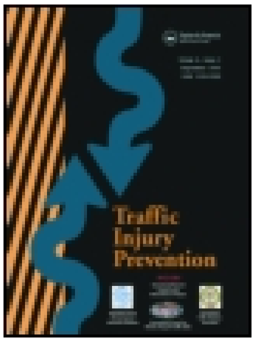

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Commercial Drivers' Health: A Naturalistic Study of Body Mass Index, Fatigue, and Involvement in Safety-Critical Events

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***Objective**: To explore the relation of commercial truck drivers' body mass indexex (BMI) to fatigued driving episodes and involvement in safety-critical events.*

***Methods**: One hundred and three professional truck drivers participated in a long-term naturalistic (on-road) driving study whereby vehicle motion data as well as video of the driver and driving environment were gathered continuously. This data set was analyzed to identify safety-critical events as well as fatigued driving episodes using two independent measures of fatigue. Odds ratio analyses were then performed to explore the relative risk of driving while fatigued and involvement in safety-critical events based on driver's BMI classification (obese versus non-obese).*

***Results**: Results indicated that of the 103 participating truck drivers, 53.4 percent were obese based on BMI. Odds ratio calculations revealed that obese individuals were between 1.22 (CI = 1.03–1.45) and 1.69 times (CI = 1.32–2.18) more likely than non-obese individuals to be rated as fatigued based on the two measures of fatigue. Other analyses showed that obese individuals were at 1.37 times (CI = 1.19–1.59) greater risk for involvement in a safety-critical event than non-obese individuals. Finally, one of the fatigue measures showed that obese individuals were 1.99 times (CI = 1.02–3.88) more likely than non-obese individuals to be fatigued while involved in an at-fault safety-critical incident.*

***Conclusion**: The results of this study support other research in the field of health and well-being that indicate a link between obesity and fatigue, which is a major safety issue surrounding commercial motor vehicle operations given the long hours these drivers spend on the road.*

Keywords Body mass index; Fatigue; Naturalistic methods; Commercial drivers; Safety-critical events; Health

INTRODUCTION

The prevalence of overweight and obese individuals in the United States has doubled over the past three decades (Audretsch and DiOrio 2007; Colditz 2001), leading the World Health Organization (2008) to decry the trend as an epidemic that poses a major risk for chronic diseases. Data gathered from 2001 to 2004 as part of the National Health and Nutrition Examination Survey suggest that approximately two thirds of the U.S. adult population are overweight or obese and estimate that of these 133.6 million individuals, nearly one third may be characterized as obese (Kuczmarski and Flegal 2000; National Institute of Diabetes and Digestive Kidney Diseases 2007). With a prevalence that is steadily increasing and has reached epidemic proportions, it is important to address obesity as a risk factor for multiple health concerns, in particular its relation to physical inactivity, fatigue, and negative influences on public health and safety.

Though there is a plethora of research examining the relationship between obesity and numerous health conditions, there is a scarce amount exploring the influence of obesity on driver performance and safety. One source reported that a recent analysis of Motor Carrier Management Information System (MCMIS) and Commercial Driver's License Information System (CDLIS) databases showed that obese commercial drivers are 1.07 times more likely to experience a crash than non-obese drivers (Lantz 2007). It is intuitive that commercial motor vehicle operations put some individuals at high risk for obesity given the long hours of driving, limited food options, and irregular schedules.

When considering commercial motor vehicle (CMV) drivers as a population, there are few published reports of body mass index (BMI) as a demographic variable. Results from a survey conducted by Korelitz et al. (1993) on 3298 commercial

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drivers suggested that more than 40 percent were overweight, with the prevalence of obesity at 33 percent. A study of 4826 randomly sampled commercial driver's license (CDL) holders in the Philadelphia area revealed that 49.6 percent of males were overweight based on a BMI value equal to or greater than 27.8 (Maislin et al. 1997). Because these findings are over a decade old, it is reasonable to hypothesize that the prevalence of overweight/obesity among CMV drivers is even higher today, given the current rise in the national level of overweight/obesity.

Recent attention in the CMV industry has focused on BMI and its relation to obstructive sleep apnea (Federal Motor Carrier Safety Administration 2008), which is a sleeping disorder characterized by frequent sleep disruption that may make one more susceptible to falling asleep at the wheel if driving for long periods. Fatigue is a major risk factor associated with CMV operations. For example, McCartt et al. (2000) found that of 593 randomly selected long-distance truck drivers, 47.1 percent reported having fallen asleep at the wheel of their truck at some point, and 25.4 percent admitted having done so in the past year. Though these instances of driving while fatigued do not necessarily end in a crash, the risk is certainly present. For example, fatigue is a frequently cited probable cause for CMV crashes (e.g., Transportation Safety Board 1990). This notion is supported both by retrospective and naturalistic driving studies (Hanowski et al. 2000; Transportation Safety Board 1990; Wiegand et al. 2008).

This study examines differences in the frequency of fatigued driving episodes among professional truck drivers based on BMI (described in more detail below), comparing those considered obese to those considered non-obese. The truck drivers were participants in a long-term naturalistic driving study whereby real-time on-road data were collected and analyzed.

METHODS

The data gathering from commercial trucks occurred in a naturalistic driving environment during normal operations. The participant sample ($N = 103$ drivers) included was a chance sample from three long-haul driving operations whereby drivers were asked to volunteer. Drivers were not selected or controlled for based on age, weight, gender, etc. The only exclusion criterion was that participants could not wear eyeglasses, because the original study purpose was to evaluate eye detection technology that would not work properly if a participant wore eyeglasses (see Blanco et al. 2009). The data gathering methodology of this study is summarized below. However, a detailed account of the methodology is available in Hanowski et al. (2005).

Forty-six truck tractors were outfitted with data collection equipment. A data acquisition system (DAS) was installed in tractors to collect data continuously whenever the instrumented trucks were on and in motion, somewhat comparable to the "black box" used on airplanes. The DAS consisted of an encased unit housing a computer and external hard drive, dynamic sensors, interface with the existing vehicle network, and four video cameras. Recorded dynamic data included basic vehicle motion parameters, such as speed, longitudinal acceleration (e.g., indicative of braking levels), and lateral acceleration.

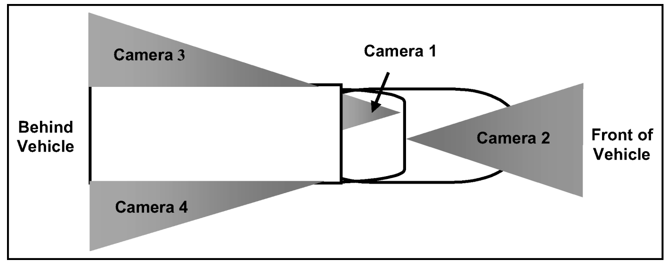

Figure 1 Camera directions and approximate fields of view.

Measurement and Analysis of Driving Data

Video and dynamic sensor data were collected continuously by the DAS. The four video cameras were oriented as follows: (1) forward road scene, (2) backward toward the driver's face, (3) rearward from the left side of the tractor, and (4) rearward from the right side of the tractor (see Figure 1 for camera directions and fields of view).

Figure 2 shows a split quadrant view of the video output used by data analysts to code the driving environment variables and driver behaviors. Low-level infrared lighting (not visible to the driver) illuminated the vehicle cab so that drivers' faces and hands could be viewed via the camera during nighttime driving. No cameras or other sensors were mounted on trailers. Therefore, there was no recorded view directly behind the truck and trailer, although following vehicles could usually be partially seen in the rearward side-view cameras. The limited number of cameras, all tractor mounted, limited the analysis to primarily those events occurring in front and at the sides of the instrumented vehicle.

Safety-critical events include crashes, near-crashes, and crash-relevant conflicts, which are defined below:

Figure 2 Split-screen presentation of the four camera views (from left: driver's face, forward view, passenger rear, driver rear).

- Crash: Any contact with an object, either moving or fixed, at any speed. Included other vehicles, roadside barriers, objects on or off of the roadway, pedestrians, pedalcyclists, or animals.
- Near crash: Any circumstance that required a rapid, evasive maneuver (e.g., hard braking, steering) by the subject vehicle or any other vehicle, pedestrian, pedalcyclist, or animal, in order to avoid a crash.
- Crash-relevant conflict: Any circumstance that required a crash-avoidance response on the part of the subject vehicle, any other vehicle, pedestrian, pedalcyclist, or animal that is less severe than a rapid evasive maneuver (as defined above) but greater in severity than a normal maneuver. A crash-avoidance response can include braking, steering, accelerating, or any combination of control inputs.

There were three primary steps in detecting and classifying safety-critical events: (1) identifying potential events (mostly through the use of an event trigger program, described below), (2) checking the validity of these triggered events via video review, and (3) applying a data directory to verified conflict events. To identify events, a software program scanned the dynamic data set to identify notable actions, called *triggers*, which included hard braking, quick steering maneuvers, and short times to collision (close proximity with consideration of both range and range rate). Threshold values of these triggers were established to flag events for further review (for specific trigger threshold values, refer to Hickman et al. 2005). Finally, analysts reviewing the data could fortuitously identify safety-critical events not associated with the above triggers during their general review of the data, but this process was not comprehensive due to the huge size of the data set.

Events were then reviewed to ensure that they represented actual safety-significant scenarios. Many events meeting the minimum dynamic trigger criteria were not actual crash threat situations. These were termed *nonconflicts*. Those events judged to be true conflicts, and thus to have safety significance, were classified through the use of a detailed data directory. This comprehensive data directory of 54 variables and data elements was developed for analyzing events in this data set (see Hickman et al. 2005 for the data directory). This included classification variables relating to each overall event, to the instrumented vehicle or V1 (the truck) and driver, and (to a limited extent) to the other involved vehicle/driver (V2) or nonmotorist. Most of the variables in the data directory were the same as, or similar to, those used in major national crash databases such as the General Estimates System (GES), the Fatality Analysis Reporting System (FARS), and the Large Truck Crash Causation Study (LTCCS). In some cases, data element choices for some variables were revised to capitalize on the principal advantage of naturalistic driving (i.e., the fact the event could be directly observed as opposed to reconstructed after the fact). These coded data represent the principal content of this study.

In addition to safety-critical events identified in this study, baseline driving epochs (periods where the vehicle was in motion yet no safety-critical event was occurring) were randomly selected and validated for each driver (one random event per week for each week of data collected with a driver) to serve as a means of comparison to safety-critical events.

Measurement of Fatigue

Two measures of driver fatigue were employed in this study, namely, observer rating of drowsiness and percentage eye closure. Observer rating of drowsiness is a subjective rating whereby trained data analysts observed a driver's face and behavior to rate fatigue on a 100-point scale. Percentage eye closure is a more objective measure, whereby data analysts coded whether the driver's eyes were 80–100 percent closed over a time interval of just over 3 min. Each measure is described in more detail below.

Observer rating of drowsiness is a subjective rating assigned by trained analysts who observed driver faces and behaviors for a 60-s period leading up to each safety-critical event and for 60 s in baseline epochs. Data analysts coded observer rating of drowsiness on a continuous scale for each driver using a previously validated methodology (Wierwille and Ellsworth 1994). The measure was computer based, and analysts would fix their rating by moving their computer cursor to a point on the continuous scale that was marked with the following five descriptors (note: the scale did not show the numbers indicated below; however, the computer scored each rating based on the placement of the cursor on the continuous scale):

- Not drowsy (0–12.49). A driver who is not drowsy while driving will exhibit behaviors such that the appearance of alertness will be present. For example, normal facial tone, normal fast eye blinks, and short ordinary glances may be observed. Occasional body movements and gestures may occur.
- Slightly drowsy (12.5–37.49). A driver who is slightly drowsy while driving may not look as sharp or alert as a driver who is not drowsy. Glances may be a little longer and eye blinks may not be as fast. Nevertheless, the driver is still sufficiently alert to be able to drive.
- Moderately drowsy (37.5–62.49). As a driver becomes moderately drowsy, various behaviors may be exhibited. These behaviors, called mannerisms, may include rubbing the face or eyes, scratching, facial contortions, and moving restlessly in the seat, among others. These actions can be thought of as countermeasures to drowsiness. They occur during the intermediate stages of drowsiness. Not all individuals exhibit mannerisms during intermediate stages. Some individuals appear more subdued, they may have slower closures, their facial tone may decrease, they may have a glassy-eyed appearance, and they may stare at a fixed position.
- Very drowsy (62.5–87.49). As a driver becomes very drowsy, eyelid closures of 2 to 3 s or longer usually occur. This is often accompanied by a rolling upward or sideways movement of the eyes themselves. The individual may also appear to not be focusing the eyes properly or may exhibit a cross-eyed (lack of proper vergence) look. Facial tone will probably

have decreased. Very drowsy drivers may also exhibit a lack of apparent activity, and there may be large isolated (or punctuating) movements, such as providing a large correction to steering or reorienting the head from a leaning or tilted position.
- Extremely drowsy (87.5–100). Drivers who are extremely drowsy are falling asleep and usually exhibit prolonged eyelid closures (4 s or more) and similar prolonged periods of lack of activity. There may be large punctuated movements as they transition in and out of intervals of dozing.

Observer rating of drowsiness scores $\geq$40 were the criterion for identification of safety-critical events or baseline epochs involving driver drowsiness (Hanowski et al. 2000).

The second fatigue measure employed was percentage eye closure (commonly referred to as PERCLOS), which is a mathematically defined proportion of a time interval that the eyes are 80 to 100 percent closed (Wierwille et al. 1994). It is a measure of slow eyelid closure not inclusive of eye blinks. PERCLOS is a valid indicator of fatigue and is significantly correlated with lane departures and lapses of attention, considered by some in the transportation safety field to be the "gold standard" of drowsiness measures (Knipling 1998).

This study utilized a manual coding scheme for calculating an estimate of PERCLOS. Data analysts would locate an event trigger (or a set point of a baseline epoch) and would rewind the video data by 3 min 10 s (1900 syncs; data is gathered at 10 Hz, so each sync represents 1/10 of a second). The analysts would then code PERCLOS sync-by-sync using the following definitions:

- Eyes open: Eyes are visibly open.
- Eyes closed: Eyes are visibly closed or mostly closed (including blinks).
- Eyes not visible: When the eyes literally cannot be seen (due to obstruction, face out of camera view, head turned to monitor mirrors, heavy shadow, etc.)

By definition, rapid eye blinks had to be eliminated from the data when calculating PERCLOS. For the purposes of this analysis, a "blink" was defined as an eye closure of 1 sync. Anything longer than 1 sync was considered a slow eye closure and, therefore, was used in the PERCLOS calculation. Also, if an event had more than 20 percent of the video coded as eyes not visible, then an PERCLOS was not performed. PERCLOS score $\geq$12 percent was the criterion for identification of safety-critical events or baseline epochs involving driver fatigue/drowsiness (Wierwille et al. 2003).

Though observer rating of drowsiness and PERCLOS are both measures of fatigue, it is important to notice the distinction between the two. Specifically, observer rating of drowsiness ratings take into account the physical appearance of the driver (e.g., drooping facial features indicative of drowsiness) and behaviors (e.g., yawning), whereas PERCLOS is based solely on the percentage of a time interval the eyes were 80 to100 percent closed, noninclusive of blinks.

Body Mass Index

The main independent variable of the current study focuses on the body mass index of driver participants, which is a measure of body fat based on height and weight (National Institutes of Health 2008). BMI is calculated using the following formula:

$$\frac{\text{Weight (kilograms)}}{\text{Height (meters)}^2}$$

The National Institutes of Health (2008) defines four BMI categories: underweight (BMI < 18.5), normal weight (BMI = 18.5–24.9), overweight (BMI = 25–29.9), and obese (BMI >30). For this study, these categories were combined to represent non-obese individuals (BMI = 0–29.9) and obese individuals (BMI $\geq$30). The decision to form these comparison groups is based on the Federal Motor Carrier Safety Administration's (2008) potential ruling to mandate obstructive sleep apnea testing for individuals with a BMI $\geq$30. Those with a positive diagnosis will be required to receive treatment before being allowed on the road. Odds ratios were calculated to estimate the relative risk of driving while fatigued and experiencing a safety-critical event based on these BMI classifications.

Odds Ratio Analyses

The odds ratio is an estimate of relative risk, which is calculated by comparing the odds of some outcome (e.g., fatigue rating above or below threshold) occurring given the presence of some predictor factor, condition, or classification (e.g., normal weight versus obese). It is usually a comparison of the presence of a condition to its absence (e.g., fatigued and nonfatigued). Odds ratios of 1 indicate that the outcome is equally likely to occur given the condition. An odds ratio greater than 1 indicates that the outcome is more likely to occur given the condition. Odds ratios of less than 1 indicate that the outcome is less likely to occur (Pedhazur 1997). The odds ratio figures presented in this report are accompanied by a lower confidence level (LCL) and upper confidence level (UCL). An odds ratio is considered statistically significant if the confidence level range does not include 1.0.

RESULTS

Using drivers' height and weight measurements which were taken prior to the naturalistic data gathering, the 103 participants were distributed in the weight categories as follows:

- Non-obese (18.5–29.9 BMI): 48 drivers (46.6 percent)
- Obese ($\geq$30 BMI): 55 drivers (53.4 percent)

Table I ORD scores above/below threshold by BMI classification

ORD	Non-obese		Obese		
	N	%	N	%	Total
0–39.9	711	71.5%	1017	64.4%	1728
$\geq$40	283	28.5%	562	35.6%	845
Total	994	100.0%	1579	100.0%	2573

Table II PERCLOS scores above/below the threshold by BMI classification

PERCLOS	Non-obese		Obese		
	N	%	N	%	Total
0–11.9	882	89.7%	1135	83.8%	2017
≥12	101	10.3%	220	16.2%	321
Total	552	100.0%	1355	100.0%	2338

The non-obese category included no underweight individuals, 19 (18.4 percent) normal weight individuals, and 29 (28.2 percent) overweight individuals.

Observer Rating of Drowsiness Results by BMI Classification for Total Driving Episodes

Table I shows descriptive statistics for observer rating of drowsiness scores above and below the fatigue threshold of 40 for each of the BMI classifications. Though non-obese individuals were above the fatigue threshold in 28.5 percent of the total driving episodes analyzed, obese individuals were over the fatigue threshold in 35.6 percent of these episodes. An odds ratio calculation revealed that obese individuals were at 1.22 times greater risk (CI = 1.03–1.45) than non-obese individuals for being rated above the observer rating of drowsiness fatigue threshold.

PERCLOS Results by BMI Classification for Total Driving Episodes

Table II shows descriptive statistics for PERCLOS scores above and below the fatigue threshold of 12 percent for each of the BMI classifications. Though non-obese individuals were above the fatigue threshold in 10.3 percent of the total driving episodes analyzed, obese individuals were over the fatigue threshold in 16.2 percent of these episodes. An odds ratio calculation revealed that obese individuals were at 1.69 times greater risk (CI = 1. 32–2.18) than non-obese individuals for being rated above the PERCLOS fatigue threshold.

Safety-Critical Event Involvement by BMI Classifications

Table III shows the descriptive statistics for safety-critical events and baseline epochs per BMI Classification. Obese individuals were involved in the greatest proportion of safety-critical events (63.4 percent). Having randomly sampled baseline epochs available allows for the determination of the relative frequency of safety-critical events, which is the frequency of safety-critical events for a particular condition when all instances of the condition are taken into account (i.e., total safety-critical events/[total safety-critical events + baseline epochs]). The relative frequencies of safety-critical event involvement for non-obese and obese individuals were .33 and .40, respectively. An odds ratio calculation revealed that obese individuals were at 1.37 times greater risk (CI = 1.19–1.59) than non-obese individuals for experiencing a safety-critical event (when the truck driver was at fault or otherwise).

ORD Scores by BMI Classification for At-Fault Safety-Critical Incidents

Table IV shows the descriptive statistics for observer rating of drowsiness scores per BMI classification for safety-critical incidents where the truck driver was judged to be at fault. Though non-obese individuals were above the fatigue threshold for 28 percent of at-fault incidents, obese individuals were over the threshold in 30.3 percent of incidents. An odds ratio comparison revealed no significant differences in risk for being above the observer rating of drowsiness threshold in at-fault safety-critical incidents (OR = 1.12; CI = 0.80–1.57).

PERCLOS Scores by BMI Classification for At-Fault Safety-Critical Incidents

Table V shows the descriptive statistics for PERCLOS scores per BMI classification for safety-critical incidents where the truck driver was judged to be at fault. Though non-obese individuals were above the fatigue threshold in 5.4 percent of at-fault incidents, obese individuals were over the threshold in 10.3 percent of incidents. An odds ratio calculation revealed that obese individuals were at 1.99 times greater risk (CI = 1.02–3.88) than non-obese individuals for being above the PERCLOS fatigue threshold.

DISCUSSION

The findings of this study indicate that obesity is a safety issue in CMV operations. Of the 103 drivers analyzed for this study, a majority (53.4 percent) were classified as obese, which is considerably more than the prevalence of obesity among the general population, recently estimated to be 34 percent in the United States (Centers for Disease Control and Prevention 2007). Combining the overweight (BMI = 25–29.9) and obese individuals in this study represented 81.6 percent of the sample. This finding is alarming considering that the sample was selected by chance.

The results of the naturalistic driving data analysis efforts led to the conclusion that being obese puts one at a slightly elevated relative risk for driving while fatigued. Obese individuals were between 1.22 and 1.69 times more likely than non-obese individuals to drive while fatigued.

The data analysis also showed that obese individuals were 1.37 times more likely to experience a safety-critical incident

Table III Safety-critical event involvement by BMI classification

Weight classification	Crashes		Crash: tire strike		Near crashes		Crash-relevant conflicts		Total safety-critical events		Baseline epochs	
	N	%	N	%	N	%	N	%	N	%	N	%
Non-obese	3	21.4%	7	46.7%	43	35.8%	392	36.7%	445	36.6%	907	44.2%
Obese	11	78.6%	8	53.3%	77	64.2%	676	63.3%	772	63.4%	1146	55.8%
Total	14	100.0%	15	100.0%	120	100.0%	1068	100.0%	1217	100.0%	2053	100.0%

Table IV ORD scores by BMI classification for at-fault safety-critical incidents

V1 at fault	Non-obese		Obese		
	N	%	N	%	Total
0–39.9	180	72%	326	69.7%	506
≥ 40	70	28%	142	30.3%	212
Total	250	100.0%	468	100.0%	718

when compared to non-obese individuals. Similar results were documented by Lantz (2007), who analyzed 171,502 drivers' BMIs from the CDLIS database to find that obese individuals were 1.07 times more likely to be involved in a crash compared to non-obese individuals. It is important to note that Lantz focused on crashes, whereas the present study focused on safety-critical events (which includes near-crashes, crash-relevant conflicts, etc.). Given the relatively low number of crashes documented in this study, it was necessary to combine all types of safety-critical events to ensure enough statistical power to perform meaningful analyses.

When investigating fatigue levels during at-fault safety-critical incidents, no significant difference was found between the BMI classifications in terms of observer rating of drowsiness scores. However, when looking at PERCLOS scores, it was found that obese individuals were at 1.99 times greater risk (CI = 1.02–3.88) than non-obese individuals for being above the fatigue threshold. As a whole, these results indicate a relationship between BMI and fatigued driving as well as between BMI and safety-critical event involvement, which suggests that obese individuals are at greater risk than non-obese individuals.

As described above, a number of trucking fleets have shown increased interest in the health and wellness of their employees over the past decade, particularly due to widespread attention to obstructive sleep apnea, which is a sleeping disorder characterized by maladaptive breathing patterns that result in frequent sleep disruption. For example, the U.S. Department of Transportation's (DOT) medical review board recently recommended that it become mandatory for CMV drivers with a BMI of 30 or greater (the threshold for obesity) to complete a sleep test to determine whether an obstructive sleep apnea diagnosis is warranted (Federal Motor Carrier Safety Administration 2008). Drivers who are diagnosed with obstructive sleep apnea are not permitted to drive until they receive treatment, so this proposed rule will have a major impact on the trucking industry. Fleets will incur significant costs due to the testing and treatment of obstructive sleep apnea, plus the time and productivity lost due to obstructive sleep apnea–positive drivers being taken off the road until they receive treatment. It is predicted that fleets will invest more resources into developing driver health and wellness programs to combat this issue and may even begin screening potential hires based on their BMIs.

Table V PERCLOS scores by BMI classification for at-fault safety-critical incidents

V1 at fault	Non-obese		Obese		
	N	%	N	%	Total
0–11.9%	209	94.6%	350	89.7%	559
≥12%	12	5.4%	40	10.3%	52
Total	221	100.0%	390	100.0%	611

The results of the present study offer some support toward the DOT's recommendation that drivers with a BMI of 30 or greater be tested for obstructive sleep apnea. Though the methodology of this study did not include a test of obstructive sleep apnea, the results do suggest that individuals with a BMI of 30 or greater are at increased risk for driving while fatigued, which may be explained by the presence of obstructive sleep apnea among some of these individuals. Obstructive sleep apnea is more common among obese individuals (American Heart Association 2009), and the prevalence of obstructive sleep apnea among CMV drivers has been found to be as high as 28 percent. By limiting the number of drivers with untreated obstructive sleep apnea in the long-haul trucking industry, it is possible that there will be a reduction of fatigue-related crashes.

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The mission of NSTSCE is defined as using state-of-the-art facilities, including the Virginia Smart Road, to develop and test transportation devices and techniques that enhance driver performance, examine advanced roadway delineation and lighting systems, address age-related driving issues, and address fatigued driver issues.

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