



# The role of fatigue and sleepiness in drivers with obstructive sleep apnea

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## ABSTRACT

**Background:** The present investigation examines the role of daytime sleepiness and fatigue and how these relate to driving behaviors and risk assessment in people newly diagnosed with obstructive sleep apnea (OSA).

**Methods:** We recruited 47 individuals, (24 female, 23 male), between the ages of 25 and 71 (mean age = 51, SD = 11.28). Of those, 24 individuals were newly diagnosed with OSA and 23 individuals were in a comparison sample with similar proportions of biological sex and ages, who tested negative for OSA. All participants completed questionnaire measures related to sleep, psychological adjustment, driving behavior, sleepiness and fatigue, immediately after their follow-up appointment. We collected data on driving violations from registered driving records for the 5 years preceding their enrolment in the study, as well as sleep-related data for all participants.

**Results:** Results show that individuals with OSA (M = 1.08, SD = 1.38) do not commit more driving violations than control participants (M = 0.64, SD = 1.26). Although drivers with OSA indicate significantly worse scores for fatigue (M = 7.73, SD = 3.71) compared with controls (M = 4.26, SD = 3.66), there was no significant difference for sleepiness between drivers with OSA (M = 10, SD = 3.57) and Controls (M = 8, SD = 3.69). An association between driving violations and sleepiness was found for drivers with OSA –  $r(24) = -0.45, p < .05$  – but not for Controls –  $r(23) = -0.22, p > .05$ .

**Conclusions:** Fatigue, and sleepiness should be assessed as distinct constructs, and each should be taken into account separately in studies of driving risk.

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## 1. Introduction

It has been demonstrated that excessive daytime sleepiness is a common symptom of obstructive sleep apnea (Hossain et al., 2005). However, recent studies indicate that fatigue is also a very common complaint (Chotinaiwattarakul, O'Brien, Fan, & Chervin, 2009; Lee, Bardwell, Ancoli-Israel, & Dimsdale, 2010). Although health care providers and patients tend to

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use the terms interchangeably, the concepts of fatigue and sleepiness are not completely overlapping, and, in fact, can be measured separately (Aguillard et al., 1998; Aksan, Dawson, Tippin, Lee, & Rizzo, 2015; Bener, Yildirim, Özkan, & Lajunen, 2017; Hossain et al., 2005). It is generally believed that sleepiness is the most important cause of highway accidents (Moradi, Nazari, & Rahmani, 2018; Tregear, Reston, Schoelles, & Phillips, 2009), however, driver fatigue has been linked to reduced performance efficiency. Fatigue has been found to predict increased risk for error and lapses (McCormick et al., 2012; Van et al., 2017) and to be a major cause of road accidents with implications for road safety (Lal & Craig, 2001). Treatment for OSA appears to reduce nocturnal sleep fragmentation, however it is unclear whether it is daytime sleepiness or fatigue that is being modified (Aksan et al., 2015).

In this paper, we define fatigue as increased feelings of tiredness, decreased energy, motivation, and alertness (Van Cutsem et al., 2017). It has also been represented as a physical state of muscular exhaustion (Lal & Craig, 2001). Fatigue has been associated with a decline in cognitive task performance (i.e. accuracy, reaction time) after prolonged periods of demanding cognitive activity (Van Cutsem et al., 2017). Depressive symptoms are strong predictor of fatigue and independently associated with worse fatigue in patients with OSA (Bardwell, Ancoli-Israel, & Dimsdale, 2007). Fatigue resolves after a period of rest (Philip et al., 2005). Sleepiness is defined as difficulty in maintaining wakefulness, even while carrying out activities, and is related to circadian and homeostatic influences (i.e. sleep pressure) (Carskadon, Brown, & Dement, 1982). Excessive daytime sleepiness can be defined as the desire or tendency to fall asleep at an inappropriate time (Hossain et al., 2005). Notably, it is, typically, sleepiness that is invoked in perceived driving risk among individuals with OSA (Baibaldi et al., 2018; Garbarino et al., 2018; Moradi et al., 2018), although, there are some studies that highlight the independent association of sleepiness and fatigue on driving behavior and risk (Bener et al., 2017; Gharagozlou et al., 2015).

This paper discusses the concepts of fatigue and sleepiness as separate constructs and investigates psychobehavioral associations with driver performance. The primary objective of the present investigation was to explore perceived fatigue and sleepiness as independent aspects of OSA, in a sample of non-commercial drivers. The specific questions addressed are: Do levels of fatigue and sleepiness differ in individuals with OSA from those without OSA? Do the constructs of fatigue and sleepiness relate differentially to driver performance? A second objective was to investigate the effect of treatment for OSA. The specific questions addressed are: Does treatment for OSA reduce experienced fatigue and sleepiness? Does treatment for OSA have an impact on driver performance?

## 2. Material and methods

### 2.1. Participants

In an experimental prospective study design, we recruited 24 individuals (mean age = 51.4, SD = 10.9, 12 females, 12 males) who were newly diagnosed with OSA by an AASM sleep medicine specialist after completing a polysomnography (PSG). Within this group, the mean AHI was moderate (mean = 36.3, SD = 25.3) and the mean yearly driving distance was 17631.3 km (SD = 18628.5). A control group of 23 individuals who had similar proportions of age (mean = 50.57, SD = 11.86), biological sex (12 females, 11 males) and yearly driving kilometres (mean = 13007.8 km, SD = 20878.1 km) was also recruited. The comparison sample had no complaints of fatigue, sleepiness or sleep problems. Control participants were recruited either at the sleep clinic (e.g. accompanying partners, family members, friends) ( $n = 6$ ), or from the community through posters ( $n = 17$ ). We verified that no Control participant had OSA and that the different recruitment approaches yielded no differences on sleep parameters (Sleep Questionnaire), quality of life (SF-36), psychological profiles (Sleep Symptom Checklist) or driving parameters (Driving Questionnaire), i.e. control participants recruited from sleep clinics were not statistically different from control participants recruited from the community. We collected baseline questionnaire data (T1) immediately after recruiting participants. All participants were then reassessed six months later (T2). This time lapse allowed participants with OSA to be re-tested after 6 months of being adherent to CPAP treatment, if treatment was accepted (Sawyer et al., 2011).

Exclusion criteria were: being a professional driver, inability to understand English or French, not having a valid driving license for at least 5 years, severe or acute medical or psychiatric condition, cardiovascular disease with end-organ effects (e.g., history of heart attack, stroke, and congestive heart failure) and substance abuse.

### 2.2. Material

**Background information form** (Libman, 1989). This measure gathers information on gender, age, marital status, living conditions, income information and education.

**Polysomnography (PSG)**. Participants with OSA were assessed by PSG in a sleep laboratory certified by the American Academy of Sleep Medicine and used standardized methods of evaluation. Apnea events and associated arousals were scored manually by registered technicians according to scoring rules established by the American Academy of Sleep Medicine 2012 (Berry et al., 2012). We did not obtain the PSG data for participants in this study. The PSG reports were seen by an AASM sleep specialist who then evaluated their sleep.

**Self-reported CPAP treatment adherence** of OSA subjects was assessed by telephone interview and was defined as the average duration of machine use, as well as percent of nights used. We asked participants: (1) Are you using prescribed CPAP

treatment, (2) For how many hours per night, (3) How many days per week, and (4) Since when? A participant was considered adherent if they reported following their prescribed treatment at least 4 h per night, at least 80% of the time, in the 6 months preceding post-treatment testing (Batool-Anwar, Baldwin, Fass, & Quan, 2017; Mashita et al., 2017; McEvoy et al., 2016).

**Sleep symptom checklist (SSC)** (Bailes et al., 2008). The SSC is a 21-item survey of a broad range of symptoms that are both directly and indirectly related to sleep disorders. It is easily completed by patients of all ages. Participants rate each symptom for its severity from 0 (not at all) to 3 (very severe) based on their experience during the previous month (Bailes et al., 2008). Temporal stability of the severity ratings was found to be acceptable (total  $r = 0.79$ ,  $p < .01$ ). Cronbach's alpha was 0.74. Factor analysis yielded four distinct subscales: Insomnia, Daytime Distress, Sleep Disorder, and Psychological Maladjustment (including items related to anxiety and depression). The SSC was also used as a screening measure to rule-out the presence of sleep disorder symptoms for Control participants.

**Sleep questionnaire** (Fichten et al., 1995). This brief retrospective measure inquires about usual sleep experiences during the past typical month, including Non-Refreshing Sleep, Sleep Quality, Time in Bed, Total Sleep Time (TST), Sleep Onset Latency (SOL), and Wake After Sleep Onset (WASO) during a typical week in the past month. This tool also assesses frequency (0–7 days/week) of non-refreshing sleep, difficulty falling asleep and getting back to sleep after nocturnal awakenings. The Sleep Questionnaire has been validated in both English and French in our research. Data indicate good test-retest reliability:  $r$  values range from 0.58 to 0.92 for intervals ranging from 2 weeks to 15 months (Alapin et al., 2000). High correlations between equivalent scores on this measure and on the Sleep Diary were also found (e.g.,  $r = 0.83$ , 0.64, and 0.69 for TST, SOL, and WASO, respectively (Libman, Fichten, Bailes, & Amsel, 2000).

**Epworth sleepiness scale.** This is a brief self-administered retrospective questionnaire of behavioral aspects of sleep tendency. It is the measure most commonly used in studies of OSA. Participants rate how likely they are to doze off or fall asleep in eight different situations commonly encountered in daily life on a 4-point scale (0 = never doze off, 3 = high chance of dozing) (Johns, 1991). Scores are summed and vary from 0 to 24. The measure has high 5-month test-retest reliability ( $r = 0.82$ ), as well as high internal consistency (Cronbach's  $\alpha = 0.88$ ) (Johns, 1991).

**Empirical sleepiness and fatigue scales.** This measure was developed by our team (Bailes et al., 2008) through correlation and factor analysis of items from four popular measures purporting to measure sleepiness and fatigue. The two Empirical Scales represent different constructs that were found to have distinctive patterns of associations and were only minimally correlated with each other in three different samples ( $r$  ranged from 0.06 to 0.33). The Empirical Sleepiness Scale consists of 6 items from the Epworth Sleepiness Scale (items are scored on a 4-point scale, with a minimum total score of 0 and a maximum score of 18). Higher scores indicate greater sleepiness. The Empirical Fatigue Scale consists of 1 item from the Fatigue Severity Scale (Krupp, LaRocca, Muir-Nash, & Steinberg, 1989) and 2 from the Chalder Fatigue Scale (Chalder et al., 1993); scoring uses a 6-point Likert scale (1 = strongly disagree, 6 = strongly agree), with a minimum score of 3 and a maximum score of 18. Higher scores indicate greater fatigue or diminished energy. Both Scales have good test-retest reliability ( $r = 0.69$ – $0.91$ ) as well as internal consistency (Cronbach's alpha scores range from 0.74 to 0.95).

**Quality of life: SF-36 health survey** (Ware, 2000). This popular 36-item measure was used to assess quality of life in eight health domains: limitations in (1) physical activities because of health problems; (2) social activities because of physical or emotional problems; (3) usual role activities because of physical health problems; (4) bodily pain; (5) general mental health (psychological distress and well-being); (6) limitations in usual role activities because of emotional problems; (7) vitality (energy and fatigue); and (8) general health perceptions. Reliability data, based on both patient and non-patient samples (Ware, 2000) range from 0.64 to 0.96. The SF-36 has demonstrable validity in that the subscales were found to correlate with ability to work, utilization of health services, as well as other mental health and quality of life measures. Low scores on all subscales indicate disability due to illness; high scores indicate better functioning due to relatively good health.

**Beck depression inventory (BDI-II).** The 7 item PC Subscale of the BDI-II (Beck, Steer, & Brown, 2006) was used to evaluate the affective and cognitive symptoms of depression independent of fatigue, sleepiness, insomnia and agitation. Beck et al. report that the test-retest reliability for PC Subscale is 0.82, while its internal consistency is 0.86. Items are scored on a 4-point scale (0–3). Scores are summed and produce a range from 0 to 21. Higher scores indicate greater depression. The PCI Subscale has no questions that inquire about non-refreshing sleep and, as a result, it measures distinct domains unique to depression. The 21 item BDI is one of the most frequently used measures of depression. As in the original version, the BDI-II also scores items on a 4-point scale (0–3). Scores are summed and produce a range from 0 to 63. Higher scores indicate greater depression. A score over 20 is usually considered indicative of clinical depression, while scores of 13 or less are generally considered non-depressed. Scores from 14 to 19 are generally considered “mildly depressed.” The scale has excellent psychometric properties (internal consistency:  $r = 0.92$ ; test-retest reliability:  $r = 0.93$ ). A new feature of the BDI-II is the 7 item Primary Care (PC) subscale which evaluates the affective and cognitive symptoms of depression independent of fatigue, sleepiness, insomnia and agitation. Test-retest reliability for this subscale is 0.82, while internal consistency is 0.86 (Beck, Croudece, Singh, & Harrison, 1997).

**Société de l'assurance automobile du Québec (SAAQ) registered driving accident and violation reports.** Frequency of accidents and violations recorded by police for the Quebec provincial automobile vehicle licensing board (SAAQ) are reported. These items comprise all violations included in the Quebec Road Safety Code. Participants gave consent to obtain their 5-year accident and violation record from the SAAQ. Records on the previous 5 years were obtained from a SAAQ officer for all participants at T1, and for the previous 6 months at T2 (Sdlaa, 2018).

**Manchester driver behavior questionnaire (DBQ)** (Lawton, Parker, Manstead, & Stradling, 1997). This is a self-report questionnaire assessing driving incidents (i.e., errors and violations) used to measure driver behaviors. Participants are asked to indicate how often they commit each of 28 behaviors on a six-point scale (0 = never; 5 = nearly all the time). We used a version adapted to Canadian driving. Our study utilizes four factors developed by Sullman et al. in 2002: Errors, Lapses, Aggressive and Ordinary violations (Sullman, Meadows, & Pajo, 2002).

**Driving violations inventory** (Rizzo et al., 2019). This is a self-report questionnaire, developed by our team, used to compare self-reported driving violations with registered driving violations using items from the SAAQ accident and violation reports records. Participants are asked to indicate how often they commit each of the violations on the registered SAAQ violations list using a six-point scale (0 = never; 5 = nearly all the time). This measure has high internal consistency (Cronbach's  $\alpha = 0.94$ ).

### 2.3. Procedure

**Time 1 (T1) – Baseline.** 24 participants newly diagnosed with OSA and 23 Control participants (Controls) were recruited from one of two sleep clinics in Montreal. Participants newly diagnosed with OSA were made aware of the study by their sleep medicine specialist at their follow-up appointment after polysomnography. They were asked for consent to have a member of the research team contact them to explain the study and request their participation. When OSA was diagnosed, the treatment offered was continuous positive airway pressure (CPAP). Once the sleep medicine physician prescribed treatment, it usually took several weeks to arrange a meeting with a sleep medicine technician, to choose a device that suited the patient. This time interval allowed us to complete all assessments at T1 for the OSA group before CPAP treatment was begun. Participants consented to allow us to obtain their 5-year violation and accident record from the SAAQ.

**Time 2 (T2) – Participants with OSA only.** To minimize attrition we followed recommendations noted by Tansey, Matté, Needham, and Herridge (2007). These include: collection of detailed contact information; sending out reminder letters with times and location of follow-up visits, placing a reminder phone message the day before a visit, making phone calls to maintain contact at least every 3 months during the interval between T1 and T2, and updating contact information at each phone call. In the 6-month period between T1 and T2, OSA participants were followed with usual medical care, without intervention from any of our team members. If participants were offered CPAP treatment, they met with technicians to purchase and receive their prescribed CPAP treatment. After 6 months (T2), the OSA group was re-tested: (1) self-reported adherence to the CPAP treatment was evaluated in an open-ended interview (2) the questionnaire package was completed, (3) we collected SAAQ accident and violation records for the previous 6 months for T2 participants.

### 2.4. Ethical approval

The protocol was approved by the McGill University Research Ethics Board, the Université de Montréal Research Ethics Board as well as by the Research Ethics Boards of the Jewish General Hospital. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

### 2.5. Statistical analysis

To analyze the overall differences between OSA and Controls, *t*-tests were performed on fatigue, sleepiness, driving behaviors, depression, anxiety, nocturnal sleep parameters (WASO, TST, Sleep efficiency) and most aspects of health-related quality of life. Items from the ESFS were factor analyzed together with the single objective SAAQ driving records item: number of driving violations in registered driving records, for all participants. To address self-reported adherence to CPAP treatment's impact on sleepiness, fatigue and driving safety, paired *t*-tests were carried out to analyze pre- and post-treatment self-report data.

## 3. Results

### 3.1. Analyses on T1 data (baseline)

Mean scores in Table 1 and *t*-test results show that drivers with OSA had significantly worse scores on fatigue and 4 aspects of health-related quality of life: physical functioning, role limitations due to physical health, body pain, general health, and energy/fatigue. There were no statistically significant differences between groups for sleepiness, driving violations, mood or sleep parameters. Our sample of participants with OSA did show correlations for fatigue and depression measures,  $r(24) = 0.471$ ,  $p < .05$ , as well as sleepiness and depression,  $r(24) = 0.427$ ,  $p < .05$  (Table 2).

We then explored relationships between night time, daytime, health-related quality of life and mood variables with driving violations and the DBQ subscales in the OSA and Control groups. As shown in Table 2, in the OSA group, daytime sleepiness was negatively correlated with registered driving violations,  $r(24) = -0.45$ ,  $p < .05$ , whereas AHI was positively correlated with registered driving violations,  $r(24) = 0.42$ ,  $p < .05$ . Furthermore, in the OSA group, sleep disorder symptoms

**Table 1**Independent sample *t*-tests comparing driving behaviors in individuals with and without OSA.

	OSA		Control		<i>t</i> -test
	M	SD	M	SD	
Official driving violations	1.08	1.38	0.64	1.26	ns
Self-reported violations	13.90	12.36	12.17	10.31	ns
DBQ total score	87.98	22.24	86.00	18.97	ns
Sleepiness	10.00	3.57	8.00	3.69	ns
Fatigue	7.73	3.71	4.26	3.66	3.227**
Depression	0.58	0.83	0.23	0.43	ns
Anxiety	0.83	0.82	0.64	0.73	ns
WASO	0.86	0.94	0.55	0.52	ns
Sleep efficiency	0.83	0.20	0.91	0.08	ns
TST	6.75	1.99	6.82	0.66	ns
SF-36:					
Physical functioning	70.00	27.62	93.91	7.68	−4.080***
Role limitations due to physical health	64.58	40.99	94.57	10.54	−3.466**
Body pain	50.08	23.36	75.96	18.01	−4.263***
General health	62.04	18.60	74.04	16.74	−2.327*
Energy/fatigue	47.40	18.44	66.52	18.12	−3.587**
Social functioning	71.35	25.66	83.70	21.13	ns
Role limitations due to emotional problems	72.22	41.31	84.06	26.34	ns
Emotional well-being	65.17	19.61	72.87	16.18	ns

Note. M = Mean. SD = Standard Deviation. OSA = Obstructive Sleep Apnea.

\*  $p < .05$ .

\*\*  $p < .01$ .

\*\*\*  $p < .001$ .

**Table 2**

Correlations between driving violations, daytime functioning and sleep parameters for individuals with OSA.

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Official driving violations													
2. Self-reported violations	−0.076												
3. Aggressive driving (DBQ)	0.126	−0.313											
4. Ordinary infractions (DBQ)	0.08	−0.311	0.884**										
5. Errors (DBQ)	0.029	−0.155	0.740**	0.770**									
6. Lapses (DBQ)	0.107	−0.366	0.540**	0.621**	0.819**								
7. Beck Depression Inventory (total)	−0.132	−0.016	0.325	0.331	0.259	0.16							
8. Fatigue	−0.106	0.268	0.063	0.105	0.159	0.028	0.471*						
9. Sleepiness	−0.450*	0.34	−0.074	−0.01	−0.172	−0.236	0.427*	0.459*					
10. Sleep efficiency	0.079	0.299	−0.159	−0.153	−0.223	−0.346	−0.155	−0.21	−0.22				
11. TST	−0.182	0.383	−0.02	−0.244	0.19	−0.009	−0.046	0.089	−0.05	−0.066			
12. WASO	−0.087	0.044	−0.086	0.195	−0.023	0.01	0.144	0.469*	0.372	−0.134	−0.28		
13. AHI	0.418*	−0.112	−0.048	−0.031	−0.247	−0.107	−0.013	0.025	−0.152	0.167	−0.468*	0.465*	

\* Correlation significant at the 0.05 level (bilateral).

\*\* Correlation significant at the 0.01 level (bilateral).

were positively correlated,  $r(24) = 0.46$ ,  $p < .05$ , with self-reported violations. In the Control group, psychological symptoms were strongly correlated with ordinary violations, driving errors and lapses while driving,  $r(24) = 0.54$ – $0.68$ ,  $p < .01$ . Additionally, driving errors were also associated with insomnia,  $r(24) = 0.42$ ,  $p < .05$ , and self-reported driving violations were associated with sleepiness for Controls,  $r(24) = 0.42$ ,  $p < .05$  (Table 3).

To evaluate whether poor driving was more closely linked to sleepiness or fatigue, all nine items of the Empirical Sleepiness and Fatigue Scale (ESFS) were factor analyzed together with the single objective item: number of registered driving violations in registered driving records, for all participants. A Maximum Likelihood factor analysis of the 10 items, using Oblimin rotations, was conducted with 3 distinct factors linking registered driving violations to the Empirical sleepiness and fatigue scale items, explaining 53.91% of the variance. An Oblimin rotation provided the best-defined factor structure, where all items were retained. All items had primary loadings over 0.3. Violations from registered driving records had a loading of 0.364, however it was a primary loading. The factor loadings are presented in Table 4. The number of driving violations item loaded with all 3 items of the ESFS that were specific to fatigue.

**Table 3**

Correlations between driving behavior, daytime functioning and sleep parameters for control group.

	Official driving violations	Self-reported violations	Aggressive driving	Ordinary infractions	Driving errors	Lapses while driving
Sleep symptom checklist						
Insomnia	0.174	−0.131	0.159	0.322	0.424*	0.278
Daytime symptoms	−0.043	0.069	−0.09	0.031	0.078	−0.029
Sleep Disorder symptoms	0.413	0.158	0.015	0.124	0.158	0.08
Psychological symptoms	0.085	0.175	0.319	0.645**	0.675**	0.539**
Fatigue	0.046	−0.011	−0.112	−0.138	−0.177	−0.265
Sleepiness	−0.223	−0.424*	−0.154	−0.147	−0.278	−0.353
Sleep efficiency	0.165	0.084	0.037	−0.046	−0.036	0.119
TST	−0.254	0.089	−0.227	−0.209	−0.142	0.063
WASO	−0.24	−0.136	0.179	0.276	0.099	0.002

\*\*  $p < .01$ .\*  $p < .05$  (bilateral).**Table 4**Exploratory factor analysis factor loadings for actual driving violations and sleepiness and fatigue scale items ( $n = 47$ ).

	Factors		
	1	2	3
Sitting and reading (ESS)	<b>0.925</b>		−0.293
Watching TV (ESS)	<b>0.698</b>		−0.286
As a passenger in a car for an hour when circumstances permit (ESS)	<b>0.501</b>	0.485	−0.421
I lacked energy (SFM)	0.484	<b>0.849</b>	−0.517
I started things without difficulty but got weak as I went on (SFM)	0.28	<b>0.792</b>	−0.287
Exercise brought on my fatigue (FSS)		<b>0.538</b>	
Official driving violations		<b>0.364</b>	
Sitting quietly after lunch without alcohol (ESS)	0.532	0.326	−0.931
Sitting, inactive in a public place (e.g., theatre, meeting) (ESS)	0.522	0.266	−0.621
Sitting and talking to someone (ESS)			−0.452

Note. Loadings less than 0.20 were excluded. Factor loadings in bold type were considered for cluster interpretation. Extraction method: Maximum likelihood. Rotation method: Oblimin with Kaiser normalisation.

### 3.2. Analyses on T2 data (6 month later)

In the OSA group, 13 drivers reported being adherent and 11 reported being non-adherent to treatment. Because of the small sample sizes, we opted for independent sample  $t$ -tests. We first wanted to analyze whether drivers who were later adherent to CPAP treatment had different profiles at baseline compared with drivers who later did not adhere to treatment. Table 5 demonstrates that for both groups there were no significant differences on AHI, number of registered driving violations, number of self-reported violations, total DBQ score, fatigue, and sleepiness (all *n.s.*).

Subsequently, we expected that self-reported violations, fatigue and daytime sleepiness would be improved with CPAP treatment. We conducted paired-sample  $t$ -tests on pre- and post-treatment data on all three variables for drivers who were adherent to treatment (Table 6). Self-reported CPAP adherence had no significant effect on subjective driving violations, fatigue, nor on daytime sleepiness (all *n.s.*). Unfortunately, violations from driving records were too few to be statistically analyzed.

A chi-square test of goodness-of-fit was performed to determine whether fatigue and sleepiness were equally reported in the adherent and non-adherent groups. Fatigue and sleepiness were equally distributed in this sample, at baseline, X2

**Table 5**Independent sample  $t$ -tests comparing driving behaviors and AHI between CPAP adherent and CPAP non-adherent drivers.

	Adherent		Non-adherent		$t$ -test
	M	SD	M	SD	
AHI	38.69	27.46	33.45	23.54	ns
Official driving violations	1.08	1.44	1.09	1.38	ns
Self-reported violations	10.08	4.97	18.41	16.74	ns
DBQ total score	80.15	8.96	97.23	29.45	ns
Fatigue	7.04	3.49	8.55	3.96	ns
Sleepiness	9.50	3.29	10.59	3.95	ns



**Table 6**Independent sample *t*-tests comparing driving violations, fatigue and sleepiness, before and after CPAP >4 h a night (n = 13).

	Pre-treatment		Post-treatment		<i>t</i> -test
	M	SD	M	SD	
Self-reported violations	9.36	5.08	9.00	9.90	ns
Fatigue	6.86	3.77	4.41	4.02	ns
Sleepiness	8.59	2.65	7.91	3.65	ns

(2, N = 13) = 1.42,  $p = .23$ , and 6 months later,  $X^2(2, N = 13) = 1.53, p = .22$ . Specifically, 69.2% of adherent participants who used CPAP >4 h per night, at least 80% of the time, in the 6 months preceding post-treatment testing, experienced sleepiness at baseline. After 6 months of CPAP therapy, 46.2% of the adherent participants still experienced sleepiness. Those who experienced sleepiness were the primary determinants of residual sleepiness 6 months later. To perform this comparison, prorated scale scores of the 6 sleepiness-related items in the ESFS (derived from the ESS) were computed to represent the 8 items of the ESS scale. On the other hand, 53.8% of adherent participants experienced fatigue at baseline, and, after 6 months of CPAP therapy, 23.1% of the adherent participants still experienced fatigue. To perform this comparison, we analyzed the 3 items from the ESFS that pertain to fatigue. Cutoff scores from Bailes, Libman (Bailes et al., 2006) determined who was considered to be fatigued.

#### 4. Discussion

Consistent with previous studies looking at daytime fatigue and daytime sleepiness as independent problems in apnea patients (Aguillard et al., 1998; Bailes et al., 2011), the present study demonstrated that levels of fatigue were higher for individuals with OSA than for those without. The factor analyses demonstrated that the number of driving violations item loaded with all 3 items of the ESFS that were specific to fatigue. In contrast, levels of sleepiness were not shown to differ between the OSA and control groups. This was unexpected as previous studies showed that it is the excessive sleepiness that needed to be managed in the context of drivers with OSA (Pagel, 2009; Pierce, 1999).

In addition, our data did not show different driving profiles between drivers with OSA who were either adherent or non-adherent to treatment, nor did our data show that CPAP treatment decreased fatigue, sleepiness or the number of self-reported driving violations after 6 months of treatment. This finding is novel and has not been previously assessed. Larger sample sizes would be needed to properly assess the important relationship between treatment of OSA and driving performance.

There was considerable variability among individuals with OSA, and we were unable to identify a risk profile in our sample. Although other research has implicated problematic daytime sleepiness in increased crash risk, and individuals with OSA have commonly been designated as prototypically sleepy, most (92%) drivers with OSA in our sample had not been involved in a motor vehicle crash in the past 5 years. Results of our investigation clearly showed that based on the results of the Empirical Fatigue and Sleepiness Scale, an important percentage of individuals with OSA (30.8%) do not experience excessive daytime sleepiness. Many prior studies have also demonstrated that not all OSA patients experience excessive sleepiness (Chervin & Aldrich, 1999; Chung, 2005; Lindberg, 2010; Roure et al., 2008). In fact, it is suggested that the presence of insomnia, level of alertness and metabolic conditions may have stronger associations with OSA than with sleepiness. For patients with OSA who do not experience sleepiness, recent studies reported that daytime sleepiness possibly relates to the domain and extent of cognitive impairment in OSA; CPAP treatment has little effect on the improvement of cognitive deficits, which can have an important impact on driving performance (Zhou, Camacho, Tang, & Kushida, 2016).

Furthermore, sleepiness in this group was not consistently related to driving violations. Registered driving violations significantly correlated with sleepiness for individuals with OSA, whereas a factor analysis on individual items of the ESFS identified 3 clear patterns of response associating fatigue with the number of registered driving violations (Table 4). Substantively, Table 2 shows self-reported sleepiness was associated with AHI,  $r(24) = 0.42, p < .05$  (an objective measure of OSA severity), drivers with OSA reported significantly higher scores on fatigue, compared to controls,  $t(47) = 3.23, p.01$ . However, drivers with OSA did not commit more driving violations than Controls overall.

Also, drivers with OSA had self-reported daytime sleepiness that was negatively correlated with registered driving violations, whereas their AHI was positively correlated with registered driving violations. Possibly, variable correlation between objective measurement and subjective experience might explain some of the discrepancy between aspects of our data and previous reports, especially for the OSA population (Kaye, Lewis, & Freeman, 2018; Rizzo et al., 2018). Although these findings are novel and have not been previously assessed, a larger sample would be needed to further the research examining the correspondence between self-report and objective measures of driving behavior.

Several studies suggest that excessive fatigue in obstructive sleep apnea patients may be strongly influenced by depressive symptoms and not apnea severity. In our sample of participants with OSA as well, fatigue and depression, as well as sleepiness and depression, measures were correlated. These findings concur with Lal and Craig (2001) that fatigue and sleepiness measures that include psychological adjustment aspects seem promising for the development of a countermeasure device (Lal & Craig, 2001).

The present report has few limitations. The numbers of road accidents obtained from the SAAQ registry involving our participants were so few that we were limited in our capacity to measure the association between registered dangerous driving and OSA. Much of our driving behavior data was based on self-report, which may have resulted in report bias. In another study we did compare self-reported and registered driving violations. We found that individuals with OSA over reported driving violations, while the comparison individuals with no OSA underreported driving violations (Rizzo et al., 2014). Registered driving violations are only representative of the violations for which participants were caught. Driving violations were certainly committed but were not reflected in their registered driving records. Furthermore, our relatively small sample size did not allow for biological sex comparisons; future studies would benefit from a larger sample and attention to potential biological sex differences.

## 5. Conclusions

Fatigue plays a key role in driving behaviors, although the extent remains unclear. Our findings suggest that fatigue is as important a determinant of poorer driving performance as is sleepiness and AHI are for OSA severity. Future research in the area of driver fatigue should not only consider the methodological limitations of this study, but also include basic cognitive measures, such as alertness and response time, which underlie driver performance and risk (Lal & Craig, 2001).

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## Conflict of interest

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

## Informed consent

Informed consent was obtained from all individual participants included in the study.

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## Appendix A. Supplementary material

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