Accident Analysis and Prevention 97 (2016) 79–86

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Understanding the role of sleep quality and sleep duration in commercial driving safety

Michael K. Lemke [a], Yorghos Apostolopoulos [a], Adam Hege [b,*], Sevil Sönmez [c], Laurie Wideman [d]

[a] Complexity & Computational Population Health Group, Department of Health & Kinesiology, Texas A&M University, 4243 TAMU, College Station, TX 77843-4243, United States
[b] Department of Health & Exercise Science, Appalachian State University, 111 Rivers Street, Boone, NC 28608, United States
[c] Rosen College of Hospitality Management, University of Central Florida, 9907 Universal Blvd., Orlando, FL 32819, United States
[d] Department of Kinesiology, University of North Carolina Greensboro, P.O. Box 26170, Greensboro, NC 27402-6170, United States

ARTICLE INFO

Article history:
Received 23 May 2016
Received in revised form 22 August 2016
Accepted 22 August 2016
Available online 31 August 2016

Keywords:
Sleep quality
Sleep duration
Commercial drivers
Accidents

ABSTRACT

Introduction: Long-haul truck drivers in the United States suffer disproportionately high injury rates. Sleep is a critical factor in these outcomes, contributing to fatigue and degrading multiple aspects of safety-relevant performance. Both sleep duration and sleep quality are often compromised among truck drivers; however, much of the efforts to combat fatigue focus on sleep duration rather than sleep quality. Thus, the current study has two objectives: (1) to determine the degree to which sleep impacts safety-relevant performance among long-haul truck drivers; and (2) to evaluate workday and non-workday sleep quality and duration as predictors of drivers' safety-relevant performance.
Materials and methods: A non-experimental, descriptive, cross-sectional design was employed to collect survey and biometric data from 260 long-haul truck drivers. The Trucker Sleep Disorders Survey was developed to assess sleep duration and quality, the impact of sleep on job performance and accident risk, and other relevant work organization characteristics. Descriptive statistics assessed work organization variables, sleep duration and quality, and frequency of engaging in safety-relevant performance while sleepy. Linear regression analyses were conducted to evaluate relationships between sleep duration, sleep quality, and work organization variables with safety composite variables.
Results: Drivers reported long work hours, with over 70% of drivers working more than 11 h daily. Drivers also reported a large number of miles driven per week, with an average of 2,812.61 miles per week, and frequent violations of hours-of-service rules, with 43.8% of drivers "sometimes to always" violating the "14-h rule." Sleep duration was longer, and sleep quality was better, on non-workdays compared on workdays. Drivers frequently operated motor vehicles while sleepy, and sleepiness impacted several aspects of safety-relevant performance. Sleep quality was better associated with driving while sleepy and with job performance and concentration than sleep duration. Sleep duration was better associated with accidents and accident risk than sleep quality.
Discussion: Sleep quality appears to be better associated with safety-relevant performance among long-haul truck drivers than sleep duration. Comprehensive and multilevel efforts are needed to meaningfully address sleep quality among drivers.

1. Introduction

There are nearly 2 million heavy and tractor-trailer truck drivers in the United States, most of whom are considered long-haul truck drivers (Bureau of Labor Statistics, 2015c). Long-haul truck drivers remain on the road for prolonged periods of time and generally haul "truckload" freight, which involves long distance traveling directly from shipper to consignee (Apostolopoulos et al., 2014; Bureau of Labor Statistics, 2015c). Long-haul truck drivers

* Corresponding author.
E-mail addresses: michael.lemke@hlkn.tamu.edu (M.K. Lemke), yaposto@hlkn.tamu.edu (Y. Apostolopoulos), hegeba@appstate.edu (A. Hege), Sevil.Sonmez@ucf.edu (S. Sönmez), l_widema@uncg.edu (L. Wideman).

http://dx.doi.org/10.1016/j.aap.2016.08.024

endure numerous hazards endemic to their occupation, many of which are related to the physical and psychological strains associated with the profession (Apostolopoulos et al., 2014). These hazards have far-reaching consequences, impacting profitability for transportation companies, health care costs for health insurance companies, and ultimately the safety of the general motoring public (Apostolopoulos et al., 2014).

The array of hazards experienced by long-haul truck drivers induce disproportionately high injury rates. Workers in the transportation and warehousing sector had 95,040 occupational injuries and illnesses in 2014, resulting in an incidence rate of 225.2 per 10,000 full-time workers, which was the highest reported among private industries (Bureau of Labor Statistics, 2015b). Of particular concern are fatal injury rates within this sector, as the transportation and material moving occupations accounted for the largest share (28%) of fatal occupational injuries of any occupation group; further, transportation incidents accounted for 40 percent of fatal workplace injuries in 2014 and rose from 1865 in 2013–1891 in 2014 (Bureau of Labor Statistics, 2015a). In comparison, during that same timeframe, fatal work injuries among farming, fishing, and forestry occupations rose 9%, yet decreased by 15% among protective service occupations (Bureau of Labor Statistics, 2015a). Among occupations within the transportation and material moving occupations, drivers/sales workers and truck drivers accounted for 2 out of every 3 fatal injuries, and heavy and tractor-trailer drivers had their highest fatal injury total since 2008 (Bureau of Labor Statistics, 2015a). Overall, fatal injury rates are seven times higher for truck drivers than the overall average across all occupations (Smith, 2015). Of these fatal injuries, 81% were due to transportation incidents, and more specifically, 70% were due to roadway incidents (Smith, 2015). In addition, there were six occupations in 2014 where the incidence rate per 10,000 full-time workers was greater than 300, and the number of cases with days away from work was greater than 10,000; among these six occupations, heavy and tractor-trailer truck drivers had the highest number of days-away-from-work injuries and illnesses in 2014, with 55,710 cases (Bureau of Labor Statistics, 2015b).

Sleep is a critical factor for long-haul truck drivers' injuries, especially roadway incidents (Howard et al., 2004; Philip, 2005; Philip and Åkerstedt, 2006; Starnes, 2006). However, sleep is often compromised among long-haul truck drivers, which often contributes to fatigue; in turn, fatigue consistently degrades multiple aspects of safety-relevant performance (Ingre et al., 2006; Moller et al., 2006; Otmani et al., 2005; Philip and Åkerstedt, 2006; Philip et al., 1999). Sleep duration in particular has been associated with long-haul truck drivers' accidents and injuries (Belenky et al., 2007; Chen et al., 2016; Dawson, 2005; Hanowski et al., 2007). Reduced sleep duration increases subjective sleepiness and performance lapses, significantly impairing the ability to long-haul truck drivers to safely operate a commercial motor vehicle (Heaton, 2009; McCartt et al., 2000); unfortunately, sleep duration among long-haul truck drivers is usually abbreviated. Work organization factors, including long work hours and schedule unpredictability, are associated with reduced sleep duration (Hege et al., 2015; Philip et al., 2002). Finally, individual factors, including obstructive sleep apnea, as well as cardiometabolic comorbidities such as increased BMI, heightened glucose and cholesterol levels, and hypertension, are associated with reduced sleep duration (Moreno et al., 2006; Pack et al., 2006).

Because of the well-established connections between sleep, fatigue, and safety, several aspects of long-haul truck drivers' work hours are federally regulated to ensure sufficient duration of sleep. Drivers are not legally allowed to driver more than 11 h total without taking a 10-h break (the "11-h rule"), nor are they allowed to drive beyond the 14th consecutive hour since taking their last 10-h break (the "14-h rule") (U.S. Federal Motor Carrier Safety Administration, 2015b). Additional regulations apply as well, such as required 30-min breaks and a 34-h "restart" provision (U.S. Federal Motor Carrier Safety Administration, 2015b). The use of logbooks is a critical component of such regulation, which not only allow law enforcement to ensure compliance but, due to the transition across the trucking industry to electronic logbooks, also allow trucking companies themselves to actively and accurately monitor drivers' compliance with hours-of-service regulations. Sleep promotion efforts by federal regulatory bodies and trucking companies are oriented towards sleep duration. However, these monitoring systems neglect sleep quality, which is compromised among long-haul truck drivers (McCartt et al., 2000). Due to its subjective and complex nature, a precise definition of sleep quality is elusive (Harvey et al., 2008; Krystal and Edinger, 2008). However, several methods exist for assessing sleep quality, including objective (e.g., polysomnography) and subjective (e.g., the Pittsburg Sleep Quality Index) measures.

Numerous factors may interrupt long-haul truck drivers' sleep while on the road. For one, long-haul truck drivers obtain the bulk of their sleep in their worksites, usually at truckstops, which feature high levels of air (e.g., diesel exhaust) and noise (e.g., trucks idling engines, blowing air horns, engaging parking brakes) pollution (Doraiswamy et al., 2005). Further, sleep is primarily obtained in the sleeper berths of their truck cabs, which are often uncomfortable (e.g., poor mattress quality, extreme ambient temperatures). Work organization characteristics, such as long work hours (Ebrahimi et al., 2015; Hege et al., 2015) and shift work (Ebrahimi et al., 2015; Hege et al., 2015; Lemke et al., 2015) may additionally compromise sleep quality. Finally, individual characteristics, such as smoking (Ebrahimi et al., 2015), higher body mass index (Chen et al., 2016), and the presence of obstructive sleep apnea (Ebrahimi et al., 2015; Parks et al., 2009) may further reduce sleep quality.

While several studies have examined the link between sleep duration and accident risk among long-haul truck drivers, few have considered the importance of sleep quality in safety-relevant performance (Braeckman et al., 2011; Filiatrault et al., 2002). Consideration of sleep quality among long-haul truck drivers has far-reaching implications for federal, corporate, and individual strategies to reduce fatal and non-fatal injuries for both drivers and the general motoring public, as the bulk of safety enhancement strategies target only sleep duration. Thus, the current study has two objectives: (1) to determine the degree to which sleep impacts safety-relevant performance among long-haul truck drivers; and (2) to evaluate workday and non-workday sleep quality and duration as predictors of safety-relevant performance. Sleep quality is defined here as long-haul truck drivers' perceptions of getting a good night's sleep, and a concise subjective measure of sleep quality is used which bifurcates responses for sleep quality on workdays versus non-workdays.

2. Materials and methods

2.1. Study design and participants

The study was approved by the Institutional Review Board (IRB) of a university in North Carolina. A more complete description of the methodology employed in this study can be found in previous publications (Hege et al., 2016; Hege et al., 2015; Lemke et al., 2015; Wideman et al., 2016). Briefly, a non-experimental, descriptive, cross-sectional design was employed to collect survey and biometric data from 260 male long-haul truck drivers over a period of six months at a large-size truckstop located in North Carolina. For numerous reasons, including its consistent and high level of trucking activity; its geographic location along a major interstate; its presence as a major national chain and its resulting draw of both company and owner-operator drivers; its abundant overnight parking spots and its resulting draw of long-haul truck drivers; and because of the transient nature of long-haul trucking, whose drivers are geographically dispersed; this location constituted a representative national truckstop.

2.2. Survey data

We developed the Trucker Sleep Disorders Survey (TSLDS) from insights gleaned from other key instruments, relevant sleep literature, and our previous work with truck drivers (Netzer et al., 1999; Philip and Åkerstedt, 2006). The TSLDS was organized into five sections, which assessed: (1) trucking work environment; (2) individual work- and health-related factors; (3) self-reported sleep disturbances and sleep disorders; (4) self-reported health consequences; and (5) self-reported comorbidities. Key variables for this study included those related to sleep duration and quality, job performance, and accident risks. Components of this survey, including questions pertaining to demographic, work organization, sleep duration and quality, job performance, and accident risks which were used in this manuscript, have been described in previous manuscripts (Hege et al., 2016, 2015; Lemke et al., 2015; Wideman et al., 2016).

2.2.1. Sleep duration and quality

To measure drivers sleep duration, drivers were asked, “On average, how many hours of sleep do you get on your workdays?”, and “On average, how many hours of sleep do you get on your non-workdays?” Based on our review of the truck driver literature regarding sleep duration (Belenky et al., 2003; Dinges et al., 1997; Hanowski et al., 2007), we created a categorical variable where “less than 6.5 h daily” was “low”, “6.5 to 7.49 h” was “moderately low”, “7.5 to 8.49 h” was “average”, and “8.5 h or more” was “high”. We defined sleep quality in our study based on receiving “a good night’s sleep,” and to assess this we used a subjective assessment where drivers rated the frequency that they perceived getting a good night’s sleep on both workdays and non-workdays. Specifically, for sleep quality, drivers were asked, “How often do you get a good night’s sleep on your workdays?” and “How often do you get a good night’s sleep on your non-workdays?” Response selections included: “never,” “rarely,” “almost every night,” and “every night.”

2.2.2. Impact on job performance and accident risk

Drivers were asked, “How often in the past month have you driven a vehicle other than your truck while sleepy?”, and “How often in the past month have you driven your truck while sleepy?” For these questions, drivers simply stated how many times both had occurred, and responses were treated as continuous variables. We measured impact on job performance and concentration by asking, “How often does sleepiness impact your job performance?” and “How often does sleepiness impact your concentration?” Response selections included: “never”, “once weekly”, “2–3 times a week”, “3–4 times a week”, “4–5 times a week”, and “5+ times a week”. For coding purposes for analyses, “never” became “0”, “once weekly” became “1”, “2–3 times a week” became “2”, “3–4 times a week” became “3”, “4–5 times a week” became “4”, and “5+ times a week” became “5”. The reliability between the impact of sleep on job performance and concentration (Cronbach’s Alpha = 0.70) allowed us to combine these two variables into a composite variable for multivariate analyses. When combining the two variables, drivers could have a score between 0 and 10. To assess drivers’ experiences with accident and near accidents, this line of questioning was followed by a series of “yes or no” questions that began with, “Due to sleepiness, you’ve. . . ”, and followed with: “made a serious error while on the job”, “caused an accident”, “been in an accident caused by someone else”, “had a near miss”, “had a crash”, “got injured”, “injured others”, and “had injury requiring medical attention”. The reliability between these questions (Cronbach’s Alpha = 0.76) allowed us to combine the variables into a composite variable for multivariate analyses. When combining the variables, drivers could have a score between 0 and 8.

2.3. Statistical analysis

We first used descriptive statistics to assess drivers’ sleep duration and sleep quality, their experiences with driving while sleepy, and the impact of sleep on job performance and accidents. Next, we examined correlations between the predictor variables sleep duration and sleep quality and found statistically significant relationships between the variables. The strongest correlations existed between workday sleep duration and non-workday sleep duration and between workday sleep quality and non-workday sleep quality. Therefore, we combined the variables to create two sleep predictor variables to allow us to assess the effects of sleep duration and sleep quality. We did this to assess for the concern of multicollinearity, which we also assessed while conducting linear regression analyses (Field, 2013). We then conducted a series of linear regression analyses to examine for possible predictive relationships with driving a vehicle other than their truck while sleepy and driving their truck while sleepy, for sleep’s impact on job performance and concentration, and drivers’ experiences with accidents and accident risks. All statistical analyses were conducted using SPSS 23.0 (IBM Corp., 2015).

3. Results

The mean age of the drivers 46.63, with nearly 60% being 46 years old or older. The majority (57.3%) identified as White/Caucasian, 32.3% identified as Black/African-American, and 10.4 percent identified as Hispanic or other. The educational attainment of the drivers included 55.4 percent of high school or less. Just over one-third of drivers (33.5%) reported having no health insurance. Regarding union membership, only 3.5% reported belonging to a labor union. Drivers reported having an average of nearly 15 years of experience ($M = 14.97$) in the long-haul truck driving profession. The most common form of compensation was “by the mile,” and drivers averaged 2813 miles of driving per week. More than 70 percent of drivers reported a combination of driving and working more than 11 h daily, and 43.8% “sometimes to always” violated the 14-h rule (see Table 1). These demographic and work organization variables have been reported in previous publications which were based on this same dataset (Apostolopoulos et al., journal article under review; Hege et al., 2016; Hege et al., 2015; Lemke et al., 2015).

Long-haul truckers in this study reported getting an average of 6 h and 55 min (6.92 h) of sleep on their workdays, as opposed to 8 h and 16 min (8.27 h) on their non-workdays. When examining sleep duration, 37.5 percent of drivers reported a short sleep duration (less than 6.5 h) on workdays, compared to 15.6 percent reporting a short sleep duration on their non-workdays. Regarding sleep quality, 38.1 percent reported never or rarely getting a good quality of sleep on their workdays, whereas only 16.7 percent reported this on their non-workdays (see Table 2). In connection with sleep, drivers reported an average of 3.80 cases of driving their truck sleepy, and an average of 0.46 cases of driving a vehicle other than their truck while sleepy, in the previous month. With regards to sleep’s impact on their job and accident risk, 38.4 percent of drivers reported sleepiness as impacting their job performance at least once a week, and 43.8 percent stated that sleepiness impacted their concentration at least once per week. Finally, regarding the influence of sleepiness, 32 percent of drivers reported making a serious error, 6.9 percent reported causing an accident, 21.2 percent

Table 1
Profile of Truckers (N = 260).

Characteristics	n	%	Mean	SD
Age			46.63	10.53
45 and younger	109	41.9		
46 and older	151	58.1		
Race/Ethnicity				
White/Caucasian	149	57.3		
Black/African-American	84	32.3		
Hispanic	22	8.5		
Other	5	1.9		
Education				
High school or less	144	55.4		
Some college	79	30.4		
College degree	37	14.2		
Health Insurance				
None	87	33.5		
Insured	173	66.5		
Union Membership				
No	251	96.5		
Yes	9	3.5		
Driving Experience			14.97	11.53
10 or less years	97	37.3		
More than 10 years	163	62.7		
Compensation				
By the mile	183	70.4		
By the load	34	13.1		
% of revenue	39	15.0		
Other	4	1.5		
Driving Miles per Week			2812.61	810.11
Less than 2500	66	25.4		
2500–3000	139	53.5		
3001+	55	21.2		
Daily Work Hours				
11 or less	77	29.7		
More than 11	182	70.3		
Work over federal daily limit of hours				
Never or rarely	146	56.2		
Sometimes to always	114	43.8		

Table 2
Sleep Duration and Quality.

	Mean	SD	N	(%)
Sleep Duration (Workdays)	6.92	1.67		
Less than 6.5 hours			98	37.5
6.5 to 7.49 hours			68	26.1
7.5 to 8.49 hours			56	21.5
8.5 hours or more			39	14.9
Sleep Duration (Non-Workdays)	8.27	2.12		
Less than 6.5 hours			41	15.6
6.5 to 7.49 hours			48	18.3
7.5 to 8.49 hours			57	21.8
8.5 hours or more			116	44.3
Sleep Quality (Workdays) "How often do you get a good night's sleep on your workdays?"				
Never			22	8.6
Rarely			76	29.6
Almost every night			112	43.6
Every night			47	18.3
Sleep Quality (Non-Workdays) "How often do you get a good night's sleep on your non-workdays?"				
Never			11	4.7
Rarely			28	12.0
Almost every night			87	37.3
Every night			107	45.9

reported being in an accident caused by someone else, 52.1 percent reported having a near-miss, 18.5 percent reported being involved in a crash, 7.7 percent reported being injured while on the job, 4.6 percent reported injuring others, and 5.1 percent reported needing medical attention for an injury due to sleep (see Table 3). Findings related to sleep quality and the influence of sleepiness on concentration, making a serious error, causing an accident, and having a near-miss or crash have been reported in a previous publication which was based on this same dataset (Hege et al., 2015).

We used linear regression to analyze for possible predictive relationships between sleep duration and sleep quality and the continuous variables of "driving vehicle other than truck sleepy" and "driving truck while sleepy" (see Table 4). We also made use of key work organization characteristics, including compensation type, miles driven per week, daily work hours, and working over the federal regulations for daily hours as possible predictor variables. Using "driving vehicle other than truck while sleepy" as the dependent variable and the sleep variables and work variables as predictors, the model results were F (6, 205) = 4.19 ($p < 0.01$, $R^2 = 0.11$). The constant was significant ($\beta = 1.08$, $p < 0.01$), which represents the predicted (Y intercept) number of times driving while sleepy, with all of the predictor variables having a value of "0". The two significant predictors in the model were compensation type ($\beta = -0.50$, $p = 0.01$) and sleep quality ($\beta = -0.45$, $p < 0.01$). This means that, when the compensation type was a form other than "by the mile", the number of times driving another vehicle while sleepy decreases by 0.50 times. It also means that, as quality of sleep on average improves per unit (i.e., never, rarely, almost, every night), the number of times driving another vehicle while sleepy decreases by 0.45 times. Using "driving truck while sleepy" as the dependent variable and the sleep variables and work variables as predictors, the model results included F (6, 216) = 4.67 ($p < 0.01$, $R^2 = 0.12$). The constant was significant ($\beta = 7.30$, $p < 0.01$), which represents the predicted (Y intercept) number of times driving while sleepy, with all of the predictor variables having a value of "0". The two significant predictors in the model were working over the daily hour limit ($\beta = 2.32$, $p < 0.01$) and sleep quality ($\beta = -3.49$, $p < 0.01$). This means that, as occurrences of working over the daily hour limit increases from "never or rarely" to "sometimes or always", the number of times driving their truck while sleepy increases by 2.32 times and as quality of sleep on average improves per unit (i.e., never, rarely, almost, every night) the number of times driving their truck while sleepy decreases by 3.49 times (see Table 4).

We also conducted linear regression analyses for possible predictive relationships between sleep duration and sleep quality with the composite variables of the impact of sleep on job performance and concentration and the impact of sleep on accident/accident risks as dependent variables (see Table 5). We again also made use of compensation type, driving mileage per week, daily work hours, and experiences with working over the federal regulations for daily hours as possible predictor variables. With "job performance and concentration" as the dependent variable, the model results were F (6, 219) = 3.89 ($p < 0.01$, $R^2 = 0.10$). The constant was significant ($\beta = 1.92$, $p < 0.01$), which represents the predicted (Y intercept) number of times sleepiness impacts job performance and concentration level, with all of the predictor variables having a value of "0". The only two significant predictors in the model were working over the daily hour limit ($\beta = 0.62$, $p < 0.01$) and sleep quality ($\beta = -0.72$, $p < 0.01$). This means that, as working over the daily limit increases to "sometimes to always" the number of times it impacts performance and concentration increases by 0.62 times and as quality of sleep on average improves per unit (i.e., never, rarely, almost, every night), the number of times of sleep impacting performance

Table 3
Impacts of Sleep on Work.

	Mean	SD	N	(%)
Drove vehicle other than truck sleepy in past month (# of times)	0.46	1.27		
Drove truck sleepy in past month (# of times)	3.80	6.78		
Impact of sleep on job performance				
Never			159	56.2
Less than once/week			53	23.5
2–3 times/week			36	13.8
3–4 times/week			7	2.7
4–5 times/week			1	1.2
5+ times/week			2	2.7
Impact of sleep on concentration				
Never			146	56.2
Less than once/week			61	23.5
2–3 times/week			36	13.8
3–4 times/week			7	2.7
4–5 times/week			3	1.2
5+ times/week			7	2.7
Due to sleep, Made a serious error				
No			176	68.8
Yes			83	32.0
Caused an accident				
No			242	93.1
Yes			18	6.9
In accident caused by someone else				
No			205	78.8
Yes			55	21.2
Had a near miss				
No			13	47.9
Yes				52.1
Had a crash				
No			212	81.5
Yes			48	18.5
Got injured				
No			240	92.3
Yes			20	7.7
Injured others				
No			248	95.4
Yes			12	4.6
Had injury requiring medical attention				
No			244	94.9
Yes			13	5.1

Table 4
Linear Regression Model for Driving Vehicle and Truck Sleepy.

	β	95% CI
Driving vehicle sleepy		
Constant	1.08**	0.50, 1.66
Daily Work Hours	−0.21	−0.59, 0.17
Driving Miles per Week	0.11	−0.14, 0.36
Compensation Type	−0.50**	−0.87, −0.14
Working Over Daily Hour Limit	0.35	−0.01, 0.71
Sleep Quality	−0.45**	−0.76, −0.14
Sleep Duration	−0.03	−0.31, 0.26
Note. F(6, 205) = 4.19, p < 0.01, R^2 = 0.11		
Driving truck sleepy		
Constant	7.30**	4.36, 10.24
Daily Work Hours	0.71	−1.20, 2.61
Driving Miles per Week	−0.34	−1.63, 0.95
Compensation Type	−0.90	−2.77, 0.97
Working Over Daily Hour Limit	2.32**	0.51, 4.14
Sleep Quality	−3.49**	−5.06, −1.92
Sleep Duration	0.75	−0.67, 2.17
Note. F(6, 216) = 4.67, p < 0.01, R^2 = 0.12		

** p < 0.01.

Table 5
Linear Regression Model for Sleep Impact on Work and Accidents/Accident Risks.

	β	95% CI
Job Performance and Concentration		
Constant	1.92**	1.15, 2.69
Daily Work Hours	0.03	−0.48, 0.54
Driving Miles per Week	0.17	−0.17, 0.51
Compensation Type	−0.27	−0.76, 0.23
Working Over Daily Hour Limit	0.62**	0.14, 1.10
Sleep Quality	−0.72**	−1.14, −0.30
Sleep Duration	0.09	−0.29, 0.47
Note. F(6, 219) = 3.89, p < 0.01, R^2 = 0.10		
Due to Sleep Had Accident or Accident Risk in Past Month		
Constant	1.71**	0.96, 2.45
Daily Work Hours	−0.43	−0.92, 0.05
Driving Miles per Week	0.12	−0.21, 0.45
Compensation Type	−0.09	−0.56, 0.38
Working Over Daily Hour Limit	0.32	−0.14, 0.78
Sleep Quality	−0.06	−0.46, 0.34
Sleep Duration	−0.38*	−0.75, −0.02
Note. F(6, 216) = 2.41, p < 0.05, R^2 = 0.06		

* p < 0.05.
** p < 0.01.

and concentration decreases by 0.72 times. Using "due to sleep had an accident or accident risk in past month" as the dependent variable, the model results included F (6, 216) = 2.41 ($p < 0.05$, $R^2 = 0.06$). The constant was significant (β = 1.71, p < 0.01), which represents the predicted (Y intercept) number of times being involved in an accident or at risk of accident, with all of the predictor variables having a value of "0". Sleep duration (β = −0.38, $p < 0.05$) was the only significant predictor. This means that, as sleep duration on average increases per unit (short, moderately short, average, high), the number of accident/accident risks due to sleep decreases by 0.38 times. (see Table 5).

4. Discussion

Drivers reported a high number of miles driven per week, very long work hours, and frequent violations of HOS statutes. These behaviors may be related to compensation methods, which were predominantly by-the-mile; thus, drivers' livelihoods are dependent on paid miles. It has been previously shown that driver pay is directly and inversely related to amount of hours that drivers will work (Belzer et al., 2002). With frequently uncompensated "down times," and with by-the-mile pay systems which evade fair pay by not including all miles actually driven, it is likely that drivers feel pressure to violate federal law to ensure adequate compensation from employers. Compensation may be further compromised by extremely low levels of union membership (Trick and Peoples, 2012).

Drivers reported shorter sleep duration and worse sleep quality on workdays than on non-workdays. Unsurprisingly, long-haul truck drivers reported that their ability to safely conduct their work was regularly compromised due to such poor sleep. These findings coincide with previous studies, which have established relationships between shorter sleep duration, sleepiness, and performance lapses (Pack et al., 2006), along with the acknowledgement of drivers of continuing driving despite being fatigued (Chen et al., 2015). With nearly half of drivers reporting that sleepiness impacts their performance and concentration at least once a week, and the potential catastrophic consequences of large truck crashes for both the long-haul truck drivers and the general motoring public, sleep remains a vital concern for the trucking industry, especially in the context of overall frequencies of accidents and near misses of long-haul truck drivers overall. For example, a recent study estimated that 35 percent of long-haul truck drivers have had a "DOT recordable" accident (indicating it was of a severe nature (U.S. Federal Motor Carrier Safety Administration, 2013), with 12 percent of these individuals having 2 or more, and an estimated 24 percent of long haul truck drivers having a near miss in the past week (Chen et al., 2015). With over half of drivers in the current study reporting that they have had a near miss due to sleepiness, and a third reporting that they made a serious error due to sleepiness, meaningful action must be undertaken to ensure long-haul truck drivers are well-rested while engaging in safety-relevant job duties.

We also evaluated work organization and sleep quality and duration as predictors of safety-relevant performance in this study. Sleep quality was the sole significant sleep-related predictor of driving a vehicle other than their truck and driving a truck while sleepy. Thus, while sleep duration is a well-established factor in driving performance (Marshall et al., 2004; Philip and Åkerstedt, 2006; Philip et al., 2003), sleep quality was instead found to be a better predictor of driving while sleepy. The other significant predictor of driving a truck while sleepy – working over the daily hour limit – reinforces the importance of federal regulations in reducing on-the-job accident risk among long-haul truck drivers. Patterns of predictor variables for driving a truck while sleepy continue for job performance and concentration, with sleep quality and working over the daily hour limit again being the significant predictors. Findings for the final composite variable – which specifically addressed accidents or accident risks – were somewhat incongruous with the other three outcome variables, with sleep duration the sole significant predictor and sleep quality a non-significant predictor. It may be that sleep quality is a precipitating factor in sleep-related accidents, such as by inducing cumulative sleep debt, but sleep duration is the most salient and proximal factor during safety-critical events.

Overall, our findings point to the underappreciated yet crucial importance of sleep quality for long-haul truck drivers' safety-relevant performance. These findings are especially troubling given that, nationally, short sleep duration is among the most prevalent in the transportation/warehousing sector, which includes long-haul truck drivers (Luckhaupt et al., 2010). Thus, sleep quality may exacerbate fatigue among long-haul truck drivers, who are already among the most sleep-deprived workers in the U.S. Our findings corroborate earlier work, whose findings led them to question the generally myopic focus on sleep duration in assessing whether long-haul truck drivers are capable of remaining vigilant while operating a motor vehicle (Filiatrault et al., 2002).

While addressing long-haul truck drivers' sleep is a complex issue (Lemke and Apostolopoulos, 2016), we suggest that comprehensive approaches offer the greatest promise to improve sleep quality and thereby enhancing safety-relevant performance. Improving long-haul truck drivers' sleep, and in particular sleep quality, will require multilevel changes in the trucking industry, as addressing workplace and work organization factors is critical (Lemke et al., 2016). Hours-of-service regulations should be re-assessed in an effort to emphasize sleep quality. Current regulations, which focus on driving (11-h and 14-h limits) and rest and sleeper berth (10-h breaks) durations, comingle with scheduling practices of trucking companies and pick-up and delivery windows stipulated by shippers and consignees, resulting in erratic work schedules which often do not match drivers' circadian clocks. Therefore, hours-of-service regulations should be modified to ensure sleep during circadian nadirs. Historically, hours-of-service regulations have included such efforts in the past – such as a "24-h rule" and a more recent provision which mandated 34-h restart periods which included two periods between 1 a.m. and 5 a.m. – which are now defunct (U.S. Federal Motor Carrier Safety Administration, 2000, 2015b). Hours-of-service regulations which mandate sleep periods that coincide with these nadirs would likely sleep quality.

Business practices of trucking companies and their customers should account for circadian rhythms of long-haul truck drivers. Technological innovations should be implemented to ensure that long-haul truck drivers are not circumventing HOS regulations (Apostolopoulos et al., 2014; Hege et al., 2015). Efforts to do so are indeed currently underway, as electronic logging devices will be mandatory by 2017 (U.S. Federal Motor Carrier Safety Administration, 2015a). However, potential flaws in these systems may be exploited by drivers seeking to maximize their driving times; thus, addressing motivating factors which fuel drivers' decisions to extend their driving times in unsafe manners, such as pay structures and pay rates (Belzer et al., 2002), may enhance drivers' individual decisions regarding sleep. Changes to the built environment would also help to improve sleep quality. A persistent and growing problem continues to be too few safe parking locations (Perry et al., 2015). Transportation planners should take the lead in creating more safe parking locations. Technological advances, such as truck parking information and management systems, can provide real-time information to drivers to both help maximize existing safe parking locations and assist sleepy drivers in finding upcoming safe parking locations along their routes (Perry et al., 2015). Proliferation of auxiliary power units and truckstop electrification systems can reduce air and noise pollution and provide more comfortable ambient temperatures (Indale, 2005).

Finally, with the connections between sleep quality and duration and other individual attributes, improving related medical conditions can improve sleep and reduce fatigue. Improving body composition of drivers may reduce disordered sleep problems, and detection of existing medical conditions which deteriorate sleep quality, such as sleep apnea, can also allow for medical interventions. Workplace health and wellness programs often incorporate elements which address body composition and medical screenings. Extant workplace health and wellness programs in the trucking industry are generally well-received and appreciated by long-haul truck drivers and have been shown to be effective, particularly those which are more comprehensive (Krueger et al., 2007; Mabry et al., 2013; Osland et al., 2011). Unfortunately, such health and wellness programs are generally lacking in the trucking industry (Lemke and Apostolopoulos, 2015). Thus, increased health promotion efforts need to occur to improve related health ailments of long-haul truck drivers. Further, changes to workplaces to support general well-being – and in particular, healthful eating and engagement in physical activity – are needed to support health-supportive behaviors among long-haul truck drivers and thereby reduce the prevalence of comorbid conditions (e.g., obesity) related to poor sleep quality (Apostolopoulos et al., 2016b).

There are several potential limitations with this study. First, our data were self-reported measures, which may have introduced various biases due to their inherently subjective nature. Second, data collection took place at one nationally representative truckstop. Although the nature of long-haul trucking likely mitigates any place-based effects or biases in our sampling procedures, the possibility that these may exist cannot be ruled out. Third, our regression models had relatively low R^2 values. This can likely be attributed to a limited number of predictor variables that were included in the analyses and a fairly large sample size, as well as the cross-sectional design of our study (Reisinger, 1997). However, our predictor models were also not intended to fully explain safety-relevant performance among drivers; instead, we aimed to investigate the relative importance of sleep quality and duration. Thus, lower R^2 values reflect our inherently incomplete models of the phenomena in question (Moksony, 1999). In addition, our study investigated human behavior, which is hard to predict and often reduces goodness-of-fit in regression models, while even the modest degree of variance explained in our study is tremendously important in the case of long-haul truck driver accidents, which can generate catastrophic and far-reaching consequences. Finally, there was a potential for selection bias during data collection. Drivers may have elected not to participate in our study for any number of reasons, including fear of reprisal from their employers or from federal regulatory bodies, as well as inherent mistrust of government entities such as the university which funded and provided oversight for the study.

5. Conclusions

Long-haul truck drivers' job performance and concentration are often inhibited by sleepiness, with accidents and injuries often occurring due to sleep. While sleep duration continues to be a primary focus on the part of federal regulatory bodies and the trucking industry itself in improving safety outcomes among long-haul truck drivers, our findings point to the crucial importance of sleep quality in such outcomes. As our data point to sleep quality as a more important predictor for safety outcomes overall, we suggest comprehensive, multilevel actions to improve the sleep quality of long-haul truck drivers as a key strategic avenue in reducing accidents and injuries for both this population and the general motoring public. These actions should include: Changes at the federal level to hours-of-service regulations such as mandating sleep during circadian nadirs, as well as changes to the built environment, including providing more safe parking locations; changes among shippers and consignees by prohibiting pick-up and delivery windows that deprive drivers of sleep during circadian nadirs; and changes among trucking companies to provide compressive workplace health and wellness programs and to modify scheduling procedures and pay structures to better support sufficient sleep.

Acknowledgements

We would like to thank Mr. Tom Liutkus, Vice President of Marketing and Public Relations for Travel Centers of America (TA) and Mr. Jerald Brisson, General Manager of the Whitsett, NC TA truck-stop and his staff for their instrumental support for our project and data collection efforts. We also thank the long-haul truck drivers who participated in this study and extend our thanks to our graduate student Kiki Hatzudis for her invaluable assistance in various phases of data collection. This paper is part of a commercial driver sleep study conducted with research funds awarded by the University of North Carolina-Greensboro's (UNCG) Office of Research and Economic Development. Additional funds were provided by UNCG's School of Health and Human Sciences, Bryan School of Business and Economics, Department of Public Health Education, and Department of Kinesiology.

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