Spring 2012

The Impact of Sleepiness and Sleep Constructs on Driving Performance

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A Dissertation Submitted to the Faculty of
Old Dominion University in Partial Fulfillment of the
Requirements for the Degree of

DOCTOR OF PHILOSOPHY

APPLIED EXPERIMENTAL PSYCHOLOGY

OLD DOMINION UNIVERSITY
May 2012

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ABSTRACT

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Sleepiness causes performance decrements that lead to thousands of crashes and fatalities annually. Research supports the conclusions that sleep duration and circadian rhythms impact sleepiness and affect driving performance. Conflicting in the literature is whether severity of sleep disorders, sleep quality and subjective sleepiness affect driving performance. The correlation between a driver's perception of their sleepiness and their driving performance is also unclear. The primary goal of this study was to create an in-depth model demonstrating which measures of sleepiness influence driving performance. It was hypothesized that sleep quality, sleep apnea severity and subjective sleepiness add to a model of how sleep constructs impact driving performance. The secondary goal of this study was to compare trait and state sleepiness to determine which correlates with driving performance. It was hypothesized that participants with state sleepiness would have a greater decline across the 60-minute drive as compared to participants with trait sleepiness. Both sleepiness groups would have increased lane position variability compared to the normal group. The tertiary goal was to examine driving performance decrements of sleep apnea drivers compared with healthy controls. It was hypothesized that the sleep apnea group would perform worse on the driving simulator test compared with the control group.

Results indicate that sleep quality and subjective trait sleepiness significantly add to models of sleepiness and driving performance. The model developed here show that years with driver's license, sleep efficiency and trait sleepiness are significant predictors of lane position variability. Also, results show that driving performance is worse for participants high in trait sleepiness. Participants with high state sleepiness had no significant performance differences compared to non-sleepy participants. Sleep apnea participants did not perform significantly worse than controls as hypothesized but there was a significant group by time interaction indicating that sleep apnea participants' performance degraded more quickly over the course of the drive. These results can be generalized to the community members and students, but not necessarily to sleep disorder center patients.

This dissertation is dedicated to my parents, Wesley & Nellie Freeman, my husband, Cris May and my son, Cameron May. Thank you for your patience, support and belief that I could come this far in my academic endeavors.

ACKNOWLEDGMENTS

Thanks to Eastern Virginia Medical School and Sentara Norfolk General Hospital for use of the Sleep Disorders Center driving simulator as well as the permission to recruit their sleep apnea patients. Thanks also to Respironics, Incorporated for the use of the Actigraph™ and R-U-Sleeping™ devices for the duration of this study.

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CHAPTER 1

INTRODUCTION

Drowsy driving is a hazard to which any driver is potentially susceptible. Sleepiness is especially dangerous because drivers do not view it as a hazardous condition and often do not realize how sleepy they are (Reyner & Horne, 1998). A recent survey indicated that although most drivers experience symptoms of sleepiness (yawning, difficulties keeping eyes open), the problem appears to be that drivers do not take these symptoms seriously (Nordbakke & Sagberg, 2007). This same survey also found that most drivers continue to drive even when they recognize they are sleepy or feel too tired to drive. Adding to the complexity of drowsy driving is the variability in how sleepiness affects driving performance and the variety of ways to define sleepiness. It is important to identify which aspects of sleepiness most influence driving performance to help better identify those drivers at risk. Major theories of sleepiness focus on sleep duration and circadian rhythms as factors attributing to sleepiness and performance decrements. This dissertation included constructs of subjective sleepiness, sleep efficiency, and severity of untreated sleep apnea. The primary goal was to determine which constructs of sleepiness influence driving performance. A model was proposed to explain the variability in performance decrements.

A current debate in the literature is how subjective sleepiness impacts driving performance. There are various measures of subjective sleepiness that capture two different types of subjective sleepiness. One measure of subjective sleepiness is a general sleepiness, or trait sleepiness. Another measure of subjective sleepiness is a time-specific measure of how sleepy a person is at that moment, or state sleepiness. A secondary goal

of this study was to compare state and trait measure of sleepiness to determine how they impact driving performance and decrements in performance over time.

One high-risk population for sleep-related crashes is drivers with untreated sleep apnea. Sleep apnea is a common sleep disorder where a person stops breathing repetitively during sleep. In evaluating how sleep apnea can affect daytime sleepiness, it is important to obtain an objective measure of driving performance on which to base recommendations for patients' fitness to drive. An obvious, safe choice for evaluation is the use of a driving simulator. The tertiary goal of this dissertation was to evaluate driving performance of sleep apnea patients compared to a control group using a driving simulator test. If performance differences existed, as in the literature, this would help support the validity of the sleep model defined in the first goal. Each major topic important to the study is reviewed below.

Sleepiness and On-Road Driving Performance

Knipling and Wang (1994) analyzed data from the Fatal Accident Reporting System (FARS) and the General Estimates System (GES) for police reported crashes occurring from 1989 to 1993 and found that an annual average of 56,000 crashes resulting in 40,000 non-fatal injuries and 1,357 fatalities were attributed to drowsiness. The most recent report from the National Highway Traffic Safety Administration (NHTSA, 2011) attributed 1,202 fatalities (2.7% of total fatalities) in 2009 to fatigue, sleepiness and illness.

These statistics may underestimate the problem because unlike alcohol impairment detection, there are currently no standardized procedures for the police to detect fatigue or sleepiness, and as such, sleep-related crashes are often attributed to other

factors such as inattention. In the State of the States report on Drowsy Driving (National Sleep Foundation, 2008), only 19 out of 51 responding states (includes Washington DC) reported training police officers on how fatigue impacts driving performance. This report gave specifics for each state in how they dealt with sleepy driving. In Virginia, a driver can be charged with reckless driving and manslaughter in the event of a fatality resulting from drowsy driving or sleep related crash. Although Virginia has provisions limiting a driver's right to drive based on medical conditions such as seizure disorder, sleep disorders are not mentioned. In the computerized version of the Virginia police report, driver fatigue is listed as an option under driver distractions. For commercial drivers, they must report how many hours they have been on the road. However, there is no training for police on the impact of fatigue and sleepiness on driving performance. The state does mandate that sleep and drowsy driving be included in the driver education curricula but the driver licensing manual does not include information on drowsy driving.

According to results from the 2003 Omnibus Sleep in America poll (National Sleep Foundation), 60% of adults aged 18-54 years reported feeling drowsy while driving at least once during that year. A more recent poll conducted in 2009 also indicates a similar result – 52% of respondents stated they had driven drowsy with 37% having done so within the past month (National Sleep Foundation, 2011). Respondent in the 19-29 years old age-range were most likely to report drowsy driving compared to older age groups. The results of this poll indicate that drowsy driving is more prevalent than what the crash statistics show. This makes sense, given that the latest NHTSA crash statistics report that there are only 186 crashes per 100 million vehicle miles traveled (NHTSA, 2011). This indicates that crashes are statistically infrequent relative to an individual

driver regardless of sleep influence; however crash statistics do not take into account unreported crashes or close calls. Results of a recent naturalistic driving study showed that drowsy driving increases near crash or crash risk by 4-6 times that of alert driving (Klauer, Dinges, Neale, Sudweeks, & Ramsey, 2006).

Sleep related crashes are usually reported as such because either the driver admitted to falling asleep or the crash characteristics were typical of a sleep related crash. According to George (2005), sleep related crashes are typically more severe, driver only, off-road crashes with no skid marks or evidence of an attempt to prevent the crash. Smith, Cook, Olson, Reading and Dean (2004) analyzed trends of behavioral risk factors in hospitalizations and fatalities due to car crashes in Utah. They found that fatigued drivers were about two times more likely to be hospitalized or die following the car crash.

Sleep and Driving Simulation Performance

Driving simulator studies have been able to look at more than crash rates. Driving performance measures such as lane position variability and speed, physiological measures, subjective measures of sleepiness and group differences can be investigated in a safe, controlled setting. Driving scenarios created to examine the effects of sleepiness are typically long (30 or more minutes), monotonous highway conditions with few passing cars and slight curves. This type of scenario can be thought of as a vigilance task, which lends itself to the unmasking of fatigue and sleepiness (Thiffault & Bergeron, 2003).

George (2003) stated that steering wheel movements and lane position variability are the most commonly used measures of driving performance and that both measures are sensitive to long periods of driving and circadian rhythm effects. Both measures increase

over the length of the drive and performance is worse during the troughs in the circadian rhythm. In the literature, lane position variability is calculated as the average standard deviation of lane position and will be the main dependent variable in this dissertation. To test the effects of sleepiness, driving simulator performance has been correlated with reliable measures of sleepiness such as EEG activity, sleep latency on the Multiple Sleep Latency Test (Carskadon et al., 1986), and scores on subjective sleep tests. Often these studies manipulate sleepiness by having participants undergo sleep deprivation.

Objective Sleepiness

In analyzing EEG, alpha activity is usually related to relaxed states, and drowsiness. Theta activity is indicative of stage 1 sleep. Beta activity is seen in awake, alert individuals. Increased sleepiness is accompanied by an increase in alpha and theta and a decrease in beta activity. Studies comparing driving performance and EEG have shown that alpha bursts and/or theta activity increase over the drive (Brookhuis & Waard, 1993; Lemke, 1982; Risser, Ware, & Freeman, 2000; Schier, 2000). In addition, Risser et al. (2000) found a strong correlation between driving measures of lane position variability and crash frequency and the frequency of 3-second alpha bursts during the drive.

Sleep latency on the Multiple Sleep Latency Test (MSLT) is another objective measure of sleepiness. The MSLT is considered the gold standard for measuring sleepiness, during which participants are asked to lie down with their eyes closed and their sleep latency (how fast they fall asleep) is measured (Carskadon et al., 1986). The MSLT has a high test-retest reliability, $r = .97$ (Zwyghuizen-Doorenbos, Roehrs, Schaefer, & Roth, 1988). George et al. (1996) examined the relationship between sleep

latency and driving performance using a group of sleep apnea patients and a group of normal, healthy adult controls. The driving simulator test was a 20-minute divided attention and tracking task (keeping the car in the lane). They found a significant correlation between sleep latency and tracking error (lane position variability), $r = -.42$. Drivers with shorter sleep latencies had more tracking errors.

Pizza, Contardi, Mostacci, Mondini and Cirignotta (2004) tested normal, healthy adults after a full night of sleep and after a night of complete sleep deprivation. Following both nights, participants completed a four-nap MSLT and a monotonous 30-minute driving simulation test after each nap. The driving simulation test included a measure of reaction time to stimuli presented in upper corners of the screen. Results showed that lane position variability, crashes, speeding and reaction time were negatively correlated with mean sleep latency. Lane position variability, as measured by the standard deviation from the center line, showed the strongest relationship to sleep latency, $r = -.53, p < .01$. In the sleep deprived condition, lane position variability increased throughout the drive.

May, Ware and Vorona (2005) investigated this relationship between sleep latency and driving simulator performance with patients at a sleep disorders center. All patients complained of excessive sleepiness and/or problems sleeping. This was a retrospective study that looked at patients who completed both an MSLT and a 60-minute monotonous highway driving simulator test. The reliability of lane position variability across the six 10-minute time blocks was calculated using coefficient alpha, $\alpha = .778$. A moderate correlation was found between sleep latency and lane position variability over the 6 time blocks ($r = -.263, p = .016$).

Most recently, Ware et al. (2007) tested the sensitivity of a critical tracking task to various levels of sleep deprivation by comparing performance on this task to driving simulator performance, performance on a psychomotor vigilance task and sleep latency on a one-nap multiple sleep latency test. Performance in the driving simulator was the most sensitive measure to levels of sleep deprivation. Lane position variability was able to most significantly discriminate among all three sleep deprivation conditions.

Subjective Sleepiness

Various measures of subjective sleepiness have been used to determine self-awareness of sleepiness and its impact on driving performance. These measures can be grouped into two categories: trait sleepiness and state sleepiness (Shahid, Shen, & Shapiro, 2010). Trait sleepiness measures such as the Epworth Sleepiness Scale (ESS) ask general questions about sleepiness to capture a person's propensity to sleep in a variety of situations. State sleepiness measures such as the Visual Analog Scale of Sleepiness (VAS), the Stanford Sleepiness Scale (SSS) and the Karolinksa Scale of Sleepiness (KSS) ask how sleepy a person is at that moment of the test. Results are varied in the literature as to how subjective sleepiness relates to driving performance decrements.

Pizza et al. (2004) investigated how subjective sleepiness relates to driving performance. Participants completed the VAS and the SSS, both subjective measures of state sleepiness. For the VAS, participants draw a vertical line through a horizontal line with two sleepiness anchors, not at all sleepy to extremely sleepy. The line is measured from the not at all sleepy anchor to the vertical line. The length of the line indicates the level of sleepiness. Lane position variability, speed variability, and reaction time

variability were all significantly correlated with the VAS and the SSS. As reported sleepiness increased, performance worsened.

Contardi, Pizza, Sancisi, Mondini and Cirignotta (2004) examined various measures of sleepiness over a 24-hour period. Participants completed a 30-minute driving simulator test, the SSS and the VAS every 2 hours from 10 A.M. on day 1 until noon on day 2. Participants were not allowed to sleep for the duration of the study, so that the effects of cumulative sleep deprivation and the circadian rhythm could be evaluated. Results showed that driving performance as indicated by reaction time, lane position variability, speed deviation, crash frequency and speeding worsened as time awake increased. In addition, significant correlations were found between subjective measures of sleepiness and driving performance measures. As sleepiness worsened, participants demonstrated a longer reaction time, greater variation in lane position and speed. Also, as sleepiness increased the number of crashes and speed exceedances also increased. These results support the idea that the driving simulator performance is influenced by sleepiness and that drivers are aware of their sleepiness.

Pizza, Contardi, Mondoni, Trentin, and Cirignotta (2009) examined driving performance, sleep performance on the MSLT and maintenance of wakefulness test (MWT) and subjective sleepiness. The MWT is similar to the MSLT, except that the objective is to try to remain awake for as long as possible. The measure of sleepiness is the duration of time the person can remain awake. Both the MWT and MSLT correlated strongly with driving performance. Results also indicated the drivers with higher subjective sleepiness on the ESS had significantly more crashes, greater lane position

variability and shorter time to first crash. However, reported sleepiness during the drive (VAS and SSS) did not have a significant impact on driving performance measures.

State subjective sleepiness was also not significantly correlated with crash risk in a simulator study investigating driving performance, microsleeps and subjective sleepiness in normal, healthy drivers (Moller, Kayumov, Bulmash, Nhan, & Shapiro, 2006). Participants drove four 30-minute test drives after a full night's sleep in a sleep center. Crash risk was calculated as the mean crash rate over the four drives. Crash risk was significantly correlated with lane position variability and frequency of microsleeps.

Schmidt et al. (2009) demonstrated a subjective sleepiness and performance mismatch after 3 hours of driving. Participants rated themselves as less tired at the end of the drive, even though their performance continued to deteriorate, as measured by reaction times and hit rates to an oddball task during a vigilant driving simulation test.

May, Ware and Vorona (2005) did not reveal a significant relationship between lane position variability and subjective measures of sleepiness, however scores from the visual analog scale of sleepiness were significantly correlated with lane position variability slope ($r = .293, p = .03$). This slope indicated a performance decrement over the course of the drive and patients who reported greater sleepiness had a greater performance decrement.

Sleep Apnea

Obstructive sleep apnea syndrome (OSAS) is a respiratory disorder during which a person stops breathing repetitively during sleep. An apnea event is defined as a cessation of breath lasting for 10 or more seconds (Thomas, Chokroverty, Bhatt, & Goldhammer, 2005). When accompanied by an effort to breathe, the apnea event is

obstructive in nature. This means that there is a collapse of the airway causing the apnea event to occur. Central apnea events are neurological in nature and with these events there is no effort to breathe. Mixed apnea events include both an obstructive and central component within the event. Central and mixed apneas are less prevalent in the population. Reductions in breathing are noted as hypopnea events. In these events the airway is partially obstructed, airflow is reduced by 15-20%, the event is followed by an arousal from sleep and there is an associated desaturation in oxygenation (Thomas et al., 2005).

When evaluating sleep apnea during a polysomnogram, the apnea / hypopnea index (AHI) is calculated and used to determine the severity of the apnea. This index is derived by counting the number of apnea and hypopnea events and dividing this number by the number of hours the patient was asleep during the test. An AHI of greater than 5 is considered abnormal. An AHI of 20 or greater is considered significant enough for treatment. Sleep apnea can occur across all age groups and races (Vorona & Ware, 2002). Sixty to 70% of OSAS patients are obese (Guilleminault, 1994). OSA is associated with an increased risk of hypertension, coronary heart disease, stroke and death (Vorona & Ware, 2002).

Night-time symptoms of OSAS include snoring, restlessness, sleep disruption, choking sensations during sleep, reflux and nocturia (Guilleminault, 1994). Day-time symptoms include excessive daytime sleepiness, performance decrements, inability to concentrate, deterioration of memory and concentration, changes in personality (moodiness or depression), sexual problems and morning headaches (Guilleminault,

1994). Many of these symptoms can impact driving performance in drivers with untreated sleep apnea.

Continuous positive airway pressure (CPAP) is the preferred treatment for obstructive sleep apnea. Air pressure is applied nasally or orally in an effort to splint the upper airway open (Sullivan & Grunstein, 1994). The force of the air prevents the airway from collapsing and allows the patient to breathe normally while asleep. The treatment pressure is determined during the PSG by a trained sleep technologist or respiratory therapist. The pressure typically ranges from 5 centimeters of water pressure (cwp) to 20 cwp, although special machines can produce higher pressures. During a PSG titration study, the pressure is slowly increased during sleep to eliminate the snoring, apnea, oxygen desaturation and arousals.

Although CPAP can sometimes help alleviate central sleep apnea, bilevel pressure treatment can be more effective for this form of apnea. This treatment utilizes a higher inspiratory pressure and a lower expiratory pressure to help ventilate the patient (Sullivan & Grunstein, 1994). Another form of pressure treatment is adaptive servo-ventilation (ASV) which is beneficial for patients who cannot tolerate CPAP or the small population of patients who start having central apnea once placed on CPAP. In these patients, the ASV unit effectively treats both the obstructive and central events.

Once an optimal pressure is established, the clinician can prescribe CPAP (or bi-level / ASV) for home use. Initially, the patient can have deep sleep and REM sleep rebound as an effort for the body to recuperate this loss (Sullivan & Grunstein, 1994). If the patient is adherent to the treatment, daytime symptoms of sleep apnea also improve.

Sleep Apnea and Driving Performance

One of the major benefits of the driving simulator test is to safely determine performance decrements in high-risk populations. Studies have shown that driving performance is worse for sleep disorder patients and participants undergoing sleep deprivation compared to control participants. Other studies have shown that treatment for sleep disorders improves driving performance in these patients.

Risser et al. (2000) compared driving simulator performance of sleep apnea patients with performance of normal, healthy control participants. They found that the sleep apnea patients had increased lane position variability, steering rate variability, speed variability and crash frequency. Lane position variability and crash frequency increased over the 60-minute drive in the sleep apnea group, indicating a vigilance decrement over the drive. The sleep apnea patients overall had greater lane position variability and crash frequency compared to controls.

Treatment for sleep apnea, CPAP, has been shown to improve driving simulator performance. Turkington, Sircar, Saralaya and Elliot (2004) compared sleep apnea patients undergoing treatment with those not yet receiving treatment over a period of seven days. The driving test was given at the same time each day and was a 20-minute drive using the Divided Attention Driving Simulator. This driving simulator also integrates a reaction time task where patients press a button every time a "2" appears on the screen. A baseline driving simulator test was performed before treatment for both groups of patients. In addition, driving simulator tests were performed 3 additional times throughout the 7 days of the study. There was no significant difference in driving performance measures at baseline between the two groups. The treatment group showed

significantly lower tracking error (lane position variability), faster reaction time and fewer off-road events post-treatment as compared to the non-treatment group.

One study compared driving simulator performance in untreated sleep disorder patients, sleep deprived participants, treated sleep disordered patients, participants consuming alcohol and normal, healthy controls (Hack, Choi, Vijayaplalan, Davies, & Stradling, 2001). Driving performance measures included lane position variability, number of off-road events and length of drive completed. Sleep deprived participants had significantly poorer driving performance compared to non-sleep-deprived controls. Participants consuming alcohol performed significantly worse, compared to their driving performance when sober. Untreated sleep apnea patients experienced greater lane position variability than participants who consumed alcohol, but better lane position variability than sleep deprived participants.

Conflicting in the literature is how the severity of sleep apnea impacts driving performance. One study indicated that crash rate is significantly higher in patients with severe sleep apnea (AHI > 34) as compared to those with an AHI of less than 34 (Horstmann, Hess, Bassetti, Gugger, & Mathis, 2000). Subjective sleepiness was also greater in the severe sleep apnea group. Findley et al. (1995) found significant correlations between severity of sleep apnea and percentage of obstacles hit during a driving simulator test. In contrast, Pizza et al. (2008) did not find a correlation between driving simulator measures (lane position variability, number of crashes) and AHI.

The Need for a Sleepiness Model of Driving Performance

Literature indicates that sleepiness degrades driving performance. However, due to the variety of definitions and measures of sleepiness it has been difficult to formulate a

detailed model of sleepiness. Theories have focused on homeostasis, circadian rhythms and sleep deprivation. However, it is argued that subjective sleepiness and severity of untreated sleep disorders also impact performance, as reviewed above. Sleep quality is a measure that has had little attention in research, but potentially also impacts driving performance.

The major theory of sleepiness is the two-process model (Borbely, Achermann, Trachsel, & Tobler, 1989; Kleitman, 1963). This theory states that sleepiness is determined by two different mechanisms in the brain. One mechanism is the pressure to sleep (i.e., the sleep drive), controlled by neuronal activity in the parts of the brain that promote non-REM sleep, such as the brain stem reticular formation (Kleitman, 1963). The primary sleep drive peaks between 10:00 p.m. and midnight, influencing bedtimes. This primary sleep drive includes the homeostatic factor of sleep duration. The other drive is the ability to stay awake (i.e., the wake drive), controlled by neuronal activation in the central nervous system that regulates wakefulness. This drive includes the circadian rhythm and core body temperature. The peak of the wake drive typically occurs at 7:00 to 9:00 p.m. and is at its lowest between 4:00 and 5:00 a.m. Not only is performance at risk during lows in the circadian rhythm, but performance degrades as time awake increases.

Johns (1998) elaborated on the sleep/wake drive theory to include a secondary sleep drive and a secondary wake drive by incorporating the influence of motivation and environment. The secondary wake drive may be influenced by sensory inputs from the environment including posture, lighting, and workload. Performance may be influenced to a greater degree by the ability to stay awake. Although a person may complain of

sleepiness, if they are interacting with the environment, this might help them stay awake. The secondary sleep drive is related to the duration of wakefulness. The longer a person stays awake, the stronger the secondary sleep drive becomes. During sleep, this secondary sleep drive is reduced or discharged. This would suggest that as sleep loss increases, effects of the environment and motivation may not be enough to keep a person awake, and sleep will prevail.

The two model theory was recently mathematically translated and used to predict road crashes (Akerstedt, Connor, Gray, & Kecklund, 2008). Time of day, time awake, and total sleep time were factors used to predict crash risk. These were combined to create the sleep/wake predictor (SWP). To test the model, these researchers fit the model to data of serious injury crashes and matched random controls. They called drivers of these crashes to obtain sleep data. The SWP was a significant predictor of crash occurrence. After controlling for covariates, each 1-unit increase in the sleep/wake predictor increased the odds of a crash by 1.72. Covariates accounted for were level of education, ethnicity, age, gender and blood alcohol level.

Sleep efficiency is defined as the percentage of time that a person is asleep while in bed. Often studies use total sleep time or time in bed as a measure of sleep duration, but sleep efficiency taps into the quality of sleep. It takes into account the arousals during sleep and any long periods of wake time during "bed time." This measure is independent of sleep duration, as a person who sleeps a full 4 hours in bed, out of the 4 hours in bed would have a sleep efficiency of 100%, but would be considered sleep restricted based on duration. However, a person sleeping 7 hours out of 8 hours in bed would have a sleep efficiency of 87%, indicating a poorer quality of their sleep.

Although this is a well-developed measure in clinical sleep studies, it is not a common variable used in research.

One goal of this dissertation was to develop a thorough model explaining how sleepiness impacts driving performance. First, the effects of a range of sleepiness constructs were examined to determine how each influences driving performance alone and together. Second, participants were grouped according to their sleepiness type for a separate analysis. The final goal was to confirm performance decrements in sleep apnea patients as compared to controls. The hypotheses were as follows:

1. It was hypothesized that sleep quality, subjective sleepiness and severity of sleep apnea would significantly add to present models by accounting for additional variance in performance. It was predicted that sleep duration and time awake would account for most of the variance in performance. Sleep quality and severity of sleep apnea would add to accounted variance. Subjective sleepiness would add the least to the model.

2. It was hypothesized that participants with state sleepiness would have a greater decline across the 60-minute drive as compared to participants with trait sleepiness. It was also hypothesized that both sleepiness groups would have increased lane position variability compared to the normal group.

3. It was hypothesized that the sleep apnea group, at risk for sleepiness and accidents, would perform worse compared to a non-apnea / non-sleepy control group. Additionally, performance of sleep apnea patients would degrade more significantly over the course of the drive.

CHAPTER 2

METHOD

Design

This study utilized a quasi-experimental design. Although many important confounds were controlled for by the design of the study (such as length of drive, exclusion of untreated sleep disorders for control participants, documentation of caffeine and nicotine use), other extraneous variables were documented and examined as possible covariates. It was expected that miles driven per year and age would be significant covariates. Tests for outliers, normality and linearity were performed prior to hypothesis testing. Transformation of data was performed as necessary to reduce the effect of outliers and to improve normality. The dependent variable for all statistical analyses was lane position variability. Independent variables in this study included age, miles driven per year, years with driver's license, apnea hypopnea index (AHI), subjective sleepiness (ESS and VAS scores), total sleep time (TST), wake duration, and sleep efficiency (SE).

Participants

A total of 57 participants (25 males, 32 females) completed the study. Thirty-eight participants self-identified as Caucasian, 13 as African American, 2 as Hispanic, 3 as Asian and 1 as multi-racial. Ages ranged from 18 to 74 (M = 39.2, SD = 17.02). Participants had their licenses for an average of 22.7 years (SD = 16.88) and drove an average of 10,200.65 miles per year (SD = 7188.46). Seventy-six percent of participants owned their vehicles and 63% drove passenger cars (19% SUVs, 12% passenger trucks). The majority of participants had received at least 1 moving violation (78.9%) and had an average of 1.64 crashes (SD = 1.64). Thirty-eight participants (66.7%) reported never

having had a crash or near crash due to sleepiness. Six participants reported having a crash or near crash due to sleepiness within the last six months, five within the last year and one within the last five years.

Average body mass index (BMI) was 30.53 (SD = 9.84). Average apnea/hypopnea index (AHI) was 14.77 (SD = 14.66), mean Epworth Sleepiness Scale (ESS) score was 8.75 (SD = 4.47) and mean Visual Analog Scale (VAS) pre-drive score was 28.35 (SD = 22.63). Participants slept for an average of 385.17 minutes the night before the driving test (SD = 77.84), with a mean sleep efficiency of 86.54% (8.80). The mean time awake before the test drive on day 2 was 4 hours and 36 minutes (SD = 3 hours and 11 minutes).

The average lane position variability over the entire drive was 1.342 feet (SD = .34). Participants averaged 5.39 line crossings (SD = 9.39) during the drive. There was low frequency of crashes during the drive. Sixty-six percent of participants did not crash during the drive. Six drivers (10.5%) had one crash, five drivers had 2 crashes (8.9%), six drivers had 3 crashes (10.5%) and one driver had 4 crashes (1.8%).

All participants were required to be at least 18 years of age and possess a valid driver's license. Participants were excluded if they were taking any medications with sedative properties (such as sleeping pills and antidepressants), were already treated for a sleep disorder, had a significant uncontrolled medical disorder (heart disease, diabetes), used excessive amounts of caffeine (greater than 5 cups per day), or used excessive amounts of nicotine (greater than ½ pack of cigarettes per day). Any participant working rotating or permanent night shift was also excluded.

Sleep apnea patients at the Sleep Disorders Center (located at Sentara Norfolk General Hospital and Eastern Virginia Medical School) were asked to participate in this study. The sleep disorder center completes almost 2,000 sleep studies a year. The majority of these are patients suspected of sleep apnea.

Participants were also recruited from Old Dominion University's Psychology Research Pool and the local community. These participants were screened for sleep disorders and excessive daytime sleepiness. Participants who demonstrated an apnea/hypopnea index of 15 or greater during their sleep night were asked to be part of the apnea group or allowed to withdraw from the study. Volunteers who exhibited sleep apnea during screening were advised to see their primary care physician for this condition.

After recruitment and data collection, participants were grouped according to their sleepiness scores. Participants were included in the state-sleepiness group if they scored greater than or equal to 30 on their visual analog scale of sleepiness pre-driving (VAS), but less than 10 on their Epworth sleepiness scale (ESS). Participants were included in the trait-sleepiness group if they scored greater than 10 on the ESS but less than 30 on the VAS pre-test. There have been no standard cut-offs for VAS in terms of sleepiness, so the mean was chosen to serve as this cut-off. Participants were included in the control group if they scored less than 10 on the ESS and less than 30 on the VAS pre-test.

As an incentive, all participants completing the study were entered into a drawing to win one of two $200 visa gift cards. Those withdrawn after screening were entered into the drawing once. Those participants completing the study had their name entered twice into the drawing. ODU psychology students were given the option of receiving 2

research participation credits for each day of participation as an alternative. If the student chose to take the credit points, a maximum of 4 participant credits were earned. This was desirable for students who were allowed extra credit for research participation in their classes. Students completing the study were alternatively able to obtain two participation credits and one entry into the drawing.

The study required 30 minutes of participation on day 1 for consent (see Appendix A) and screening. Participants then took the sleep sensors home. Participants spent approximately 5 to 10 minutes applying the Actiwatch and RU Sleeping device at bedtime and detaching upon wakening. Driving tasks on day 2 required 1.5 hours to complete.

A number of measures were used to test the hypotheses of this dissertation. These measures are described below. They are grouped according to purpose. Demographics and screening measures are discussed first. Next, driving performance equipment is reviewed, the driving simulator is detailed, objective sleepiness equipment is outlined, and subjective sleepiness scales are presented.

Measures

Demographics Questionnaire

The demographics and screening questionnaire is included as Appendix B. No personally identifying information was collected on the questionnaire. A general demographics section included statistics such as age, sex, height, weight, education, and occupation. A sleep history section included questions about caffeine and nicotine use, stimulant and depression medication usage, bedtime and wake time, and napping frequency. Other questions screened for sleep disorders such as sleep apnea, narcolepsy

and periodic limb movement disorder. A driving history section recorded miles driven per year, crash history, drowsy driving incidence, and frequency of driving per week.

Driving Performance Measures

Driving simulator. The Systems Technology, Inc. STISIM driving simulator is a moderate-fidelity simulator used at Eastern Virginia Medical School's Sleep Disorder Center to test clinical patients. The roadway, hood of the car and the speedometer were projected on a 47.5" wide, 44" tall screen in front of the participant. The distance from screen to driver's eyes ranged from 50 to 60 inches, depending on driver height. The mean useful field of view was horizontally calculated as 46.7 degrees. The vertical useful field of view was 43.6 degrees. The participant sat in a real car seat with a steering wheel, brake and accelerator pedals much like in a typical car. The steering wheel was equipped with force-feedback. The steering and pedal controls connected to a potentiometer which received the voltage inputs and this connected to analog to digital boards in the computer to transform the analog potentials into digital data. Vibrations could also be felt from under the seat to increase the fidelity of the drive. A fan, back-light and motion sickness bands were provided when needed to help reduce simulator sickness.

A 10-minute practice and acclimation drive in a city-based scenario allowed participants to become accustomed to the feel of the simulator. A city-based scenario allows for the driver to become accustomed to all the controls of the simulator. The clinical test drive was a 60-minute monotonous highway scenario, with 6 passing cars, and 6 slight curves throughout the drive. Participants were instructed to stay quiet and

not engage in any activities that might keep them awake (such as tapping their fingers or whistling). The computer recorded lane position, lane position variability, speed, and number of line crossings (center line and off-road line) sampled at 30 hz. These data were averaged each second and saved to a data file. Crash occurrence was also recorded. A crashed was defined by departing the lane by 3 feet or more. After the drive, the data were averaged into six -10-minute epochs. Variables of interest included lane position variability, number of line crossings and number of crashes.

The Division of Sleep Medicine at Eastern Virginia Medical School has collected driving performance data using the same driving scenario with various groups. Each study examined the differences between a high-risk group (i.e., night shift workers, sleep disorder patients, adults with ADHD, cognitively impaired elderly) and a normal, healthy adult control group (Freeman, Freeman, & Ware, 2003; Freeman et al., 2002; May et al., 2005; Risser et al., 2000; Ware, Freund, Freeman, & Gravenstein, 2003). In comparing data from each of the control groups across studies, there were no significant differences in lane position variability among control groups, $F(4, 62) = 1.603, p = .185$. This indicated that different control groups, recruited using the same criteria, performed similarly on the driving simulation test. This suggests that the scenario is reliable in obtaining similar results across different samples of the same population. In addition, results demonstrated strong reliability over the length of the drive among normal, healthy adults when comparing lane position variability from each epoch, $\alpha = .953$. Based on this previous research, normal control groups typical have a mean lane position variability of less than 1.5 feet.

Objective Sleep Measures

Actiwatch. The Actiwatch™ is a special wrist-worn device that records wrist movement as a measure of physical activity. Actigraphy measures activity level by recording the number of wrist movements over time. Lack of movement indicates rest or sleep. Software for the Actiwatch enables sleep analysis based on the amount of movement. Total amount of sleep and sleep efficiency (percentage of sleep from lights off to lights on) were computed. Actigraphy is an accepted and validated estimate of sleep patterns and total sleep time in normal, healthy populations as well as sleep disordered populations, children and the elderly (Morgenthaler et al., 2007). The Actiwatch is worn on the non-dominant wrist for standardization. See Appendix C for sample Actiwatch results.

Respironics "RUSleeping." The RUSleeping device is a small 1-channel airflow apnea detection monitor. The actual device is a 3 inch by 2 inch by 0.5 inch device with a connection for a disposable nasal cannula. The monitor records airflow throughout the night and a computer chip within the device counts the number of times breathing is reduced by at least 50% for 10 seconds or more in duration. The apnea hypopnea index is displayed on the device at the end of testing (Herrle, 2007).

The RUSleeping has been validated against scored airflow during polysomnogram data in multiple studies with both lab and at-home environments. Gorny, Allen, and Krausman (2000) compared RUSleeping with a complete polysomnogram (PSG) on sleep times, sleep efficiency and apnea/hypopnea events. The RUS was worn during the PSG. There was a correlation of .97 between airflow wave forms recorded with RUS and the PSG. Scoring relation of apnea/hypopnea events

between the RUS monitor and visual scoring of the PSG was $r = .94$, with a 100% hit rate and a 5% false alarm rate for detection of events. Detection hit rate was lowest for patients with the mild sleep apnea, at a hit rate of 78% and false alarm rate of 0%. An extension of this study also showed good agreement between sleep lab PSG data and at-home RUS data ($r = .91$). A larger study (45 subjects) also found a high correlation between RUS and visual scoring of PSG airflow (Gorny, Spiro, Phillips, Allen, & Krausman, 2001). This correlation was .97 and there were no significant differences between the RUS apnea count and the visual scoring of apneas from the PSG. A third study (Spiro, Gorny, Allen, & Krausman, 2002) stated that the RUS was as accurate and reliable as PSG with respect to waveform of airflow and detecting of apnea events.

Time awake. On the day of the driving test, time awake was calculated at the beginning of each drive. Time of awakening was documented from that morning and used to determine time awake in combination with the time of the drive. Time of drive minus time of awakening provided a measure of time awake.

Subjective Sleepiness

Epworth Sleepiness Scale – subjective sleepiness. The Epworth Sleepiness Scale (ESS) is a measure of general daytime sleepiness (Johns, 1991, 1992, 1994). Participants are asked to rate how likely they are to fall asleep or doze in eight different situations. The scale ranges from 0 (would never doze) to 3 (high chance of dozing). The ratings are then summed to give a total score of general sleepiness. Normal, healthy adults score between 0 – 10, while sleep apnea patients score between 4 and 23 (Johns, 1991). Scores on the ESS are sensitive to severity of sleep apnea, correlate with sleep latency on PSG and on the MSLT (Johns, 1991). Johns (1992) has also shown that the scale has a high

internal consistency ($r = 0.88$) and only one factor in factor analysis when given to healthy medical students and patients with sleep apnea, pre/post treatment. See Appendix D for a copy of the ESS.

Visual Analog Scale – subjective sleepiness. The Visual Analog Scale of sleepiness (VAS) is an immediate rating of current sleepiness. Participants are asked to draw a vertical line through a 100mm horizontal line with anchors of "not at all sleepy" to "extremely sleepy." Results range from 0 – 100. Results of this scale significantly increase with sleep deprivation (Babkoff, Caspy, & Mikulincer, 1991). Scores on the VAS also significantly correlate with lane position variability ($r = -.31, p < .05$; Pizza et al., 2004). See Appendix D for a copy of the VAS.

Procedure

Participants were recruited verbally at the Eastern Virginia Medical School Division of Sleep Medicine and Sentara Norfolk General Hospital Sleep Disorders Center and via flyers and email in the community and in the psychology department at Old Dominion University. An advertisement was placed in the Daily Bulletin at Sentara Norfolk General Hospital and in Old Dominion University campus email announcements. Participants called or emailed to schedule their participation dates. Interested sleep apnea patients were asked to participate if their sleep study results indicated an AHI of greater than 15. Sleep apnea patients were allowed to participate in the study only before they were started on treatment. These patients would be driving during this time before treatment for personal and work reasons, but cautioned to pull over if they felt too tired to drive. Clinical protocol in the sleep disorders center is that results are given to the patient 10-14 days after the sleep study during a follow up office visit. The decision to treat the

sleep apnea would be made by the clinician and patient at that time. The prescription to set the patient up on a continuous positive airway pressure machine (CPAP) would be sent to a home care company at the end of their follow up appointment.

Participants arrived at the Sleep Disorders Center on day one for consent provision, questionnaire completion and simulator driving practice. The researcher reviewed the consent form and process of the study with each participant. If participants agreed to participate, they completed the demographics and screening questionnaire and provided documentation of their driver's licenses. Next, they were acclimated to the driving simulator by completing the 10-minute practice drive. Six participants (10% of all recruited participants) experienced simulator sickness and were withdrawn from the study. Participants who passed the screening and successfully completed the driving simulator practice were entered into the study.

Participants received verbal and written instructions about how to use the RU-Sleeping monitor and Actiwatch. These were given to the participant to wear the night between the first and second day of participation. Participants attached these devices at bedtime and slept with them attached during the night. The RU-Sleeping monitor and Actiwatch were removed upon awakening and brought to the sleep disorder center the next day.

The next day, participants again came to the sleep disorders center to complete the test. Participants completed the 10-minute practice drive. After the practice drive, they completed the VAS. Participants were given the opportunity to use the bathroom, and then the researcher explained the instructions for the hour-long test drive. After the hour-long simulator drive was completed, participants again reported their sleepiness using the

VAS. If participants needed a break before they drove home, or if they scored more than 70 on the VAS, they were recommended to rest at the sleep disorders center before driving home.

There were no night drives and the period of 1- 3pm each day was avoided as this is the trough in the circadian rhythm during which drivers are more susceptible to sleepiness. The time of day was recorded at the start of each test drive in order to calculate duration of time awake.

CHAPTER 3

RESULTS

Descriptive Statistics

All variables used in hypothesis testing were analyzed for normality by assessing skewness and kurtosis values, as well as visually inspecting of normal quantile to quantile (Q-Q) probability plots and histograms with normal distribution overlay. Variables with skewness or kurtosis values of one or greater were considered non-normal. Outliers were identified if they were 2 standard deviations above or below the mean. LPV was the main dependent variable of all the statistical analyses. LPV ranged from 0.81 feet to 2.48 feet (M = 1.34, SD = .34). Tests of normality on LPV indicated a leptokurtic distribution with a value of 2.57 (SE = .623) that was also slightly positively skewed, 1.25 (SE = .316). Additional exploratory analyses identified three outliers.

Two of the three outliers added variability to three of the sleepiness variables: exhibiting apnea; high ESS; and VAS delta scores. Scoring high in both ESS, VASdelta and having significant sleep apnea could compound the impact of fatigue on driving performance. Instead of eliminating all three outliers, the researcher transformed LPV to bring these outliers back into a normal distribution. LPV was transformed reciprocally to bring the outliers closer to the mean. The reciprocal of LPV (LPVreciprocal) showed a normal distribution. Transformation of the six 10-minute time points of LPV also allowed for normal distribution in all six epochs (see Table 1 for the raw and transformed statistics for LPV and LPV epochs). Visual inspection of the Q-Q plots and histograms for these transformed variables also indicated a normal distribution.

Table 1

Descriptive Statistics for Lane Position Variability (LPV)

	N	M (SE)	SD	Skewness (SE)	Kurtosis (SE)
Raw Data					
Total LPV	57	1.34 (.04)	.34	1.25 (.316)	2.57 (.623)
LPV1	57	1.15 (.03)	.22	.29 (.316)	-.54 (.623)
LPV2	57	1.21 (.03)	.26	.61 (.316)	.81 (.623)
LPV3	57	1.30 (.05)	.35	1.48 (.316)	4.17 (.623)
LPV4	57	1.34 (.04)	.33	1.04 (.316)	1.89 (.623)
LPV5	57	1.39 (.05)	.40	1.04 (.316)	1.26 (.623)
LPV6	57	1.48 (.07)	.53	2.32 (.316)	8.67 (.623)
Reciprocal Data					
Reciprocal LPV	57	.787 (.02)	.18	.37 (.316)	.21 (.623)
Reciprocal LPV1	57	.90 (.02)	.18	.58 (.316)	-.026 (.623)
Reciprocal LPV2	57	.87 (.02)	.19	.674 (.316)	.347 (.623)
Reciprocal LPV3	57	.82 (.03)	.20	.327 (.316)	-.125 (.623)
Reciprocal LPV4	57	.79 (.02)	.19	.403 (.316)	-.126 (.623)
Reciprocal LPV 5	57	.77 (.03)	.21	.672 (.316)	1.06 (.623)
Reciprocal LPV6	57	.74 (.03)	.21	.324 (.316)	.56 (.623)

Predictor variables for the regression analysis included ESS, VASpre, AHI, age, miles driven per year, SE, TST, and time awake (see Table 2 for a list of all variables and acronyms). Descriptive statistics were also performed on years with license as an alternative measure of driving exposure due to the difficulties many participants had estimating miles driven per year. All measures indicated a normal distribution both visually and statistically except for AHI, age and SE. The mean age of the sample was 39 (SD = 17), with a skewness of .31 (SE = .316) and kurtosis of -1.29 (SE = .623). Visual inspection showed a slightly positively-skewed distribution on the histogram and a

slight S shape on the Q-Q plot. Because data were relatively normal, this variable was not transformed.

Table 2

Study Variables

Acronym	Variable	Definition
AHI	Apnea/Hypopnea Index	Number of Apneas/Hypopneas per hour of sleep
SE	Sleep Efficiency	Percentage of time asleep from lights off to lights on
TST	Total Sleep Time	Number of minutes asleep from lights off to lights on
	Time Awake	Time of drive minus time of awakening (minutes)
VASpre	Visual Analog Scale - Sleepiness	Current feeling of sleepiness, 0-100 score
VASdelta	Visual Analog Scale – Sleepiness (Pre/Post Change)	Score on VAS after the drive minus the score on VAS before the drive
ESS	Epworth Sleepiness Scale	General measure of sleepiness, 0-24 score

The mean AHI was 14.8 (SD = 14.67). This variable was positively skewed (1.48, SE = .316) and leptokurtic (1.61, SE = .623). The majority of participants had an AHI of < 20, allowing for a high peak in the distribution at the lower end of the data and a flattening of the higher end of the data. Transformation of this variable did not improve normality. Exclusion of the seven outliers was not feasible due to apnea grouping for one of the hypotheses. The variable was retained with the understanding that generalization of results might be limited due to the skewness and leptokurtic nature of the data.

Sleep efficiency was negatively skewed (-2.02, *SE* = .316) and extremely leptokurtic (5.53, *SE* = .623). The mean SE was 86.5 (*SD* = 8.80). Traditional logistic, inverse and square root transformations of this variable exacerbated the skewness and kurtosis. Reciprocal, logistic, inverse and square root transformations were attempted. Further analysis identified 3 outliers with SE < 70%. Exclusion of these three outliers normalized the data with a skewness of -.70 (*SE* = .325) and kurtosis of .245 (*SE* = .639). These outliers were excluded for the correlation and regression tests utilizing this variable. See Table 3 for descriptive statistics of the predictor variables.

Table 3

Descriptive Statistics for Predictor Variables

	N	M (SE)	SD	Skewness (SE)	Kurtosis (SE)
ESS	57	8.75 (.59)	4.47	.50 (.316)	-.24 (.623)
VASpre	57	28.35 (3.0)	22.63	.62 (.316)	-.73 (.623)
VASdelta	57	27.8 (3.1)	23.18	.73 (.316)	.98 (.623)
AHI	57	14.77 (1.94)	14.66	1.48 (.316)	1.61 (.623)
Age	57	39.2 (2.26)	17.03	.31 (.316)	-1.29 (.623)
Years with license	57	22.71 (2.24)	16.88	.3 (.316)	-1.27 (.623)
Miles driven/year	57	10040.98 (943.19)	7120.90	.59 (.316)	-.048 (.623)
SE	57	86.54 (1.17)	8.80	-2.02 (.316)	5.53 (.623)
SE (No Outliers)	54	88.1 (.78)	5.77	-.70 (.325)	.25 (.639)
TST	57	385.17 (10.31)	77.84	-.23 (.316)	.98 (.623)
Time awake	57	276.07 (25.43)	191.0	.86 (.316)	-.58 (.623)

Hypothesis 1: Stepwise Regression of Sleep Variables on LPV

The first hypothesis stated that sleep quality as measured by sleep efficiency, subjective sleepiness as measured by the ESS and VAS scores, and severity of sleep

apnea as measured by AHI would add to present models by accounting for additional variance in performance.

Assumptions of regression were evaluated before testing this hypothesis (Tabachnick & Fidell, 2007). All predictors used in the model were continuous variables. Earlier tests of normality indicated that age, AHI and SE were non-normal. Age and AHI were not transformed and are used with caution. Three outliers of SE were excluded to create a normal distribution of this variable. Inspection of correlations revealed that VASpre, AHI, age, miles driven per year and wake duration did not significantly correlate with LPVreciprocol. See Table 4 for variable for raw, uncorrected correlations.

Table 4

Correlation Matrix of Study Variables

Measure	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
1. ESS	1.0							
2. VASpre	0.20	1.0						
3. VASdelta	0.21	-.42**	1.0					
4. AHI	0.19	0.04	-.17	1.0				
5. Age	.16	-.13	0.12	0.52**	1.0			
6. Years with License	0.17	-.12	0.12	0.52**	0.997**	1.0		
7. Miles Driven/Year	-.16	0.02	0.6	-.03	-.12	-.11	1.0	
8. SE (N = 54)	-.35**	-.22	-.05	-.15	0.11	0.09	-.11	1.0
9. TST	-.27*	-.17	0.03	-.11	0.09	0.08	-.10	.55**
10. Wake Duration	-.02	0.18	-.33*	-.12	-.01	-.01	-.02	0.20
11. LPV	0.54**	0.08	0.31*	0.13	0.19	0.21	-.06	-.55**
12. LPV Reciprocal	-.50**	-.06	-.28*	-.16	-.25	-.27*	-.01	.45**

Table 4

Continued

Measure	*9*	*10*	*11*
9. TST	1.0		
10. Wake Duration	0.01	1.0	
11. LPV	-.31*	-.21	1.0
12. LPV Reciprocal	0.29*	0.24	-.94**

Note. * $p < .05$; ** $p < .01$; N = 57 except for SE Variable where correlations use N = 54.

In light of several key predictors not significantly correlating with lane position variability or LPVreciprocol, the regression was performed two different ways. The regression was performed as hypothesized, with all predictors entered into the model. Next, some predictor substitutions were made for variables with non-significant correlations to the DV, to allow for stronger predictors to be considered. VASdelta substituted for VASpre as a correlated measure of state sleepiness with LPVreciprocol. VASdelta and VASpre are both state measures of sleepiness, and correlated significantly with each other. Years with license substituted for both age and miles driven as a combined measure of exposure and age. Years with license was significantly correlated with LPVreciprocol. Years with license was also significantly correlated with age and miles driven per year. Wake duration and AHI were eliminated from the model as they did not meet one or more assumptions and no substitutions were suitable. Both the original hypothesized regression and the modified regression were performed for comparison.

For the original hypothesized regression, age and miles driven per year were entered as step 1 into the model. Total sleep time (TST) and wake duration were entered

in step 2. The third step included ESS, VASpre, AHI, and SE. Age and miles driven per year accounted for 5.9% of the variance, but this was nonsignificant, $R^2 = .059$, $F(2, 51) = 1.6$, $p = .21$ With TST and wake duration added to the model, there was a significant increase in variance accounted for, $\Delta R^2 = .164$, $\Delta F(2, 49) = 5.18$. $p = .01$. Variables in step 2 accounted for an additional 16.4% of the variance, cumulative $R^2 = .22$, $F(4, 49) = 3.52$, $p = .01$. There was also a significant increase in variance accounted for with step 3 of the model, $\Delta R^2 = .21$, $\Delta F(4, 45) = 4.16$, $p = .006$. Variables in step 3 accounted for an additional 21% of variance in the model, cumulative $R^2 = .43$, $F(8, 45) = 4.297$, $p = .001$. Examining the coefficients for step 2, age and TST were significant contributors to the model. At step 3, only ESS was a significant predictor ($t = -2.95$, $p < .05$). See Table 5 for regression statistics. Tolerance statistics showed acceptable collinearity. Inspection of the scatter plot displaying the standardized residuals to standardized predicted DV indicated the model met assumptions of normal distribution, linearity and homoscedasticity.

Table 5

Stepwise Hierarchical Regression of Sleep Constructs on LPVreciprocol: Original Model (N = 54)

Variable	B	SEB	β	R^2	Adj R^2	ΔR^2
Step 1				.059	.022	.059
Age	-.003	.001	-.24			
Miles Driven per Yr	-4.96E-7	.00	-.019			
Step 2				.22*	.160	.164**
Age	-.003	.001	-.291*			
Miles Driven per Yr	9.70E-7	.000	.038			
TST	.001	.000	.346**			
Wake Duration	.000	.000	.243			
Step 3				.43*	.332	.21**
Age	-.003	.001	-.280			
Miles Driven per Yr	-6.45E-7	.000	-.025			
TST	.000	.000	.129			
Wake Duration	.000	.000	.191			
ESS	-.016	.005	-.376**			
VASpre	.000	.001	.049			
AHI	.001	.002	.08			
SE	.008	.005	.257			

Note. * $p < .05$; ** $p < .01$.

In the modified regression analysis, years with license was entered as step 1 into the model. Total sleep time (TST) was entered in step 2. The third step included ESS, VASdelta, and SE. Years with license accounted for 6.6% of the variance, but this was not significant, $R^2 = .066$, $F(1, 52) = 3.65$, $p = .062$. With TST added to the model, there was a significant increase in variance accounted for, $\Delta R^2 = .11$, $\Delta F(1, 51) = 6.42$. $p = .014$. The variable in step 2 accounted for an additional 10.5% of the variance, cumulative $R^2 = .17$, $F(2, 51) = 5.23$, $p = .009$. There was also a significant increase in variance accounted for with step 3 of the model, $\Delta R^2 = .25$, $\Delta F(3, 48) = 6.88$, $p = .001$.

Variables in step 3 accounted for an additional 25% of variance in the model, cumulative $R^2 = .42$, $F(5, 48) = 6.94$, $p < .001$. Examining the coefficients for step 2, both years with license and TST were significant contributors to the model. At step 3, years with license, ESS and SE were significant predictors. See Table 6 for regression statistics of the modified model. Tolerance statistics showed no assumption violations of collinearity. Inspection of the scatter plot displaying the standardized residuals to standardized predicted DV indicated the model met assumptions of normal distribution, linearity and homoscedasticity.

Table 6

Stepwise Hierarchical Regression of Sleep Constructs on LPVreciprocol: Modified Model (N = 54)

Variable	B	SEB	β	R^2	Adj R^2	ΔR^2
Step 1				.07	.048	.07
Years with License	-.003	.001	-.256			
Step 2				.17**	.137	.11*
Years with License	-.003	.001	-.301*			
TST	.001	.000	.326*			
Step 3				.42***	.359	.25***
Years with License	-.003	.001	-.241*			
TST	.000	.000	.107			
ESS	-.013	.005	-.314*			
VASdelta	-.001	.001	-.166			
SE	.009	.004	.292*			

Note. * $p < .05$; ** $p < .01$; *** $p < .001$.

There are noticeable differences between the two regression models. For both, ESS was a strong significant predictor of LPVreciprocol. However, the second model met assumptions of a regression model and this developed a better fit model with ESS, years with license and sleep efficiency as significant predictors. This second model appears superior and will be discussed in the Discussion section below.

Hypothesis 2: Mixed ANOVA of time and sleepiness groups on LPV

It was hypothesized that participants with state sleepiness would show greater lane position variability across the 60-minute drive than participants with trait sleepiness. Both sleepiness groups were expected to have increased lane position variability compared to the normal group.

Participants were grouped after data collection by their ESS and VASpre scores. The ESS represented a measure of trait sleepiness, whereas the VASpre score was a measure of state sleepiness. ESS has a well-established criterion of 10, such that participants scoring greater than 10 are excessively sleepy and equal to or less than 10 are considered normal (Johns, 1991, 1992, 1994). The VAS scale does not have such a criterion, so the mean score was used as the cut off for state sleepiness. There were three groups for sleepiness: NORM (ESS < 10, VAS < 30), TRAIT (ESS > 10, VAS < 30) and STATE (ESS < 10, VAS > = 30,). Participants who scored greater than 10 on the ESS and also greater than 30 on the VAS were excluded from the analysis (N = 11). Reciprocal transformation of LPV across time was represented by six 10-minute epochs (LPVreciprocol1 – LPVreciprocol6). See Table 7 for descriptive statistics for each sleepiness group.

Table 7

Descriptive Statistics by Sleepiness Group

	NORM (N = 21)		STATE (N = 15)		TRAIT (N = 10)	
	M	SD	M	SD	M	SD
Age	39.62	17.79	32.8	15.37	46.4	16.01
Years with License	23.12	17.42	16.55	15.42	29.8	16.4
ESS	5.71	2.4	6.4	2.4	13.5	2.4
VASpre	11.62	8.14	47.8	15.32	13.7	10.43
AHI	13.12	16	8.77	8.55	20.25	13.98
BMI	28.21	6.54	31.90	14.62	31.58	5.21
SE	90.4	3.41	89.52	5.24	79.82	14.84
TST	6.8h	59.84m	6.75h	97.93m	6.14h	77.38m
Total LPV	1.17	0.18	1.25	0.25	1.72	0.32
LPVreciprocol	0.87	0.14	0.83	0.19	0.6	0.11

A 6 (epochs) x 3 (groups) ANOVA was performed. There were 21 NORM participants, 10 TRAIT participants and 15 STATE participants in this analysis. After an inspection of the epsilon values, the Hyundt-Feldt's correction was used for reporting results of the within-subjects effects (i.e., the Greenhouse-Geisser epsilon > .75). There was a significant effect of time, F (4.47, 192.36) = 20.91, p< .001. LPV increased across the hour long drive (as indicated by a decrease in LPVreciprocol). There was a main effect for group, F (2, 43) = 10.36, p < .001. See Table 8 for ANOVA statistics.

Table 8

Repeated Measures ANOVA for Sleepiness Groups

	df	*MS*	*F*	*p*	Partial η^2
Time	4.47	.17	20.91	.00	.327
Time x Group	8.95	.009	1.11	.36	.05
Group	2	1.54	10.36	.001	.33
Error (time)	192.36	.008			

For the main effect of time, a linear contrast was significant, $F(1, 43) = 52.0$, $p < .001$. LPVreciprocol decreased over the length of the drive, which translates into an increase in LPV over time. No other trends were significant. For the main effect of group, REGWQ and Games Howell post hoc tests were used as they are less sensitive to unequal sample sizes and violations of homogeneity of variances which occurred in the last two epochs (Howell, 2007). Both post-hoc tests indicated that the TRAIT group ($M = .60$, $SD = .11$) had significantly greater LPV than both the NORM ($M = .87$, $SD = .14$, $p = .00$) and STATE ($M = .83$, $SD = .19$, $p < .001$) groups. The NORM and STATE group were not significantly different from each other. There was not a significant time by group interaction. Figure 1 illustrates the difference between the TRAIT group and the NORM and STATE groups with the LPVreciprocal over time.

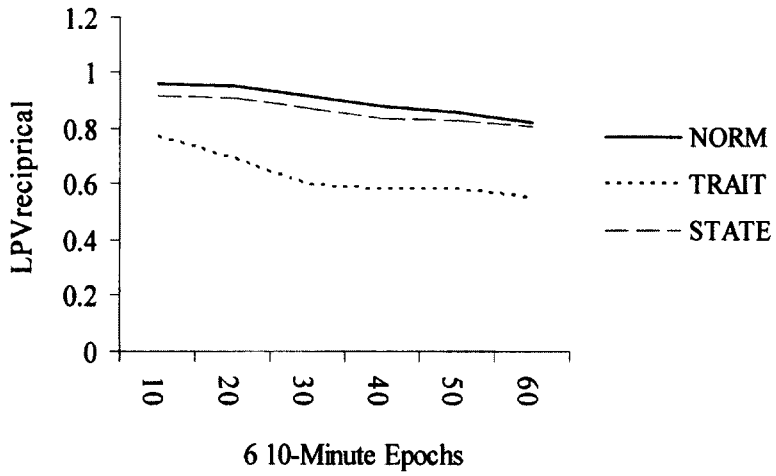

Figure 1. Effect of Sleepiness Group and Time on LPV (Reciprocal).

Hypothesis 3: Mixed ANOVA of time and apnea group on LPV

It was hypothesized that the sleep apnea group, at risk for sleepiness and accidents, would perform worse compared to healthy, normal controls. Additionally, performance of sleep apnea patients would degrade more significantly over the course of the drives.

Groups were formed *a priori* according to apnea severity, with participants exhibiting an AHI > 15 in the APNEA group, participants with an AHI ≤ 10 in the NORM group and participants with AHI between 10 and 15 excluded for this analysis. Participants were excluded from the NORM group if they also scored > 10 on the ESS, indicating a high level of subjective sleepiness. Reciprocal transformation of LPV across time was represented by six 10-minute epochs (LPVrec1 – LPVrec6). See Table 9 for descriptive statistics for each group.

Table 9

Descriptive Statistics by APNEA Group

	APNEA (N = 22)		NORM (N = 23)	
	M	SD	M	SD
Age	50.77	14.8	30.5	12.88
Years with License	34.5	14.57	14.03	12.58
ESS	10.32	5.2	6.18	2.4
VASpre	30.64	24.9	29.3	21.8
AHI	28.9	14.4	4.28	2.7
BMI	34.13	12.19	27.22	6.07
SE	92.44	11.79	89.95	4.46
TST	6.13h	68.09m	6.69h	78.99m
Total LPV	1.43	0.39	1.22	0.21
LPVreciprocol	0.74	0.18	0.85	0.16

A 6 (epochs) x 2 (groups) mixed ANOVA was performed. There were 23 participants in the NORM group and 22 participants in the APNEA group. The Greenhouse-Geisser (G-G) correction was used for interpretation of results. The G-G epsilon was < .75. There was a significant effect of time, F (3, 73, 160.34) = 18.72, p < .001. The group effect was not significant, F (1, 43) = 4.03, p = .051. There was a significant time by group interaction, F (3.73, 160.34) = 2.74, p = .03. Homogeneity of variances was confirmed. See Table 10 for ANOVA statistics.

For the main effect of time, there was a significant linear trend, F (1, 43) = 47.91, p < .001. The reciprocal LPV decreased as time progressed over the drive, translating into an increase of LPV over the drive. This effect was more pronounced for the APNEA group. Independent samples t-tests were performed between the two groups at time periods 2 through 6. A Bonferroni correction was used to account for multiple tests,

giving a significance goal of $p < .01$. Results did not reveal any significant differences between the particular epochs. Further analysis of trends indicated a significant linear trend for both the APNEA group, $F(1) = 15.96, p = .001$ and the NORM group, $F(1) = 11.85, p = .002$. See Figure 2 for a visual display of the group by time interaction and main effect of time. The figure illustrates how LPVreciprocol decreases over the six epochs, and the difference between APNEA and NORM groups over the drive. A linear trend is evident for both groups, but the APNEA group has a steeper linear slope.

Table 10

Repeated Measures ANOVA for APNEA and NORM groups (Reciprocal LPV)

	df	*MS*	*F*	*P*	Partial η^2
Time	4.22	.163	18.72	.001	.30
Time x Group	4.22	.024	2.74	.03	.06
Group	1	.696	4.03	.05	.09
Error (time)	160.34	.01			

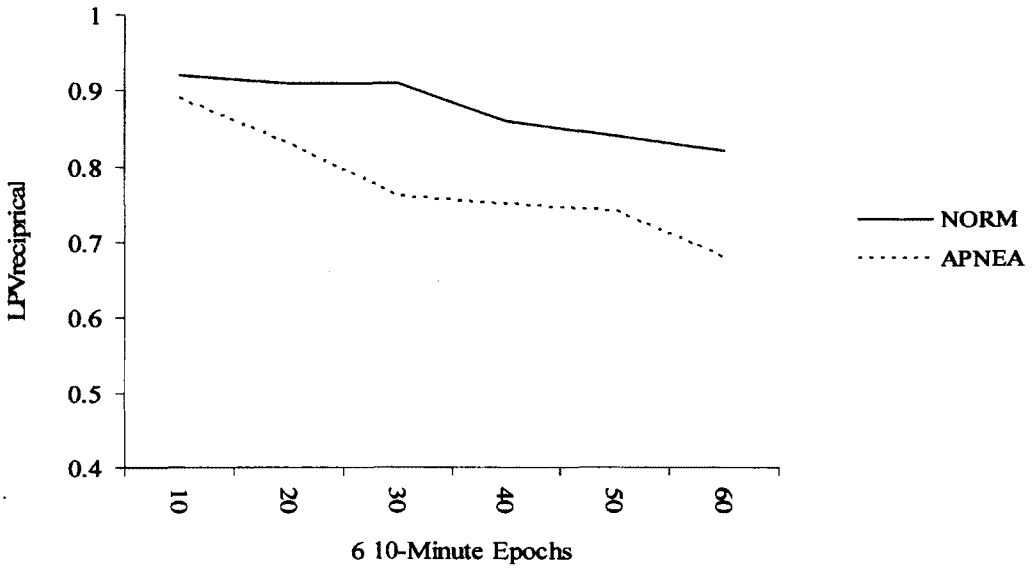

Figure 2. Effect of APNEA Group and Time on LPV.

CHAPTER 4

DISCUSSION

Interpretation of Results

Results of this experiment indicate that years of driving experience, subjective trait sleepiness and sleep efficiency (as an indicator of sleep quality) are all strong predictors of driving performance as defined by lane position variability. Drivers with high trait sleepiness had greater lane position variability than drivers with high state sleepiness or no subjective sleepiness. The results did not support group differences between drivers with an apnea/hypopnea index of 15 or greater and drivers with an apnea/hypopnea index of less than 10. Both the apnea and control participants had a linear decline in driving performance and this was more pronounced for the apnea group, providing a significant group by time interaction. Although a reciprocally transformed variable of lane position variability was used for all testing, the results will be discussed in terms of the original lane position variability for ease of interpretation.

Hypothesis 1

The first hypothesis stated that sleep quality, subjective sleepiness and severity of sleep apnea would significantly add to present models by accounting for additional variance in performance. In this hypothesized model, sleep duration and time awake would account for most of the variance in performance, sleep quality and severity of sleep apnea would add to accounted variance. It was predicted that subjective sleepiness would add the least to the model.

Due to violations of assumptions of regression, interpretation of the revised model of sleepiness is presented here to best represent how sleepiness predicts driving

performance. In the revised model, wake duration and the apnea hypopnea index dropped from the model, as these measures did not strongly nor significantly correlate with lane position variability. Participants averaged 4.6 hours of wakefulness between their wake time and drive. This duration is within normal wake time of individuals. Research that links wake duration and decrements in performance has examined prolonged wakefulness of 12 hours or more (Arnedt, Ainsley, Geddes, & MacLean, 2005; Matthews et al, 2012).

Participants demonstrated a mean apnea hypopnea index of 14.77 events per hour. Only 9 out of the 54 participants included in the regression analysis had an AHI of greater than 20. It is likely that a wider distribution of AHI would have presented with a stronger correlation with lane position variability. Categorically, drivers with sleep apnea have greater lane position variability than controls (Hack, Choi, Vijayaplalan, Davies, & Stradling, 2001; Horstmann, Hess, Bassetti, Gugger, & Mathis, 2000; Risser, Freeman & Ware, 2000) so this lack of correlation was surprising. However, when AHI is used as a grouping variable, often the range between AHI of 5 and 15 or 20 are excluded. This could be a "grey area" of severity that may or may not predict performance or sleepiness due to the individual differences of tolerance of or susceptibility to symptoms of sleep apnea.

In the revised model, years with driver's license replaced the variables of age and miles driven per year as a combined measure of driving experience. During data collection, many participants had difficulty answering how many miles they drove per year. Many estimated the mileage and this may have led to a reduction in accuracy of this variable. Papadakaki et al., (2008) also did not find age and miles driven per year to

increase sleep-related road risk. As such, this substitution seemed a reasonable variable for the model with significant correlations to age, miles driven per year and lane position variability.

The revised regression model included the following variables: years with driver's license, total sleep time, sleep efficiency, Epworth sleepiness scores and the pre to post drive change score on the Visual Analog Scale of Sleepiness. The final step of the model presented with three significant predictors of driving performance: years with driver's license, sleep efficiency and Epworth Sleepiness Score. This model indicates that the longer a driver has had his or her license, the higher the sleep efficiency and the less the sleepiness score predicts lane position variability.

Adding subjective sleepiness and sleep efficiency in the third step of the model reduced the significant variance accounted for by total sleep time in the second step of the model. Total sleep time and sleep efficiency were significantly correlated, but measure difference constructs. These results suggest that sleep efficiency or quality of sleep is the overriding factor accounting for variability in driving performance compared with total sleep time.

Counter to the hypothesis, subjective sleepiness accounted for a significant amount of variance in the model. Specifically, subjective trait sleepiness presented as a significant predictor in the model. The Epworth Sleepiness Scale may provide a more accurate measure of a person's sleepiness and their susceptibility to sleepiness as compared to state measures of sleepiness. In fact, Curcio, Casagrande, and Bertini (2001) indicated that unlike other subjective measures of sleepiness, the Epworth Sleepiness Scale is more robust and not easily influenced by other factors.

These results do present a new variable to be considered in future research, sleep efficiency. Future researchers should investigate how this measure of sleep quality compares with the currently used total sleep time or sleep duration measure in driving performance, reaction time studies, and other task domains. The results reported here indicate that the quality of the time actually spent sleeping is more important to alertness and performance than the duration of that sleep, at least within a normal range of sleep duration (not less than 4 hours).

Hypothesis 2

The second hypothesis tested the assumption that participants with state sleepiness would have a greater decline across the 60-minute drive as compared to participants with trait sleepiness. Both sleepiness groups were predicted to have increased lane position variability compared to the normal group.

Results did not support the first part of this hypothesis. Participants scoring high in trait sleepiness demonstrated significantly worse lane position variability than participants high in state sleepiness and non-sleepy participants. There have been conflicting results in the literature about subjective sleepiness, as discussed in the introduction to this dissertation. These results support the literature that indicates drivers with high trait sleepiness have poorer driving performance. These results also support the notion that drivers may not be good judges of their state sleepiness at the time of driving and that scores on state sleepiness scales should be used with caution both in future research and in the commercial driving industry.

A significant time effect demonstrated that lane position variability increased over the course of the drive for all groups. This indicates a strong time-on-task influence for

all drivers and has been seen in other studies (Liu, Hosking, & Lenne, 2009; Risser, Ware, & Freeman, 2000). However, results showed no time by group interaction. This finding indicates that high scores on the Epworth Sleepiness Scale are associated with poorer driving performance, but this trait sleepiness did not impact the rate of degradation over time any differently than the other groups.

Hypothesis 3

The final hypothesis stated that the sleep apnea group would perform worse compared to healthy, normal controls. Additionally, performance of sleep apnea patients was predicted to degrade more significantly over the course of the drive.

Results did not support the first part of this hypothesis. There were no significant differences in lane position variability between the two groups. This was counter-intuitive to results in the literature and could be due to the low AHI cut-off for the apnea group. However, other researchers have used this cut off with significant results (George, Boudreau & Smiley, 1996; Young, Blustein, Finn & Paulta, 1997). The AHI group criterion was chosen for two reasons: 1) an AHI of 15 qualifies a patient for treatment and 2) to allow for a continuous measure of AHI for the regression analysis.

The results did support the second part of this hypothesis. The apnea group demonstrated a greater increase in lane position variability as the drive progressed. There was a main effect of time, indicating that performance significantly changed over time and this was a linear trend for both groups. The significant group by time interaction demonstrated that the increase in lane position variability over time was more pronounced for the sleep apnea group, as indicated by the significant group by time interaction. Post-hoc analyses between each groups at each time point did not reveal

specific significant group differences. These results were conservative given that a Bonferoni correction was used to account for conducting multiple tests.

The significant interaction indicates that untreated apnea drivers are more susceptible to time-on-task factors while driving and as such should be cautioned against driving long periods until treated. This also adds support to the screening of commercial drivers for sleep disorders, especially long-haul truck drivers and the need to better track and legislate hours of work laws for the commercial driving industry.

Limitations of Study

Several limitations of this study are recognized. One is the extent to which simulated driving performance can be generalized to on-road driving. The second limitation relates to selection and sample issues. A third limitation involves the collection of sleep measures the night before driving and lack of objective sleepiness measures during the drive.

Driving Simulation

Carsten and Jamson (2011) reviewed the use of driving simulators in research settings. They state that the use of driving simulators is common. They emphasize how driving simulators offer a safe and controlled environment compared to on-road driving. A variety of impaired-driving situations can be tested in a simulator without jeopardizing safety in a real driving environment. In addition, the driving scenarios can be manipulated to produce standard conditions or limit external influences. The scenario used in this study is typical for driver fatigue research as this long, monotonous highway scenario can unmask sleepiness so that the results of this sleepiness on performance measures can be seen more quickly than in real-world driving.

However, a criticism of driving simulation is the lack of realism, in that the consequences of poor performance do not end in death or injury (Reimer et al., 2006). As such, drivers may be motivated to perform better in real-world driving because of these real consequences. One study supports this idea, demonstrating more line crossings in a driving simulator task compared with an on-road driving task (Davenne et al., 2012). In addition, there is a risk for simulator sickness, motion sickness or manifestation of Sopite's syndrome. Sopite's syndrome is a form of motion sickness caused by vestibular or visual motion. This syndrome is related to increased drowsiness and as such could confound the study with those patients experiencing simulator sickness (Kennedy, Drexler, & Kennedy, 2010; Lawson & Mead, 1998). We limited this possibility by eliminating participants complaining of dizziness or nausea during the practice drives.

A second criticism of the use of driving simulation is how valid the test is at predicting or mirroring results in on-road scenarios. Several recent studies lend validity to driving simulator research for sleepiness, showing similar trends in lane position variability and line crossings between sleepiness groups and over time. Considering this support, the use of a simulator in the current study is a reasonable limitation and a safe, controlled environment for testing a high-risk population for sleep-related crashes such as drivers with untreated sleep apnea. Three studies supporting the validity of driving performance in the simulator to on-road performance will now be briefly reviewed.

Philip et al. (2003) studied drivers' reaction times in simulated driving and on-road driving conditions. With similar sleeping conditions the night prior, results showed no significant differences in reaction time between driving conditions. Reaction time increased for both driving conditions in the sleep restriction condition. Subjective

sleepiness correlated with reaction time only in the simulated driving condition. In the on-road driving condition, there was an experimenter in the car with the participant who had a second set of controls, ready to take over the driving if needed.

Sandberg et al (2011) utilized an instrumented car that used a video monitor to record edge of lane, lane position and speed. The purpose was to evaluate the driving performance measures typically used in simulated driving scenarios to characterize sleepiness in a real-world environment. Eye movements, brainwaves and subjective sleepiness were measured throughout the drives. Daytime and nighttime drives were compared. Results showed that there was greater lane position variability, speed variability, subjective sleepiness and blink duration in the night time drives compared to the daytime drives. There was also an increase in lane position variability over the drive during the nighttime drive. There was an experimenter in the car during this study as well with additional controls to take over driving if needed.

Davenne et al. (2012) examined the effects of sleepiness and prolonged driving on performance in both simulated and on-road conditions in a group of healthy adults. For both conditions, there were more inappropriate line crossings in the night time drives compared with the daytime drives. Drivers had similar ratings of subjective sleepiness and fatigue in the simulator and the on-road driving situations. As mentioned above, they did record significantly more line crossings in the simulated drive compared with on-road driving. The researchers concluded that sleepiness and driving duration impacted driving performance similarly in both conditions despite the higher number of line crossings in the simulator.

Selection and Sample Issues

The second limitation of this study is the selection of participants and demographic differences between groups. Although attempts were made to recruit patients from the Sleep Disorders Center, the majority of participants were recruited in the community and also at Old Dominion University. There were very few sleep apnea patients who volunteered to participate in the study. The majority of the sleep apnea group consisted of volunteers who did not have a diagnosis of sleep apnea but whose results of the R-U-Sleeping device indicated they had apnea. These volunteers might differ from actual sleep apnea patients, and as such there should be caution in generalizing these results to sleep disorder patients. In addition, although the R-U sleeping device is a valid and reliable screening tool for sleep apnea, plotting an average AHI over several nights in future studies would eliminate any concern of proper appliance of the device and external factors biasing results such as having a cold.

In comparing the sleep apnea group and control group, the apnea group was significantly older with a mean age of 50. The control group had a mean age of 30. Older participants were more likely to have sleep apnea. It is recognized that younger participants may have an advantage in performance during driving simulation due to experience with video games and that older participants may have a larger learning curve due to their lack of computer or video game experience. Given the results that at the beginning of the task the apnea and normal group means of lane position variability were very close with little variability, there is little worry that this was a factor in this study. Participants were given two practice drives to also help eliminate practice effects.

Sleep and Sleepiness Measures

The focus of this study was to use the previous night's data of sleep performance as a predictor in the model of sleepiness. The Actiwatch is a reliable and valid measure that operated reliably during this experiment. However, a limitation of this study is the assumption that one night of sleep data is representative of the participant's sleep habit. It does not take into account any participants who consistently sleep short in duration and accumulate a sleep debt and how that sleep debt influenced their performance. This study can generalize only to sleep the night before driving and not to a general behavior of sleep duration or quality.

A second methodological limitation is the lack of physiological data collected during the driving task. Eye closures and EEG are two well-supported measures used to objectively document sleepiness during driving tasks. Increased eye closures and alpha activity typically increase over the drive and with increased lane position variability. This omission was intentional, as the researchers wanted quick and direct measures of sleep and sleepiness. These tools could be used in large scale and perhaps as a screening package for sleepiness and sleep quality/quantity in commercial settings in a workplace setting to identify drivers at risk for sleepiness. The assumption is made in this study based on previous research with similar participant groups and similar driving scenarios that increases in driving performance across the drive were due to present sleepiness during the drive. Post-drive subjective sleepiness ratings were significantly higher for those with higher lane position variability.

Future Directions

Further researchers should continue to investigate sleepiness measures to predict driving performance. In particular, they should include a larger number of more severe sleep apnea participants to see if apnea severity could account for a significant amount of variance in driving performance. Replicating this model with different clinical sleep disorder populations could help create a tool that could be used to caution or limit patients' driving until adequately treated. Additional research investigating the impact of sleep efficiency will also help strengthen the understanding of this measure as a predictor of driving performance. Future studies comparing sleep duration and sleep efficiency would add a significant contribution to the literature investigating how much sleep one actually needs at night. Perhaps the more important consideration is the quality of that sleep during that sleep time.

A recurring theme in this research showed how trait sleepiness impacted driving performance. This was a strong predictor in the sleepiness model. Participants with high trait sleepiness performed significantly worse compared with participants high in state sleepiness and non-sleepy participants. This scale seems to be a strong, robust measure of sleepiness that would be quick and easy to use in commercial settings as a screening tool for drivers. A high score on this scale could trigger a referral of that driver to a sleep specialist to determine the cause of the sleepiness. This would be beneficial for long-haul truckers but also for emergency transport, night-time drivers and night-shift workers who drive home in the morning.

Future research should continue to take into consideration the differences between trait and state sleepiness to determine if trait sleepiness should be the main measure of

subjective sleepiness in this type of research. Additionally, researchers should work to create a clear definition of subjective sleepiness and perhaps stronger descriptive wording in the scales and anchors of those scales to ensure standardization of how participants interpret sleepiness in their responses.

Finally, there should be continued effort to translate simulation results to real world results. Most research in this area has been conducted in Europe where there seem to be fewer restrictions on this type of endeavor. Limitations in those studies include having an experimenter in the car with the participant to take over if necessary. Having an observer in the car could impact the results. Equipping cars of normal, healthy drivers with current monitoring technology and comparing those results to paired results in a driving simulator would be very beneficial to this debate.

Researchers at the Virginia Tech Transportation Institute have conducted naturalistic, longitudinal studies with instrumented cars recording variables similar to those in simulation studies (Klauer et al., 2006; Klauer, Perez, & McClafferty, 2011). These researchers were able to monitor normal, healthy drivers without an in-car experimenter. Previously reviewed studies involving on-road tests included an in-car experimenter and this interaction could influence driver behavior and motivation. Unfortunately, this non-biased, driver-only data collection method has not been compared with driving simulation data. Ideally, researchers could compare line crossings or lane position variability looking at similar roadway designs and traffic density in different situations and replicate these in the simulator to compare. A good starting place would be comparing daytime and nighttime driving performances.

Conclusions

Results of this research indicate that sleep quality and trait subjective sleepiness add to models of sleepiness and driving performance. The model developed shows that years with driver's license, sleep efficiency and trait sleepiness are significant predictors of lane position variability. Additionally, results show that driving performance is worse for participants high in trait sleepiness. Participants with high state sleepiness performed comparably to non-sleepy participants. Sleep apnea participants did not perform significantly worse than controls as hypothesized but there was a significant group by time interaction indicating that sleep apnea participants' performance degraded more quickly over the course of the drive.

The results of this study are instructive and show potential tendencies, but the analyses performed cannot allow for cause and effect assumptions. Readers are cautioned from making these assumptions and interpret these results as relationships and not that sleepiness or sleep constructs do or do not cause performance decrements. This study does show significant relationships between sleep and driving performance, and as such attention should be given to sleepiness when determining fitness to drive, especially in the commercial driving industry.

These results can be generalized to the community members and students, but not necessarily to sleep disorder center patients. Further research needs to replicate these results with those patients to determine translation to those patients. Future research also should continue to investigate the differences between state and trait sleepiness and how they impact performance. Replication of the impact sleep efficiency has on driving

performance would add support for use of this measure over sleep duration in predicting driving performance. Finally, researchers should continue the pursuit of translating simulator performance to on-road driving.

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APPENDIX A

CONSENT FORM

Subject Consent Form

Eastern Virginia Medical School (EVMS) Institutional Review Board

STUDY TITLE

The Impact of Sleepiness and Sleep Constructs on Driving Performance

INVESTIGATORS

Jennifer F. May, MS
Department of Psychology, Old Dominion University
Sleep Disorders Center, Sentara Norfolk General Hospital and Eastern Virginia Medical School

Bryan E. Porter, PhD
Department of Psychology, Old Dominion University

J. Catesby Ware, PhD
Sleep Disorders Center, Sentara Norfolk General Hospital and Eastern Virginia Medical School

SPONSOR

None

WHY IS THIS STUDY BEING DONE?

The purpose of this study is to determine which aspects of sleepiness influence driving performance.

WHY ARE YOU BEING ASKED TO TAKE PART?

You are being asked to participate in this research project because you are either a healthy adult, suspect you may have sleep apnea or are a patient at the Sleep Disorders Center diagnosed, but not yet treated, for sleep apnea. Sleep apnea is a disorder that can affect alertness and can increase the risk of driving crashes. A control group of healthy adults with no history of sleep disorders is needed to compare the performance of the two groups. This is a research study. This study includes only people who choose to take

part. Please take your time to make your decision and feel free to ask any questions you might have.

WHAT ARE SOME IMPORTANT DETAILS ABOUT THIS STUDY?

A total of about 44 people are expected to take part in this study at one site throughout the United States. We will need you to be in the study for two days.

WHEN SHOULD YOU NOT TAKE PART?

If you have any of the following conditions or are taking any of the medications listed below, you should not take part in this study:

Sleep Apnea Participants:
- Significant medical disorder (i.e. Congestive heart failure, diabetes)
- Prescribed medication with sedative effects (such as antidepressants, sleeping pills)
- Consume more than 5 caffeinated drinks per day
- Consume more than 1/2 a pack of cigarettes per day
- Work night shift or rotating shift work
- Not comfortable with interstate driving

Control Participants:
- Diagnosis of a sleep disorder, such as insomnia, narcolepsy or sleep apnea
- Significant medical disorder (i.e. Congestive heart failure, diabetes)
- Prescribed medication with sedative effects (such as antidepressants, sleeping pills)
- Consume more than 5 caffeinated drinks per day
- Consume more than 1/2 a pack of cigarettes per day
- Work night shift or rotating shift work
- Not comfortable with interstate driving

WHAT IS INVOLVED IN THE STUDY?

Day 1

After consent, you will fill out a questionnaire asking for demographics information, sleep history and driving history information. You will need to provide your age, sex, height, weight and race. The driving history section will ask questions about your driving history and about any crashes you have had. You will complete the Epworth Sleepiness Scale. You will be screened for any of the above exclusionary criteria. You will need to provide your driver's license as proof of age and that you are legally able to drive. You will then complete a 10-minute practice drive in the driving simulator. Few people experience "simulator sickness" during the simulator test which is like sea-sickness or motion sickness. If you feel nauseous during the drive, you will be allowed to

withdraw your participation. Following the practice drive, you will receive instruction on how to use the RU-Sleeping monitor and Actiwatch device. The RU-Sleeping is a nasal cannula (like how oxygen is delivered, but this only monitors breathing) attached to a pager like device to record your breathing. The Actiwatch device is a watch worn on your wrist to monitor your movements during sleep. These will be given to you to take home and wear that night.

Day 2

On Day 2 of your study you will complete a simulator driving test. Results of the sleep tests (RU-Sleeping and Actiwatch) will first be reviewed. If the sleep results show that you stop breathing 15 times per hour or more during the night, you will be asked if you would continue as part of the apnea group. For the driving simulator, you will again complete the 10-minute practice drive. After the practice drive, you will complete a brief scale indicating your sleepiness. The hour-long simulator drive will follow. Studies will also not be conducted between 1 and 3pm to exclude the time of day when most people are more susceptible to sleepiness.

Procedures

Day 1	Day 2
Consent (15 minutes)	Review of Sleep Data (10 minutes)
Questionnaires, Scales and Screening (15 minutes)	Driving Simulator Test Pre/Post Sleepiness Scale (70 minutes)
Driving Simulator Practice (15 minutes)	Rest Break if Needed
Sleep Instructions (15 Minutes)	Complete Raffle Entry
Apply the Sleep Sensors before Bed (5 minutes)	
Complete Raffle Entry	

The following are standard procedures that will be done because you will be in this study:

Driving simulator

The Systems Technology, Inc. STISIM driving simulator is a moderate-fidelity simulator used at Eastern Virginia Medical School's Sleep Disorder Center to test clinical patients. A 10-minute practice and acclimation drive in a city-based scenario allows participants to become accustomed to the feel of the simulator. The clinical test drive is a 60-minute monotonous highway scenario, with few passing cars, and slight curvature throughout the drive.

Actiwatch

The Actiwatch is a special wrist-worn watch that records wrist movement as a measure of physical activity. Actigraphy measures activity level by recording the number of wrist movements over time. Lack of movement indicates rest or sleep.

Respironics RU-Sleeping

The RU-Sleeping device is a small 1-channel airflow apnea detection monitor. The actual device is the size of a pager with a connection for a disposal nasal cannula. The monitor records airflow throughout the night and a computer chip within the device counts the number of times breathing is reduced by at least 50% for 10 seconds or more in duration.

Epworth Sleepiness Scale

The Epworth Sleepiness Scale (ESS) is a measure of general daytime sleepiness. Participants are asked to rate how likely they are to fall asleep or doze in eight different situations.

Visual Analog Scale of Sleepiness

The Visual Analog Scale of sleepiness (VAS) is an immediate rating of current sleepiness. Participants are asked to draw a vertical line through a 100mm horizontal line with anchors of "not at all sleepy" to "extremely sleepy."

WHAT ARE THE RISKS OF THE STUDY?

There are very few known risks to you. You may experience nauseousness or dizziness during the driving simulator. A small percentage of drivers experience this "simulator sickness." There also may be other risks that are unknown and we cannot predict.

For more information about risks and side effects, ask the investigator, Jennifer May. You may contact her at 757-635-1122.

ARE THERE BENEFITS TO TAKING PART IN THE STUDY?

If you agree to take part in this study, there may or may not be direct benefit to you. There is no guarantee that you will personally benefit from taking part in this study. We hope the information learned from this study will benefit other people with sleep disorders in the future.

WHAT OTHER OPTIONS DO YOU HAVE?

Instead of being in this study, you have these options:

- Psychology students at Old Dominion University can receive alternative credit for critiquing journal articles instead of participating in research studies.
- You may choose not to participate in this research study.

Sleep apnea patients will still receive the same clinical treatment if you do not take part in the study.

WHAT ABOUT CONFIDENTIALITY?

There will be no protected health information collected for this study. You will not be personally identified in any way. Your study records may be reviewed and/or copied in order to meet state and/or federal regulations. Reviewers may include, for example, an Eastern Virginia Medical School Institutional Review Board and Old Dominion University Institutional Review Board.

Information learned from this research may be used in reports, presentations and publications. None of these will personally identify you.

WHAT WILL PARTICIPATION IN THE STUDY COST OR PAY?

There are no additional costs to you associated with taking part in this study.

You will receive no payment for taking part in this study to help cover your expenses and inconvenience. However, you will be entered into a drawing to win one of two $200 Visa cards for each day of study completed (for a maximum of 2 drawing entries per participants).

WHAT IF YOU GET INJURED?

In the case of injury or illness resulting from this study, emergency medical treatment is available and will be provided by Sentara Norfolk General Hospital and paid for by you.

Eastern Virginia Medical School, Old Dominion University and Sentara Norfolk General Hospital will not provide free medical care for any sickness or injury resulting from being in this study. Financial compensation for a research related injury or illness, lost wages, disability, or discomfort is not available. However, you do not waive any legal rights by signing this consent form.

WHAT ARE YOUR RIGHTS AS A PARTICIPANT?

Taking part in this study is your choice. If you decide not to take part, your choice will not affect any medical benefits to which you are entitled. You may choose to leave the study at any time. If you do leave the study, discuss it with the investigator who will help you do so in the safest way. If you leave the study it will not result in any penalty or loss of benefits to you.

The investigator may decide to take you off this study if you cancel your approval or experience simulator sickness.

We will tell you about new information that may affect your health, welfare, or willingness to stay in this study.

WHOM DO YOU CALL IF YOU HAVE QUESTIONS OR PROBLEMS?

For questions about the study, contact the investigator, Jennifer May, MS at 757-635-1122 or Bryan Porter, PhD at 757-683-4458.

For questions about your rights as a research participant, contact a member of the Institutional Review Board through the Institutional Review Board office at (757) 446-8423.

If you believe you have suffered an injury as a result of your participation in this study, you should contact the principal investigator, Jennifer May at 757-635-1122. You may also contact Dr. Robert Williams, an employee of Eastern Virginia Medical School, at (757) 446-8423.

SIGNATURE			
You will get a copy of this signed form. You may also request information from the investigator. By signing your name on the line below, you agree to take part in this study and accept the risks.			
_____ Signature of Participant/LAR	_____ Typed or Printed Name	_____ Relationship to Subject	__/__/__ MM/ DD/ YY

STATEMENT OF THE INVESTIGATOR OR APPROVED DESIGNEE	
I certify that I have explained to the above individual the nature and purpose of the study, potential benefits, and possible risks associated with participation in this study. I have answered any questions that have been raised and have witnessed the above signature. I have explained the above to the volunteer on the date stated on this consent form.	
_____ Signature of Investigator or Approved Designee	____/____/____ MM/ DD/ YY

APPENDIX B

DEMOGRAPHICS QUESTIONNIARE

Participant # _____

Age: ____

Gender: A. Male B. Female

How would you describe your race?

A. White B. Black C. Alaskan Native/Native American

D. Hispanic E. Asian F. Mult-racial G. Other

Years driving with driver's license: _____

How often do you drive a motor vehicle on a *weekly* basis?

A. every day B. 3-5 times a week C. once or twice a week

D. rarely drive E. I do not drive

Approximately how many miles *per week* do you drive?

A. 0 miles B. 1 - 24 miles C. 25 – 49 miles

D. 50 – 99 miles E. 100 - 199 miles F. 200 – 299 miles

G. 300 miles or more

Estimate miles driven per year: _____

Do you have a valid, current driver's license?

A. Yes B. No

What type of vehicle do you drive most often?

A. passenger car B. mini-van C. SUV

D. pickup truck E. motorcycle F. other

Are you the primary owner of your vehicle? That is, are you responsible for its payments, insurance, title?

A. Yes B. No

Have you ever received a ticket for a driving violation?

A. Yes B. No

Have you ever been involved in a traffic crash?

A. Yes B. No

Have you ever had an accident or near-accident due to sleepiness?

A. Never B. within the last 6 months C. within the last year

D. Within last 5 years

What time do you usually go to bed during the week? _____ Weekend? _____

What time do you usually wake up during the week? _____ Weekend? _____

Do you usually take daytime naps? _____ How often? _____

How many caffeinated beverages do you drink per day? _____

Do you smoke? _____ If yes, how many packs per day? _____

Have you ever been diagnosed or treated for a sleep disorder? Yes No

If yes, please explain

_____

_____

_____

Are you currently taking any medications with sedative effects? Yes No

If yes, Please list:

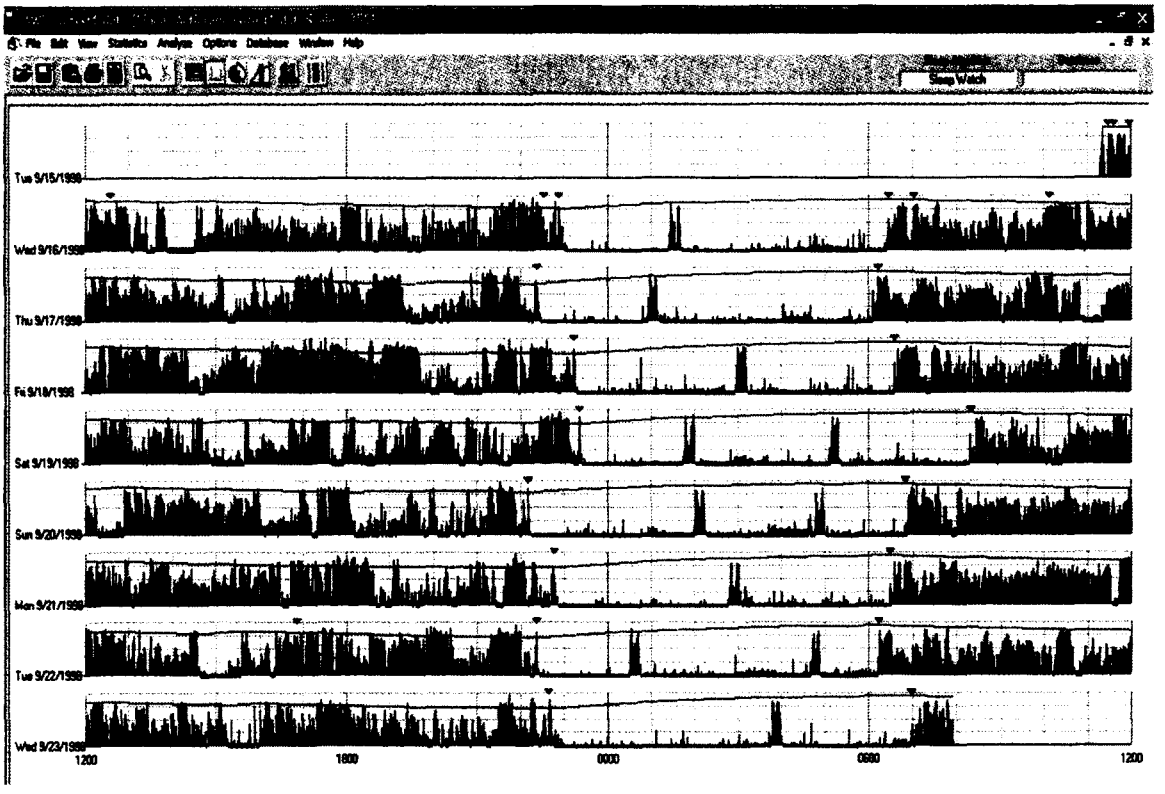
_____

_____

_____

APPENDIX C

SAMPLE ACTIWATCH RESULTS



Sleep

APPENDIX D

SLEEPINESS SCALES

Visual Analog Scale

Please place a vertical line through the horizontal line below at the place which best indicates how sleepy or alert you feel *right now*.

Not At All Sleepy _____ Extremely Sleepy

Epworth Sleepiness Scale

In contrast to just feeling tired, how *likely* are you to doze off or fall asleep in the following situations? (Even if you have not done some of these things recently, try to work out how they would have affected you.) Use the following scale to choose the most appropriate number for each situation:

0 = Would never doze
1 = Slight chance of dozing
2 = Moderate chance of dozing
3 = High chance of dozing

Situation	Chance of Dozing
Sitting and Reading	_____
Watching TV	_____
Sitting inactive in a public place (i.e. theater)	_____
As a car passenger for an hour without a break	_____
Lying down to rest in the afternoon	_____
Sitting and talking to someone	_____
Sitting quietly after lunch without alcohol	_____
In a car, while stopping for a few minutes in traffic	_____

VAS measurement _____ *ESS total* _____

VITA

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EDUCATION

2004 to 2012	**PhD,** Applied Experimental Psychology, June 2012. Old Dominion University, Norfolk, Virginia
2000 to 2002	**M.S.,** Psychology. August 2002. Old Dominion University, Norfolk, Virginia.
1996 to 2000	**B.S.,** Psychology. May 2000. Old Dominion University, Norfolk, Virginia.

EMPLOYMENT

10/09 to present	**Manager, Clinical Neurophysiology**. *Sleep Centers at Sentara Norfolk General Hospital, Sentara Independence and Sentara Princess Anne.*

RESEARCH GRANTS

1/02	**Virginia Department of Motor Vehicles** (Principal Investigator) *Highway Safety Mini-Grant* Grant # CP02-05-58105-1. "Relationship between behavioral measures in a driving simulator and EEG activity on day-shift and night-shift workers" ($1200)
8/05 – 1/07	**Graduate Student Research Program** (GSRP) funding through NASA Langley. Development of User's Manual, Testing Procedures and Validation for the NIRS ISS Oximeter ($24,000).

PUBLICATIONS

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