Accident Analysis and Prevention 89 (2016) 95–102

Contents lists available at ScienceDirect

Accident Analysis and Prevention

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

The deterioration of driving performance over time in drivers with untreated sleep apnea

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ARTICLE INFO

Article history:
Received 5 March 2015
Received in revised form
29 December 2015
Accepted 8 January 2016

Keywords:
Sleep apnea
Driver fatigue
Sleepiness
Driving performance

ABSTRACT

Sleep apnea increases risk of driving crashes when left untreated. This study examined the driving performance decrements of untreated, undiagnosed sleep apnea drivers compared with healthy controls in a monotonous highway driving simulator task. It was hypothesized that the sleep apnea group would perform worse during a driving simulator test compared with the control group. A significant group by time interaction occurred indicating that sleep apnea participants' performance degraded more quickly over the course of the drive. In contrast with previous studies, this sleep apnea group did not include sleep disorder center patients, but rather community volunteers whose screening indicated a significant apnea/hypopnea index of 15 or greater. There may be inherent differences between patients and nonpatients with sleep apnea, as patients may have a more significant impact on their quality of life, causing them to seek treatment. Still, the results are clear that although the sleep apnea group drove similarly to the control group at the start of the drive, they are sensitive to time on task effects. These results support the need to diagnose and treat sleep apnea.

1. Introduction

Drivers with untreated sleep apnea are at high risk for sleep-related crashes. Sleep apnea is a common sleep disorder in which a person stops breathing repetitively during sleep. In evaluating how sleep apnea affects drivers, it is important to obtain an objective measure of driving performance on which to base recommendations for patients' fitness to drive. A safe choice for evaluation is the use of a driving simulator. The goal of this study was to evaluate driving performance of community volunteers with sleep apnea compared to a control group using a driving simulator test.

Apnea is defined by the American Academy of Sleep Medicine (AASM) as a period of at least 10 seconds where a person stops breathing (Berry et al., 2012). This can be a period of non-breathing where the person is still exerting effort to breathe (obstructive sleep apnea) or when effort to breathe has also ceased (central sleep apnea). Hypopnea events are defined as a 30% reduction in airflow instead of a complete cessation of breath, with a corresponding 3% oxygen desaturation or arousal (Berry et al., 2012). 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 slept during the test. An AHI between 5 and 15 is considered mild, 15–30 considered moderate and greater than 30 considered severe (Kushida et al., 2006; Epstein et al., 2009). Sleep apnea can occur across all age groups and races (Vorona and Ware, 2002). Sixty to 70% of obstructive sleep apnea (OSA) patients are obese (Guilleminault, 1994). OSA is associated with an increased risk of hypertension, coronary heart disease, stroke and death (Vorona and 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). One study illustrated the vigilance and attention impairments in OSA patients on a sustained attention, divided attention and maintenance of wakefulness tests (Mazza et al., 2005). Many of these symptoms can impact driving performance in drivers with untreated sleep apnea.

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http://dx.doi.org/10.1016/j.aap.2016.01.002
0001-4575/

One benefit 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 (Risser et al., 2000; Vakulin et al., 2009). Other studies have shown that treatment for sleep disorders improves driving performance in these patients and that when withdrawn from treatment, performance declines (Filtness et al., 2011, 2012; Hack et al., 2001; Mazza et al., 2006; Orth et al., 2005; Turkington et al., 2004). For many of these studies, untreated sleep apnea patients, or sleep deprived participants demonstrated a more pronounced performance decrement over time (Filtness et al., 2011, 2012; Risser et al., 2000; Vakulin et al., 2009). A few of these studies are highlighted below.

Risser et al. (2000) compared driving simulator performance of sleep center 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-min drive in the sleep apnea group, suggesting a vigilance decrement over the drive. The sleep apnea patients overall had greater lane position variability and crash frequency compared to controls.

In comparing sleep restriction and alcohol consumption in untreated sleep apnea patients and controls, Vakulin et al. (2009) also demonstrated group differences and a time on task effect. Each group was exposed to 3 different conditions, a normal night's sleep, a night of 4 h sleep (or less) and consumption of vodka to equate to a blood alcohol level of .05. During the normal night's sleep, sleep apnea patients had greater steering deviations and more deviations over time. This result was exacerbated both by the sleep restriction and the alcohol consumption. The sleep apnea patients also had more crashes than controls in all three conditions.

One treatment for sleep apnea, continuous positive airway pressure (CPAP), improves driving simulator performance. Turkington et al. (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-min drive using their divided attention driving simulator. This driving simulator also integrated a reaction time task where patients pressed a button every time a "2" appeared on the screen. A baseline driving simulator test was performed before treatment for both groups of patients. Driving simulator tests were performed three additional times throughout the seven 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.

Mazza et al. (2006) found sleep apnea patients prior to CPAP treatment had longer reaction time, and twice the number of collisions as compared to controls in an on-road safety platform. This was an instrumented test track which monitored the car's speed and sent up a spout of water the driver had to stop for. Collisions were counted when the car hit the spout of water. CPAP treatment eliminated performance differences between the sleep apnea patients and controls.

Filtness et al. (2011) compared treated sleep apnea patients (using CPAP) and control participants after a night of normal sleep and a night of sleep restriction. Treated patients after sleep restriction had significantly greater lane crossings and shorter time to first major incident (crossing out of lane with all 4 wheels). There was also a significant time effect where the longer the drive, the more line crossings for this sleep deprived treated apnea patient group. These results indicate that although CPAP is effective, these patients are more sensitive to the effects of sleep restriction as compared to their healthy counterparts.

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 et al., 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.

These studies stress the driving performance decrements in driving simulation tasks for sleep apnea patients, highlighting the time on task effects of performance decrements. In addition, these studies stress the ability of driving performance measures to capture the effects of sleep apnea, the improvement with treatment and the susceptibility of these patients for performance decrements during sleep restriction while on treatment.

The purpose of this study was to confirm performance decrements in participants with sleep apnea as compared to controls. The unique difference in this study versus previous studies was that these apnea participants were not patients in a sleep disorders center; they had not sought help or treatment for sleepiness or potential sleep disorders. These participants were not clinically diagnosed, but identified as having apnea via the home sleep test results obtained during the study. There may be fundamental differences between apneics who have sought out treatment and those who have not. However, it is believed that having sleep apnea, having sought treatment or not, impacts performance. It was hypothesized that the performance decrements in sleep apnea patients would be robust and present even with undiagnosed community participants screening positive for sleep apnea. Based on the previous literature, we predicted that the sleep apnea group, at risk for sleepiness and crashes, 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.

2. Method

2.1. Design

This study utilized a quasi-experimental 2 (group) by 6 (time epoch) ANOVA design. We controlled for length of drive, excluded untreated sleep disorders for control participants and documented caffeine and nicotine use. Tests for outliers, normality and linearity were performed prior to hypothesis testing. The dependent variable was standard deviation of lane position variability (transformed to reduce the effect of outliers). The independent variable was condition (sleep apnea versus no sleep apnea).

2.2. Participants

There were 57 participants (25 males, 32 females) who completed the study. Of these, 45 met the criteria for one of the two groups, having an AHI $\geq$ 15 (APNEA group) or <10 (normal, NORM group). Participants having an AHI between 10 and 15 were excluded from analysis. Demographics reported are from the 45 participants included in the analysis.

Of the participants, 31 participants self-identified as Caucasian, 10 as African American, 2 as Hispanic, 1 as Asian and 1 as multiracial. Ages ranged from 18 to 74 (M = 40.4, SD = 17.11). Participants

had driver's licenses for an average of 24.04 years (*SD* = 16.96) and drove an average of 10,220.80 miles per year (*SD* = 7267.65). 76% of participants owned their vehicles and 62% drove passenger cars (18% SUVs, 15% passenger trucks). The majority of participants had received at least 1 moving violation (80%) and had an average of 1.74 crashes (*SD* = 1.60). A total of 14 participants (31.1%) reported having a crash or near crash due to sleepiness within the last 5 years (4 reported within the past 6 months).

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, equating to 10–12 cigarettes per day). Any participant working rotating or permanent night shift was also excluded.

Participants were recruited from Old Dominion University's Psychology Research Pool and the local community. Participants were asked if they had ever been diagnosed or treated for any sleep disorder. Participants also completed the Epworth Sleepiness Scale.

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 min of participation on day 1 for consent and screening. Participants then took the sleep sensors home. Participants spent approximately 5–10 min applying the Actiwatch and RU Sleeping device at bedtime and detaching upon wakening. Driving tasks on day 2 required 1.5 h to complete.

Participants who demonstrated an apnea/hypopnea index of 15 or greater during their sleep night were asked to be part of the apnea group. Volunteers who exhibited sleep apnea during screening were advised to see their primary care physician for this condition to discuss obtaining a referral to a sleep specialist.

2.3. Measures

Demographics questionnaire

For the demographics and screening questionnaire, no personally identifying information was collected. 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 simulator

The Systems Technology, Inc. STISIM driving simulator is a moderate-fidelity simulator used at Sentara Norfolk General and 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.

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.

Respironics "RUSleeping"

The RUSleeping device is a small 1-channel airflow apnea detection monitor. This device is utilized as a screening tool for sleep apnea. 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 s or more in duration. This device uses a more conservative criterion of airflow reduction than recommended by the American Academy of Sleep Medicine (Berry et al., 2012) because it does not include measurements of respiratory effort. The apnea hypopnea index is displayed on the device at the end of testing (Herrle, 2007). The device also provides apnea/hypopnea counts per each hour of sleep and a rating of signal quality. A registered polysomnographic technologist reviewed the results in conjunction with the actigraphy results to ensure there was sleep during the night.

The RUSleeping has been validated against scored airflow during polysomnogram data in multiple studies of both lab and at-home environments (Gorny et al., 2000, 2001; Spiro et al., 2002). Other studies have validated the use of a single-channel device in identifying sleep apnea (Oktay et al., 2011; Gutierrez-Tobal et al., 2015). This device does not distinguish between obstructive and central sleep apnea, however we excluded participants with uncontrolled cardiovascular disease where centrals are more prevalent.

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.

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 and 10, while sleep apnea patients score between 4 and 23 (Johns, 1991). Scores on the ESS are sensitive to severity of sleep apnea, and correlate with sleep latency on polysomnogram and multiple sleep latency (Johns, 1991). Johns (1992) also demonstrated

Table 1
Descriptive statistics for lane position variability (LPV).

	n	*M* (SE)	SD	Skewness (SE)	Kurtosis (SE)
Raw data					
Total LPV	45	1.32 (.05)	.33	1.60 (.35)	4.37 (.70)
LPV1	45	1.14 (.03)	.20	0.40 (.35)	.19 (.70)
LPV2	45	1.19 (.04)	.24	0.57 (.35)	1.44 (.70)
LPV3	45	1.28 (.05)	.37	1.71 (.35)	5.03 (.70)
LPV4	45	1.30 (.04)	.30	1.28 (.35)	4.31 (.70)
LPV5	45	1.36 (.06)	.39	1.22 (.35)	2.33 (.70)
LPV6	45	1.46 (.08)	.55	2.64 (.35)	10.03 (.70)
Reciprocal data					
Reciprocal LPV	45	0.79 (.03)	.18	0.40 (.32)	0.71 (.70)
Reciprocal LPV1	45	0.90 (.02)	.18	0.64 (.35)	0.51 (.70)
Reciprocal LPV2	45	0.87 (.03)	.18	0.86 (.35)	0.95 (.70)
Reciprocal LPV3	45	0.84 (.03)	.21	0.27 (.35)	−0.08 (.70)
Reciprocal LPV4	45	0.81 (.03)	.18	0.53 (.35)	0.27 (.70)
Reciprocal LPV 5	45	0.79 (.03)	.21	0.75 (.35)	1.26 (.70)
Reciprocal LPV6	45	0.75 (.03)	.21	0.30 (.35)	1.05 (.70)

that the scale has a high internal consistency ($r = 0.88$) and only 1 factor in factor analysis when given to healthy medical students and patients with sleep apnea, pre/post treatment.

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 100 mm horizontal line with anchors of "not at all sleepy" to "extremely sleepy." Results range from 0 to 100. Scores on this scale significantly increase with sleep deprivation (Babkoff et al., 1991).

2.4. Procedure

Participants were recruited 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.

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 a 10-min practice drive. The 10-min practice drive in a city-based scenario allowed participants to become accustomed to the controls of the simulator. Only 6 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 ($n = 45$).

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 at home.

The next day, the RU-Sleeping monitor and Actiwatch were removed upon awakening and brought to the sleep disorder center. A registered polysomnographic technologist downloaded and viewed the results of these tests. Participants completed a 10-min 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.

The test drive was a 60-min 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 crash was defined by departing the lane by 3 feet or more. After the drive, the data were averaged into six 10-min epochs. Variables of interest included lane position variability, number of line crossings and number of crashes.

After the hour-long simulator drive was completed, participants again reported their sleepiness using the VAS. If participants scored more than 70 on the VAS, the research team recommended they rest at the sleep disorders center before driving home, and two participants opted to lie down and rest after the drive.

There were no night drives and the period of 1–3 pm 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.

3. Results

3.1. Descriptive statistics

Of the 45 participants included in the analysis, the average body mass index (BMI) was 30.60 ($SD = 10.07$). Average apnea/hypopnea index (AHI) was 16.29 ($SD = 16.04$), mean Epworth Sleepiness Scale (ESS) score was 8.2 ($SD = 4.51$) and mean Visual Analog Scale (VAS) pre-drive score was 29.96 ($SD = 23.07$). Participants slept for an average of 385.01 min the night before the driving test ($SD = 74.98$), with a mean sleep efficiency of 88.24% ($SD = 5.90$). The mean time awake before the test drive on day 2 was 4 h and 44 min ($SD = 3$ h and 21 min).

The average lane position variability over the entire drive was 1.32 feet ($SD = .33$). Participants averaged 5.04 line crossings ($SD = 8.93$) during the drive. There was low frequency of crashes during the drive. 89% of participants did not crash during the drive. 2 drivers (4.4%) had one crash and 3 drivers had 2 crashes (6.7%).

LPV was the main dependent variable of all the statistical analyses. LPV ranged from 0.81 feet to 2.48 feet ($M = 1.32$, $SD = .33$). Tests of normality on LPV indicated a leptokurtic distribution

Table 2
Descriptive statistics by APNEA group.

	APNEA ($n = 22$)		NORM ($n = 23$)		t (df)	p
	M	SD	M	SD		
Age	50.77	14.8	30.50	12.88	−4.91 (43)	<.01
Years with License	34.50	14.57	14.03	12.58	05.05 (43)	<.01
ESS	10.32	5.20	6.18	2.40	03.44 (43)	<.01
VASpre	30.64	24.90	29.30	21.8	−0.19 (43)	.85
AHI	28.90	14.40	4.28	2.70	−8.08 (43)	<.01
BMI	34.13	12.19	27.22	6.07	−2.42 (43)	.02
SE	92.44	11.79	89.95	4.46	2.15 (40)	.04
TST (h)	6.13	1.13	6.69	1.32	1.53 (43)	.134
Total LPV	1.43	0.39	1.22	0.21	2.29 (43)	.03
LPVreciprocol	0.74	0.18	0.85	0.16	2.11 (43)	.04
Reciprocal LPV1	0.89	0.15	0.92	0.18	0.53 (43)	.57
Reciprocal LPV2	0.82	0.17	0.91	0.18	1.66 (43)	.11
Reciprocal LPV3	0.76	0.20	0.91	0.19	2.45 (430	.02
Reciprocal LPV4	0.75	0.16	0.86	0.18	2.14 (43)	.04
Reciprocal LPV5	0.73	0.21	0.84	0.21	1.73 (43)	.09
Reciprocal LPV 6	0.68	0.20	0.82	0.20	2.28 (43)	.03

Notes: p-value for t-tests are not adjusted for alpha inflation. Caution should be used when interpreting these comparative data which are provided only to give readers exploratory group differences.

with a value of 4.37 ($SE = .70$) that was also slightly positively skewed, 1.60 ($SE = .35$). Additional exploratory analyses identified three outliers in LPV. 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-min time points of LPV also allowed for normal distribution in each epoch (see Table 1 for the raw and transformed statistics for LPV and LPV epochs).

3.2. Hypothesis: split plot ANOVA for time and apnea group predicting reciprocal LPV

It was hypothesized that the sleep apnea group (APNEA), at risk for sleepiness and crashes, would perform worse compared to healthy, normal controls (NORM). Additionally, performance of sleep apnea patients was expected to degrade more significantly over the course of the drives (over time epochs).

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-min epochs (LPVrec1 – LPVrec6). See Table 2 for descriptive statistics for each group.

A 6 (epochs) × 2 (groups) split plot ANOVA was performed. There were 23 participants in the NORM group and 22 participants in the APNEA group. This analysis was first performed including age, total sleep time and time of day as covariates, to consider potential confounds of the study. As these three covariates had no significant effect on the dependent variable, nor had any interactions, the model presented here is the most parsimonious model with no covariates included. The Greenhouse–Geisser (G-G) correction was used to adjust degrees of freedom for sphericity violations. There was a significant time by group interaction, $F(3.73, 160.34) = 2.74$, $p = .03$. There was a significant effect of time, $F(4.22, 160.34) = 18.72$, $p < .001$. The group effect was not significant, $F(1, 43) = 4.03$, $p = .051$. See Table 3 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. As per the significant interaction, 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, requiring $p < .01$ for statistical significance. Results did not reveal any significant differences between the particular epochs. However, further analysis of trends indicated a significant linear trend for both the APNEA group, $F(1) = 15.96$, $p = .001$ and the NORM group, $F(1) = 11.85$, $p = .002$. Fig. 1 illustrates how LPVreciprocol decreases over the six epochs, and the difference between APNEA and NORM groups over the drive. The APNEA group has a visually steeper linear slope.

Table 3
Split-plot ANOVA for APNEA and NORM groups (reciprocal LPV).

	df	MS	F	p	Partial η^2
Time	4.22	.16	18.72	.00	.30
Time × Group	4.22	.02	2.74	.03	.06
Group	1.00	.70	4.03	.05	.09
Error (time)	160.34	.01			

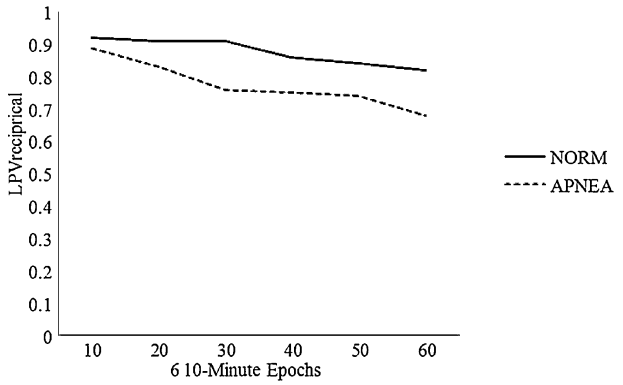

Fig. 1. Effect of APNEA group and time on LPV reciprocal. Note decreases indicate a decline in performance, higher lane position variability.

4. Discussion

The hypothesis of this study 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.

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. Analyses were not able to identify specific time blocks were significantly different in the interaction, but the apnea group showed a steeper slope over time. Although only 1 hour, the driving test was designed to unmask sleepiness effects quickly in a monotonous driving environment (Risser et al., 2000). As performance decrements were observed during the first hour, it is reasonable to assume decrements would continue with longer driving durations.

Given there was no main effect for group differences as has been found by previous studies with clinically diagnosed patients, the data suggest that there may be subtle differences between sleep apnea patients that present to sleep centers to seek treatment and those with undiagnosed sleep apnea with no subjective sleepiness. However, the fact that the driving performance of the sleep apnea participants in this study deteriorated over the length of the drive stresses the potential risks of not seeking treatment and the dangers of driving for this population.

The significant interaction indicates that untreated apnea drivers appear to be 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 drivers particularly exposed to long drives. For example, there is cause for concern among commercial drivers, especially long-haul truck drivers. Another new population where this is especially relevant is the new industry of internet taxi services where any driver can be a “commercial” driver with unknown sleep apnea and risks with little oversight by a company. It is important to note that there were no significant differences between the sleep apnea and control participants at the beginning of the drive, so a quick test of sleepiness or performance before letting a commercial driver begin his shift may not be the best indicator of fitness to drive. This stresses that companies need to be proactive in having their drivers screened for sleep apnea, and treated for sleep apnea as appropriate.

4.1. 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. The third limitation is task duration. The final limitation is the use of a screening tool for sleep apnea instead of a diagnostic test.

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 et al., 2010; Lawson and Mead, 1998). We limited this possibility by eliminating participants complaining of dizziness or nausea during the practice drives.

Another 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 (e.g., Davenne et al., 2012; Philip et al., 2003; Sandberg et al., 2011) 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 was 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.

A final criticism of driving simulation is task duration. Commercial truck drivers routinely drive long distances, more than 1 h in duration. However, typical driving simulation scenarios, including the one used in this study, are designed to be monotonous in an attempt to quickly unmask sleepiness or fatigue effects. It is suggested that if time-on-task differences or declines are seen in a one-hour driving simulation test, such results may be translated into further declines with longer time-on-task (Park et al., 2007; Ware et al., 2007).

Regarding sampling, in comparing the groups, 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 was less concern that this was a factor in this study. Participants were also given two practice drives to help eliminate practice effects. As the analyses indicated no age effect for this study, age differences were not considered a confound of the study but remain here as a potential consideration for future comparative studies.

A final potential limitation of the study is the use of a sleep apnea screening tool instead of a more thorough home sleep diagnostic test or in-lab overnight polysomnography. In-lab polysomnography is the gold standard of diagnosing sleep apnea, but the RUSleeping device has been validated against polysomnography as a reliable measure of sleep apnea (Gorny et al., 2000, 2001; Oktay et al., 2011; Spiro et al., 2002). Other studies also validate a 1-channel device for detecting sleep apnea (Oktay et al., 2011; Gutierrez-Tobal et al., 2015). Although this R-U-Sleeping device may underestimate severity, we feel that actually strengthens our results, as we found significant differences within the two groups despite this restrictive scoring. As these participants were

not actually patients of the sleep center, we did not feel it necessary to utilize more costly means to screen for sleep apnea given the validation of other studies.

To further restrict our normal group, we did eliminate any participants in the normal group that scored as having excessive daytime sleepiness as determined by an Epworth sleepiness scale score of >10. Per Medicare guidelines, CPAP is indicated for patients with AHI greater than 5 or less than 15 if also presenting with symptoms of excessive daytime sleepiness, impaired cognition, mood disorders or insomnia, or documented hypertension, ischemic heart disease or history of stroke. To this end, our normal population with AHI < 10 with our exclusionary criteria would not qualify for treatment. Using the criteria we did, we still found differences between groups. We were able to identify drivers that are more at-risk for performance decrements over time.

4.2. Conclusions

Results of this research demonstrate that performance of drivers with untreated sleep apnea degrades more quickly over time than drivers without sleep apnea. The fact that the sleep apnea participants in this study were community volunteers, and not sleep center patients, stresses the robust nature of the performance decrement over time, regardless of whether a driver has gone to a sleep center or not. This indicates that regardless of whether a person's sleep apnea presents enough subjective sleepiness symptoms to prompt them to seek a sleep specialist, they still present a higher risk when driving. The duration of the monotonous driving simulation task unmasked the sleepiness in these patients as illustrated by their performance decrements over the drive. The results of this study are instructive and show significant relationships between sleep and driving performance, and as such attention should be given to sleep apnea when determining fitness to drive. The most recent report from the National Highway Traffic Safety Administration (NHTSA, 2011) attributed 1202 fatalities (2.7% of total fatalities) in 2009 to fatigue, sleepiness and illness. There should be emphasis on screening of all commercial drivers for sleep disorders, not just traditional long-haul truck drivers, to minimize risk undiagnosed sleep apnea has on driving performance. Proactive screening would save society billions of dollars in accident and injury costs, as well as prevent many deaths caused each year by drowsy driving.

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