL
Crash	73 24.58 73.74	17 32.08 17.17	6 13.95 6.06	3 30.00 3.03	99
No Crash	224 75.42 73.68	36 67.92 11.84	37 86.05 12.17	7 70.00 2.30	304
TOTAL	297	53	43	10	403

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	4.624	0.2015
Pearson	4.386	0.2227

Table 33. Crash Involvement by Marital Status (Post-Diagnosis Crashes)

Crash Involvement	Married: Count, Column %, Row %	Single: Count, Column %, Row %	Separated/ Divorced: Count, Column %, Row %	Widow(er): Count, Column %, Row %	TOTAL
Crash	36 12.12 73.47	6 11.32 12.24	7 16.28 14.29	0 0.00 0.00	49
No Crash	261 87.88 73.73	47 88.68 13.28	36 83.72 10.17	10 100.00 2.82	354
TOTAL	297	53	43	10	403

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	3.255	0.3539
Pearson	2.103	0.5513

Table 34. Sleep Apnea Severity by Marital Status

Sleep Apnea Severity	Married: Count, Column %, Row %	Single: Count, Column %, Row %	Separated/ Divorced: Count, Column %, Row %	Widow(er): Count, Column %, Row %	TOTAL
Severe SA	23 7.74 82.14	3 5.66 10.71	1 2.33 3.57	1 10.00 3.57	28
Moderate SA	21 7.07 67.74	5 9.43 16.13	3 6.98 9.68	2 20.00 6.45	31
Mild SA	66 22.22 76.74	9 16.98 10.47	8 18.60 9.30	3 30.00 3.49	86
No SA	187 62.96 72.48	36 67.92 13.95	31 72.09 12.02	4 40.00 1.55	258
TOTAL	297	53	43	10	403

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	6.760	0.6621
Pearson	6.809	0.6570

Table 35. Crash Involvement by Daytime Sleepiness (Pre-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	22 37.29 22.00	78 22.61 78.00	100
No Crash	37 62.71 12.17	267 77.39 87.83	304
TOTAL	59	345	404

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	5.412	0.0200
Pearson	5.829	0.0158

Table 36. Crash Involvement by Daytime Sleepiness (Post-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	1 1.69 2.04	48 13.91 97.96	49
No Crash	58 98.31 16.34	297 86.09 83.66	355
TOTAL	59	345	404

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	10.070	0.0015
Pearson	7.057	0.0079

Table 37. Sleep Apnea Severity by Daytime Sleepiness

Sleep Apnea Severity	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Severe SA	6 10.17 21.43	22 6.38 78.57	28
Moderate SA	4 6.78 12.50	28 8.12 87.50	32
Mild SA	10 16.95 11.63	76 22.03 88.37	86
No SA	39 66.10 15.12	219 63.48 84.88	258
TOTAL	59	345	404

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	1.758	0.6241
Pearson	1.824	0.6097

Table 38. Crash Involvement by High Blood Pressure (Pre-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	9 21.95 9.00	91 25.07 91.00	100
No Crash	32 78.05 10.53	272 74.93 89.47	304
TOTAL	41	363	404

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	0.197	0.6573
Pearson	0.192	0.6611

Table 39. Crash Involvement by High Blood Pressure (Post-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	3 7.32 6.12	46 12.67 93.88	49
No Crash	38 92.68 10.70	317 87.33 89.30	355
TOTAL	41	363	404

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	1.119	0.2902
Pearson	0.991	0.3194

Table 40. Sleep Apnea Severity by High Blood Pressure

Sleep Apnea Severity	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Severe SA	10 24.39 35.71	18 4.96 64.29	28
Moderate SA	6 14.63 18.75	26 7.16 81.25	32
Mild SA	12 29.27 13.95	74 20.39 86.05	86
No SA	13 31.71 5.04	245 67.49 94.96	258
TOTAL	41	363	404

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	25.380	<0.0001
Pearson	31.419	<0.0001

Table 41. Crash Involvement by Restless Sleep (Pre-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	25 23.58 25.00	75 25.17 75.00	100
No Crash	81 76.42 26.64	223 74.83 73.36	304
TOTAL	106	298	404

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	0.106	0.7448
Pearson	0.105	0.7457

Table 42. Crash Involvement by Restless Sleep (Post-Diagnosis Crashes)

Crash Involvement	Count, Column %, Row %	Count, Column %, Row %	TOTAL
Crash	10 9.43 20.41	39 13.09 79.59	49
No Crash	96 90.57 27.04	259 86.91 72.96	355
TOTAL	106	298	404

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	1.026	0.3112
Pearson	0.979	0.3224

Table 43. Sleep Apnea Severity by Restless Sleep

Sleep Apnea Severity	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Severe SA	10 9.43 35.71	18 6.04 64.29	28
Moderate SA	9 8.49 28.13	23 7.72 71.88	32
Mild SA	33 31.13 38.37	53 17.79 61.63	86
No SA	54 50.94 20.93	204 68.46 79.07	258
TOTAL	106	298	404

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	11.253	0.0104
Pearson	11.656	0.0087

Table 44. Crash Involvement by Other Heart Disease (Pre-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	1 16.67 1.00	99 24.87 99.00	100
No Crash	5 83.33 1.64	299 75.13 98.36	304
TOTAL	6	398	404

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	0.233	0.6295
Pearson	0.214	0.6438

Table 45. Crash Involvement by Other Heart Disease (Post-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	0 0.00 0.00	49 12.31 100.00	49
No Crash	6 100.00 1.69	349 87.69 98.31	355
TOTAL	6	398	404

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	1.564	0.2111
Pearson	0.841	0.3592

Table 46. Sleep Apnea Severity by Other Heart Disease

Sleep Apnea Severity	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Severe SA	1 16.67 3.57	27 6.78 96.43	28
Moderate SA	0 0.00 0.00	32 8.04 100.00	32
Mild SA	4 66.67 4.65	82 20.60 95.35	86
No SA	1 16.67 0.39	257 64.57 99.61	258
TOTAL	6	398	404

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	8.341	0.0395
Pearson	9.331	0.0252

Table 47. Crash Involvement by Cannot Fall Asleep (Pre-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	8 20.51 8.00	92 25.21 92.00	100
No Crash	31 79.49 10.20	273 74.79 89.80	304
TOTAL	39	365	404

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	0.432	0.5108
Pearson	0.417	0.5186

Table 48. Crash Involvement by Cannot Fall Asleep (Post-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	1 2.56 2.04	48 13.15 97.96	49
No Crash	38 97.44 10.70	317 86.85 89.30	355
TOTAL	39	365	404

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	5.094	0.0240
Pearson	3.705	0.0542

Table 49. Sleep Apnea Severity by Cannot Fall Asleep

Sleep Apnea Severity	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Severe SA	1 2.56 3.57	27 7.40 96.43	28
Moderate SA	3 7.69 9.38	29 7.95 90.63	32
Mild SA	6 15.38 6.98	80 21.92 93.02	86
No SA	29 74.36 11.24	229 62.74 88.76	258
TOTAL	39	365	404

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	3.018	0.3888
Pearson	2.642	0.4502

Table 50. Crash Involvement by Rotating Shift (Pre-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	15 25.86 15.79	80 24.69 84.21	95
No Crash	43 74.14 14.98	244 75.31 85.02	287
TOTAL	58	324	382

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	0.036	0.8499
Pearson	0.036	0.8493

Table 51. Crash Involvement by Rotating Shift (Post-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	6 10.34 12.50	42 12.96 87.50	48
No Crash	52 89.66 15.57	282 87.04 84.43	334
TOTAL	58	324	382

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	0.321	0.5710
Pearson	0.307	0.5796

Table 52. Sleep Apnea Severity by Rotating Shift

Sleep Apnea Severity	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Severe SA	6 10.34 21.43	22 6.79 78.57	28
Moderate SA	5 8.62 17.86	23 7.10 82.14	28
Mild SA	9 15.52 11.11	72 22.22 88.89	81
No SA	38 65.52 15.51	207 63.89 84.49	245
TOTAL	58	324	382

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	2.070	0.5580
Pearson	2.067	0.5587

Table 53. Crash Involvement by Steady Night Shift (Pre-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	14 29.17 15.56	76 23.68 84.44	90
No Crash	34 70.83 12.19	245 76.32 87.81	279
TOTAL	48	321	369

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	0.660	0.4167
Pearson	0.683	0.4087

Table 54. Crash Involvement by Steady Night Shift (Post-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	7 14.58 15.56	38 11.84 84.44	45
No Crash	41 85.42 12.65	283 88.16 87.35	324
TOTAL	48	321	369

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	0.281	0.5960
Pearson	0.294	0.5877

Table 55. Sleep Apnea Severity by Steady Night Shift

Sleep Apnea Severity	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Severe SA	4 8.33 15.38	22 6.85 84.62	26
Moderate SA	8 16.67 29.63	19 5.92 70.37	27
Mild SA	8 16.67 10.13	71 22.12 89.87	79
No SA	28 58.33 11.81	209 65.11 88.19	237
TOTAL	48	321	369

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	6.165	0.1039
Pearson	7.600	0.0550

Table 56. Crash Involvement by Overall Sleep Quality (Pre-Diagnosis Crashes)

Crash Involvement	Very Good: Count, Column %, Row %	Fairly Good: Count, Column %, Row %	Fairly Bad: Count, Column %, Row %	Very Bad: Count, Column %, Row %	TOTAL
Crash	18 19.57 18.37	58 25.66 59.18	20 27.40 20.41	2 28.57 2.04	98
No Crash	74 80.43 24.67	168 74.34 56.00	53 72.60 17.67	5 71.43 1.67	300
TOTAL	92	226	73	7	398

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	1.817	0.6111
Pearson	1.761	0.6234

Table 57. Crash Involvement by Overall Sleep Quality (Post-Diagnosis Crashes)

Crash Involvement	Very Good: Count, Column %, Row %	Fairly Good: Count, Column %, Row %	Fairly Bad: Count, Column %, Row %	Very Bad: Count, Column %, Row %	TOTAL
Crash	10 10.87 20.83	30 13.27 62.50	8 10.96 16.67	0 0.00 0.00	48
No Crash	82 89.13 23.43	196 86.73 56.00	65 89.04 18.57	7 100.00 2.00	350
TOTAL	92	226	73	7	398

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	2.317	0.5092
Pearson	1.481	0.6868

Table 58. Sleep Apnea Severity by Overall Sleep Quality

Sleep Apnea Severity	Very Good: Count, Column %, Row %	Fairly Good: Count, Column %, Row %	Fairly Bad: Count, Column %, Row %	Very Bad: Count, Column %, Row %	TOTAL
Severe SA	8 8.70 28.57	16 7.08 57.14	3 4.11 10.71	1 14.29 3.57	28
Moderate SA	5 5.43 16.13	21 9.29 67.74	5 6.85 16.13	0 0.00 0.00	31
Mild SA	20 21.74 23.53	43 19.03 50.59	19 26.03 22.35	3 42.86 3.53	85
No SA	59 64.13 23.23	146 64.60 57.48	46 63.01 18.11	3 42.86 1.18	254
TOTAL	92	226	73	7	398

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	7.354	0.6003
Pearson	7.065	0.6304

Table 59. Crash Involvement by Sleep Medicine Use (Pre-Diagnosis Crashes)

Crash Involvement	None: Count, Column %, Row %	< 1 Time/Week Count, Column %, Row %	1–2 Times/Week Count, Column %, Row %	> 3 Times/Week Count, Column %, Row %	TOTAL
Crash	77 24.06 79.38	8 38.10 8.25	4 30.77 4.12	8 22.22 8.25	97
No Crash	243 75.94 82.94	13 61.90 4.44	9 69.23 3.07	28 77.78 9.56	293
TOTAL	320	21	13	36	390

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	2.271	0.5182
Pearson	2.455	0.4836

Table 60. Crash Involvement by Sleep Medicine Use (Post-Diagnosis Crashes)

Crash Involvement	None: Count, Column %, Row %	< 1 Time/Week Count, Column %, Row %	1–2 Times/Week Count, Column %, Row %	> 3 Times/Week Count, Column %, Row %	TOTAL
Crash	31 9.69 64.58	3 14.29 6.25	7 53.85 14.58	7 19.44 14.58	48
No Crash	289 90.31 84.50	18 85.71 5.26	6 46.15 1.75	29 80.56 8.48	342
TOTAL	320	21	13	36	390

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	16.688	0.0008
Pearson	24.593	<0.0001

Table 61. Sleep Apnea Severity by Sleep Medicine Use

Sleep Apnea Severity	None: Count, Column %, Row %	< 1 Time/Week Count, Column %, Row %	1–2 Times/Week Count, Column %, Row %	> 3 Times/Week Count, Column %, Row %	TOTAL
Severe SA	21 6.56 77.78	2 9.52 7.41	0 0.00 0.00	4 11.11 14.81	27
Moderate SA	25 7.81 78.13	1 4.76 3.13	3 23.08 9.38	3 8.33 9.38	32
Mild SA	64 20.00 76.19	6 28.57 7.14	3 23.08 3.57	11 30.56 13.10	84
No SA	210 65.63 85.02	12 57.14 4.86	7 53.85 2.83	18 50.00 7.29	247
TOTAL	320	21	13	36	390

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	9.262	0.4134
Pearson	9.741	0.3719

Table 62. Crash Involvement by Fall Asleep at Work (Pre-Diagnosis Crashes)

Crash Involvement	Never: Count, Column %, Row %	Rarely: Count, Column %, Row %	1–2/Week Count, Column %, Row %	3–4/Week Count, Column %, Row %	5–7/Week Count, Column %, Row %	TOTAL
Crash	65 23.30 65.66	17 24.29 17.17	12 46.15 12.12	5 33.33 5.05	0 0.00 0.00	99
No Crash	214 76.70 72.30	53 75.71 17.91	14 53.85 4.73	10 66.67 3.38	5 100.00 1.69	296
TOTAL	279	70	26	15	5	395

Test	**Chi Square**	**Prob > ChiSq**
Likelihood Ratio	5.893	0.1169
Pearson	6.643	0.0842

Table 63. Crash Involvement by Fall Asleep at Work (Post-Diagnosis Crashes)

Crash Involvement	Never: Count, Column %, Row %	Rarely: Count, Column %, Row %	1–2/Week Count, Column %, Row %	3–4/Week Count, Column %, Row %	5–7/Week Count, Column %, Row %	TOTAL
Crash	34 12.19 69.39	8 11.43 16.33	2 7.69 4.08	4 26.67 8.16	1 20.00 2.04	49
No Crash	245 87.81 70.81	62 88.57 17.92	24 92.31 6.94	11 73.33 3.18	4 80.00 1.16	346
TOTAL	279	70	26	15	5	395

Test	**Chi Square**	**Prob > ChiSq**
Likelihood Ratio	3.122	0.5377
Pearson	3.678	0.4513

Table 64. Sleep Apnea Severity by Fall Asleep at Work

Sleep Apnea Severity	Never: Count, Column %, Row %	Rarely: Count, Column %, Row %	1–2/Week Count, Column %, Row %	3–4/Week Count, Column %, Row %	5–7/Week Count, Column %, Row %	TOTAL
Severe SA	15 5.38 53.57	9 12.86 32.14	2 7.69 7.14	1 6.67 3.57	1 20.00 3.57	28
Moderate SA	19 6.81 59.38	6 8.57 18.75	5 19.23 15.63	2 13.33 6.25	0 0.00 0.00	32
Mild SA	63 22.58 75.00	16 22.86 19.05	3 11.54 3.57	2 13.33 2.38	0 0.00 0.00	84
No SA	182 65.23 72.51	39 55.71 15.54	16 61.54 6.37	10 66.67 3.98	4 80.00 1.59	251
TOTAL	279	70	26	15	5	395

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	14.816	0.2516
Pearson	15.141	0.2338

Table 65. Crash Involvement by Excessive Sleepiness (Pre-Diagnosis Crashes)

Crash Involvement	Never: Count, Column %, Row %	Rarely: Count, Column %, Row %	1–2/Week Count, Column %, Row %	3–4/Week Count, Column %, Row %	5–7/Week Count, Column %, Row %	TOTAL
Crash	39 22.67 40.21	23 21.30 23.71	20 32.79 20.62	12 38.71 12.37	3 15.79 3.09	97
No Crash	133 77.33 45.24	85 78.70 28.91	41 67.21 13.95	19 61.29 6.46	16 84.21 5.44	294
TOTAL	172	108	61	31	19	391

Test	Chi Square		Prob > ChiSq
Likelihood Ratio	6.947	0.1387	
Pearson	7.256	0.1230	

Table 66. Crash Involvement by Excessive Sleepiness (Post-Diagnosis Crashes)

Crash Involvement	Never: Count, Column %, Row %	Rarely: Count, Column %, Row %	1–2/Week Count, Column %, Row %	3–4/Week Count, Column %, Row %	5–7/Week Count, Column %, Row %	TOTAL
Crash	24 13.95 50.00	10 9.26 20.83	7 11.48 14.58	4 12.90 8.33	3 15.79 6.25	48
No Crash	148 86.05 43.15	98 90.74 28.57	54 88.52 15.74	27 87.10 7.87	16 84.21 4.66	343
TOTAL	172	108	61	31	19	391

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	1.670	0.7962
Pearson	1.628	0.8038

Table 67. Sleep Apnea Severity by Excessive Sleepiness

Sleep Apnea Severity	Never: Count, Column %, Row %	Rarely: Count, Column %, Row %	1–2/Week Count, Column %, Row %	3–4/Week Count, Column %, Row %	5–7/Week Count, Column %, Row %	TOTAL
Severe SA	10 5.81 38.46	8 7.41 30.77	4 6.56 15.38	2 6.45 7.69	2 10.53 7.69	26
Moderate SA	10 5.81 31.25	11 10.19 34.38	4 6.56 12.50	6 19.35 18.75	1 5.26 3.13	32
Mild SA	36 20.93 43.37	21 19.44 25.30	14 22.95 16.87	8 25.81 9.64	4 21.05 4.82	83
No SA	116 67.44 46.40	68 62.96 27.20	39 63.93 15.60	15 48.39 6.00	12 63.16 4.80	250
TOTAL	172	108	61	31	19	391

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	8.459	0.7483
Pearson	9.618	0.6494

Table 68. Crash Involvement by Currently Using Sleep Med. (Pre-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	3 27.27 4.05	71 23.28 95.95	74
No Crash	8 72.73 3.31	234 76.72 96.69	242
TOTAL	11	305	316

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	0.091	0.7626
Pearson	0.094	0.7586

Table 69. Crash Involvement by Currently Using Sleep Med. (Post-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	1 9.09 2.86	34 11.15 97.14	35
No Crash	10 90.91 3.56	271 88.85 96.44	281
TOTAL	11	305	316

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	0.048	0.8264
Pearson	0.046	0.8309

Table 70. Sleep Apnea Severity by Currently Using Sleep Med.

Sleep Apnea Severity	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Severe SA	1 9.09 6.25	15 4.92 93.75	16
Moderate SA	2 18.18 8.33	22 7.21 91.67	24
Mild SA	2 18.18 3.33	58 19.02 96.67	60
No SA	6 54.55 2.78	210 68.85 97.22	216
TOTAL	11	305	316

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	1.864	0.6010
Pearson	2.369	0.4995

Table 71. Crash Involvement by Using Antihist./Decong. (Pre-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	16 34.78 19.28	67 22.64 80.72	83
No Crash	30 65.22 11.58	229 77.36 88.42	259
TOTAL	46	296	342

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	2.986	0.0840
Pearson	3.196	0.0738

Table 72. Crash Involvement by Using Antihist./Decong. (Post-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	9 19.57 21.43	33 11.15 78.57	42
No Crash	37 80.43 12.33	263 88.85 87.67	300
TOTAL	46	296	342

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	2.329	0.1269
Pearson	2.618	0.1057

Table 73. Sleep Apnea Severity by Using Antihist./Decong.

Sleep Apnea Severity	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Severe SA	4 8.70 22.22	14 4.73 77.78	18
Moderate SA	5 10.87 20.00	20 6.76 80.00	25
Mild SA	13 28.26 18.31	58 19.59 81.69	71
No SA	24 52.17 10.53	204 68.92 89.47	228
TOTAL	46	296	342

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	4.951	0.1754
Pearson	5.226	0.1560

Table 74. Crash Involvement by Treated for Apnea (Pre-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	0 0.00 0.00	92 25.00 100.00	92
No Crash	6 100.00 2.13	276 75.00 97.87	282
TOTAL	6	368	374

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	3.420	0.0644
Pearson	1.989	0.1584

Table 75. Crash Involvement by Treated for Apnea (Post-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	1 16.67 2.38	41 11.14 97.62	42
No Crash	5 83.33 1.51	327 88.86 98.49	332
TOTAL	6	368	374

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	0.161	0.6886
Pearson	0.181	0.6707

Table 76. Sleep Apnea Severity by Treated for Sleep Apnea

Sleep Apnea Severity	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Severe SA	2 33.33 9.52	19 5.16 90.48	21
Moderate SA	2 33.33 6.45	29 7.88 93.55	31
Mild SA	2 33.33 2.50	78 21.20 97.50	80
No SA	0 0.00 0.00	242 65.76 100.00	242
TOTAL	6	368	374

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	14.748	0.0020
Pearson	17.310	0.0006

Table 77. Crash Involvement by Drives a Local Truck (Pre-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	47 35.07 51.65	44 22.92 48.35	91
No Crash	87 64.93 37.02	148 77.08 62.98	235
TOTAL	134	192	326

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	5.742	0.0166
Pearson	5.797	0.0160

Table 78. Crash Involvement by Drives a Local Truck (Post-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	12 8.96 27.27	32 16.67 72.73	44
No Crash	122 91.04 43.26	160 83.33 56.74	282
TOTAL	134	192	326

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	4.195	0.0405
Pearson	4.020	0.0450

Table 79. Sleep Apnea Severity by Drives a Local Truck

Sleep Apnea Severity	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Severe SA	6 4.48 35.29	11 5.73 64.71	17
Moderate SA	10 7.46 35.71	18 9.38 64.29	28
Mild SA	26 19.40 38.24	42 21.88 61.76	68
No SA	92 68.66 43.19	121 63.02 56.81	213
TOTAL	134	192	326

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	1.197	0.7537
Pearson	1.188	0.7559

Table 80. Crash Involvement by Drives a Van (Pre-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	12 23.08 13.19	79 29.04 86.81	91
No Crash	40 76.92 17.17	193 70.96 82.83	233
TOTAL	52	272	324

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	0.795	0.3726
Pearson	0.770	0.3803

Table 81. Crash Involvement by Drives a Van (Post-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	6 11.54 13.64	38 13.97 86.36	44
No Crash	46 88.46 16.43	234 86.03 83.57	280
TOTAL	52	272	324

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	0.228	0.6329
Pearson	0.220	0.6390

Table 82. Sleep Apnea Severity by Drives a Van

Sleep Apnea Severity	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Severe SA	4 7.69 22.22	14 5.15 77.78	18
Moderate SA	3 5.77 10.71	25 9.19 89.29	28
Mild SA	13 25.00 19.12	55 20.22 80.88	68
No SA	32 61.54 15.24	178 65.44 84.76	210
TOTAL	52	272	324

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	1.678	0.6419
Pearson	1.678	0.6418

Table 83. Crash Involvement by Drives a Bus (Pre-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	14 22.58 15.56	76 29.12 84.44	90
No Crash	48 77.42 20.60	185 70.88 79.40	233
TOTAL	62	261	323

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	1.101	0.2939
Pearson	1.065	0.3020

Table 84. Crash Involvement by Drives a Bus (Post-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	12 19.35 27.27	32 12.26 72.73	44
No Crash	50 80.65 17.92	229 87.74 82.08	279
TOTAL	62	261	323

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	1.986	0.1588
Pearson	2.143	0.1432

Table 85. Sleep Apnea Severity by Drives a Bus

Sleep Apnea Severity	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Severe SA	4 6.45 22.22	14 5.36 77.78	18
Moderate SA	8 12.90 28.57	20 7.66 71.43	28
Mild SA	10 16.13 14.93	57 21.84 85.07	67
No SA	40 64.52 19.05	170 65.13 80.95	210
TOTAL	62	261	323

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	2.374	0.4985
Pearson	2.484	0.4782

Table 86. Crash Involvement by Drives Construction Vehicle (Pre-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	20 29.41 22.22	70 27.45 77.78	90
No Crash	48 70.59 20.60	185 72.55 79.40	233
TOTAL	68	255	323

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	0.102	0.7496
Pearson	0.103	0.7486

Table 87. Crash Involvement by Drives Construction Vehicle (Post-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	5 7.35 11.36	39 15.29 88.64	44
No Crash	63 92.65 22.58	216 84.71 77.42	279
TOTAL	68	255	323

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	3.249	0.0715
Pearson	2.877	0.0898

Table 88. Sleep Apnea Severity by Drives Construction Vehicle

Sleep Apnea Severity	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Severe SA	4 5.88 22.22	14 5.49 77.78	18
Moderate SA	4 5.88 14.29	24 9.41 85.71	28
Mild SA	17 25.00 25.37	50 19.61 74.63	67
No SA	43 63.24 20.48	167 65.49 79.52	210
TOTAL	68	255	323

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	1.621	0.6547
Pearson	1.581	0.6638

Table 89. Crash Involvement by Drives Tractor-Trailer (Pre-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	40 30.53 45.45	48 25.13 54.55	88
No Crash	91 69.47 38.89	143 74.87 61.11	234
TOTAL	131	191	322

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	1.135	0.2867
Pearson	1.142	0.2852

Table 90. Crash Involvement by Drives Tractor-Trailer (Post-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	28 21.37 66.67	14 7.33 33.33	42
No Crash	103 78.63 36.79	177 92.67 63.21	280
TOTAL	131	191	322

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	13.303	0.0003
Pearson	13.513	0.0002

Table 91. Sleep Apnea Severity by Drives Tractor-Trailer

Sleep Apnea Severity	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Severe SA	8 6.11 44.44	10 5.24 55.56	18
Moderate SA	14 10.69 50.00	14 7.33 50.00	28
Mild SA	31 23.66 46.97	35 18.32 53.03	66
No SA	78 59.54 37.14	132 69.11 62.86	210
TOTAL	131	191	322

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	3.262	0.3529
Pearson	3.284	0.3498

Table 92. Crash Involvement by History of High BP (Pre-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	20 21.74 20.00	80 25.97 80.00	100
No Crash	72 78.26 24.00	228 74.03 76.00	300
TOTAL	92	308	400

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	0.693	0.4053
Pearson	0.678	0.4104

Table 93. Crash Involvement by History of High BP (Post-Diagnosis Crashes)

Crash Involvement	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Crash	14 15.22 28.57	35 11.36 71.43	49
No Crash	78 84.78 22.22	273 88.64 77.78	351
TOTAL	92	308	400

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	0.937	0.3331
Pearson	0.979	0.3225

Table 94. Sleep Apnea Severity by History of High Blood Pressure

Sleep Apnea Severity	Yes: Count, Column %, Row %	No: Count, Column %, Row %	TOTAL
Severe SA	15 16.30 53.57	13 4.22 46.43	28
Moderate SA	11 11.96 36.67	19 6.17 63.33	30
Mild SA	24 26.09 27.91	62 20.13 72.09	86
No SA	42 45.65 16.41	214 69.48 83.59	256
TOTAL	92	308	400

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	22.953	<0.0001
Pearson	25.394	<0.0001

Table 95. Crash Involvement by Employment Status (Pre-Diagnosis Crashes)

Crash Involvement	Full Time: Count, Column %, Row %	Part Time: Count, Column %, Row %	Not Currently Employed: Count, Column %, Row %	TOTAL
Crash	85 33.73 84.16	15 19.23 14.85	1 1.32 0.99	101
No Crash	167 66.27 54.75	63 80.77 20.66	75 98.68 24.59	305
TOTAL	252	78	76	406

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	46.324	<0.0001
Pearson	34.475	<0.0001

Table 96. Crash Involvement by Employment Status (Post-Diagnosis Crashes)

Crash Involvement	Full Time: Count, Column %, Row %	Part Time: Count, Column %, Row %	Not Currently Employed: Count, Column %, Row %	TOTAL
Crash	40 15.87 80.00	5 6.41 10.00	5 6.58 10.00	50
No Crash	212 84.13 59.55	73 93.59 20.51	71 93.42 19.94	356
TOTAL	252	78	76	406

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	8.455	0.0146
Pearson	7.788	0.0204

Table 97. Sleep Apnea Severity by Employment Status

Sleep Apnea Severity	Full Time: Count, Column %, Row %	Part Time: Count, Column %, Row %	Not Currently Employed: Count, Column %, Row %	TOTAL
Severe SA	16 6.35 57.14	4 5.13 14.29	8 10.53 28.57	28
Moderate SA	16 6.35 50.00	7 8.97 21.88	9 11.84 28.13	32
Mild SA	56 22.22 65.12	16 20.51 18.60	14 18.42 16.28	86
No SA	164 65.08 63.08	51 65.38 19.62	45 59.21 17.31	260
TOTAL	252	78	76	406

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	4.753	0.5758
Pearson	5.057	0.5366

Table 98. Crash Involvement by Type of Driving (Pre-Diagnosis Crashes)

Crash Involvement	**Over the Road**: Count, Column %, Row %	**Local**: Count, Column %, Row %	**Both**: Count, Column %, Row %	TOTAL
Crash	9 32.14 9.09	62 28.05 62.63	28 30.11 28.28	99
No Crash	19 67.86 7.82	159 71.95 65.43	65 69.89 26.75	243
TOTAL	28	221	93	342

Test	**Chi Square**	**Prob > ChiSq**
Likelihood Ratio	0.283	0.8681
Pearson	0.286	0.8669

Table 99. Crash Involvement by Type of Driving (Post-Diagnosis Crashes)

Crash Involvement	**Over the Road**: Count, Column %, Row %	**Local**: Count, Column %, Row %	**Both**: Count, Column %, Row %	TOTAL
Crash	4 14.29 8.89	27 12.22 60.00	14 15.05 31.11	45
No Crash	24 85.71 8.08	194 87.78 65.32	79 84.95 26.60	297
TOTAL	28	221	93	342

Test	**Chi Square**	**Prob > ChiSq**
Likelihood Ratio	0.487	0.7840
Pearson	0.495	0.7808

Table 100. Sleep Apnea Severity by Type of Driving

Sleep Apnea Severity	Over the Road: Count, Column %, Row %	Local: Count, Column %, Row %	Both: Count, Column %, Row %	TOTAL
Severe SA	1 3.57 4.35	10 4.52 43.48	12 12.90 52.17	23
Moderate SA	1 3.57 4.00	20 9.05 80.00	4 4.30 16.00	25
Mild SA	5 17.86 6.94	47 21.27 65.28	20 21.51 27.78	72
No SA	21 75.00 9.46	144 65.16 64.86	57 61.29 25.68	222
TOTAL	28	221	93	342

Test	**Chi Square**	**Prob > ChiSq**
Likelihood Ratio	10.081	0.1213
Pearson	10.664	0.0993

Table 101. Crash Involvement by Driving Schedule (Pre-Diagnosis Crashes)

Crash Involvement	Days Only: Count, Column %, Row %	Nights Only: Count, Column %, Row %	Both: Count, Column %, Row %	TOTAL
Crash	41 27.89 41.41	5 31.25 5.05	53 30.99 53.54	99
No Crash	106 72.11 45.11	11 68.75 4.68	118 69.01 50.21	235
TOTAL	147	16	171	334

Test	**Chi Square**	**Prob > ChiSq**
Likelihood Ratio	0.387	0.8241
Pearson	0.386	0.8246

Table 102. Crash Involvement by Driving Schedule (Post-Diagnosis Crashes)

Crash Involvement	Days Only: Count, Column %, Row %	Nights Only: Count, Column %, Row %	Both: Count, Column %, Row %	TOTAL
Crash	17 11.56 36.17	3 18.75 6.38	27 15.79 57.45	47
No Crash	130 88.44 45.30	13 81.25 4.53	144 84.21 50.17	287
TOTAL	147	16	171	334

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	1.477	0.4779
Pearson	1.471	0.4793

Table 103. Sleep Apnea Severity by Driving Schedule

Sleep Apnea Severity	Days Only: Count, Column %, Row %	Nights Only: Count, Column %, Row %	Both: Count, Column %, Row %	TOTAL
Severe SA	4 2.72 17.39	1 6.25 4.35	18 10.53 78.26	23
Moderate SA	11 7.48 45.83	1 6.25 4.17	12 7.02 50.00	24
Mild SA	38 25.85 53.52	3 18.75 4.23	30 17.54 42.25	71
No SA	94 63.95 43.52	11 68.75 5.09	111 64.91 51.39	216
TOTAL	147	16	171	334

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	10.347	0.1108
Pearson	9.717	0.1371

Table 104. Crash Involvement by Epworth Sleepiness Scale (Pre-Diagnosis Crashes)

Crash Involvement	Heavy Daytime Sleepiness: Count, Column %, Row %	Moderate Daytime Sleepiness: Count, Column %, Row %	No Daytime Sleepiness: Count, Column %, Row %	TOTAL
Crash	39 30.71 40.21	39 23.49 40.21	19 20.43 19.59	97
No Crash	88 69.29 30.45	127 76.51 43.94	74 79.57 25.61	289
TOTAL	127	166	93	386

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	3.392	0.1834
Pearson	3.429	0.1801

Table 105. Crash Involvement by Epworth Sleepiness Scale (Post-Diagnosis Crashes)

Crash Involvement	Heavy Daytime Sleepiness: Count, Column %, Row %	Moderate Daytime Sleepiness: Count, Column %, Row %	No Daytime Sleepiness: Count, Column %, Row %	TOTAL
Crash	15 11.81 31.25	25 15.06 52.08	8 8.60 16.67	48
No Crash	112 88.19 33.14	141 84.94 41.72	85 91.40 25.15	338
TOTAL	127	166	93	386

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	2.426	0.2973
Pearson	2.351	0.3087

Table 106. Sleep Apnea Severity by Epworth Sleepiness Scale

Sleep Apnea Severity	Heavy Daytime Sleepiness: Count, Column %, Row %	Moderate Daytime Sleepiness: Count, Column %, Row %	No Daytime Sleepiness: Count, Column %, Row %	TOTAL
Severe SA	8 6.30 32.00	12 7.23 48.00	5 5.38 20.00	25
Moderate SA	12 9.45 37.50	17 10.24 53.13	3 3.23 9.38	32
Mild SA	24 18.90 30.00	36 21.69 45.00	20 21.51 25.00	80
No SA	83 65.35 33.33	101 60.84 40.56	65 69.89 26.10	249
TOTAL	127	166	93	386

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	6.076	0.4147
Pearson	5.254	0.5117

Table 107. Crash Involvement by Sleep Apnea Severity (Pre-Diagnosis Crashes)

Crash Involvement	Severe SA: Count, Column %, Row %	Moderate SA: Count, Column %, Row %	Mild SA: Count, Column %, Row %	No SA: Count, Column %, Row %	TOTAL
Crash	6 21.43 5.94	8 25.00 7.92	20 23.26 19.80	67 25.77 66.34	101
No Crash	22 78.57 7.21	24 75.00 7.87	66 76.74 21.64	193 74.23 63.28	305
TOTAL	28	32	86	260	406

Test	Chi Square	Prob > ChiSq
Likelihood Ratio	0.417	0.9367
Pearson	0.410	0.9381

Table 108. Crash Involvement by Sleep Apnea Severity (Post-Diagnosis Crashes)

Crash Involvement	Severe SA: Count, Column %, Row %	Moderate SA: Count, Column %, Row %	Mild SA: Count, Column %, Row %	No SA: Count, Column %, Row %	TOTAL
Crash	5 17.86 10.00	5 15.63 10.00	11 12.79 22.00	29 11.15 58.00	50
No Crash	23 82.14 6.46	27 84.38 7.58	75 87.21 21.07	231 88.85 64.89	356
TOTAL	28	32	86	260	406

Test	**Chi Square**	**Prob > ChiSq**
Likelihood Ratio	1.367	0.7133
Pearson	1.464	0.6907

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