Transportation Research Part F 62 (2019) 78–85

Contents lists available at ScienceDirect

Transportation Research Part F

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

Self-reported driving violations as a putative mirror measure of real-world driving quality in individuals with and without Obstructive Sleep Apnea

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A R T I C L E I N F O

Article history:
Received 9 April 2018
Received in revised form 1 November 2018
Accepted 16 December 2018

Keywords:
Obstructive sleep apnea
Driving risk
Driving violations

A B S T R A C T

Sleepiness is recognized as an important risk factor for risky driving and motor vehicle accidents. This study explores whether self-reported driving violations can be used as an accurate assessment of driving risk in individuals with obstructive sleep apnea (OSA). We recruited 29 participants with OSA and 29 age- and biological sex-matched controls, obtained governmental sourced driving records for all participants and administered a monotonous driving simulator task to measure driving performance. We administered the Driving Violations Inventory (DVI) to all participants—a self-report measure that asks participants to record which of the official list of violations were committed. Data from DVI were compared with official driving records and with driving simulator results. Drivers with OSA did not have more registered driving violations than the control group. The overall number of self-reported violations was highly correlated with the driving simulator lateral position variable only for drivers with OSA. There were no significant associations between the number of official driving violations and simulator deviation of the lateral position for either group. Our findings indicate that the DVI is an accessible measure that could mirror some of the risk associated with impaired driving behavior in general, perhaps particularly for individuals with OSA.

1. Background

Obstructive Sleep Apnea (OSA) is a highly prevalent disorder that affects at least 10% of adult males and 5% of adult females (McNicholas, 2008; Simpson et al., 2013). This sleep-disordered breathing is highly prevalent, with important public health outcomes (Heinzer et al., 2015). Severe OSA has been associated with sleepiness, car crashes, depressed mood, cardiovascular and cerebrovascular morbidity, cognitive and metabolic dysfunction, and accelerated mortality (Peppard & Hagen, 2017). The disorder consists of recurring episodes of partial or complete upper airway occlusion during sleep with

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https://doi.org/10.1016/j.trf.2018.12.015
1369-8478/

associated sleep fragmentation; its most prominent daytime symptom is excessive sleepiness. Sleepiness itself is recognized as a major risk factor for impaired driving and has been reported to account for 5–7% of all motor vehicle accidents (Bioulac, Micoulaud Franchi, & Arnaud, 2017; Tefft, 2012), however, the role of sleepiness, as well as other risk-related factors and co-morbidities among individuals with OSA is not yet fully understood (Di Milia et al., 2011; Ellen et al., 2006; Karimi et al., 2014; Mulgrew et al., 2008; Philip et al., 2014; Stevenson et al., 2013).

Multiple experimental studies using driving simulators or real city roads have made the link between impaired driving performance and OSA (George, Boudreau, & Smiley, 1996, 1997; Hack, Choi, Vijayapalan, Davies, & Stradling, 2001; May, Porter, & Ware, 2016; Vakulin et al., 2016). For example, variability in lateral position on the road (diverging away from the center-line, "weaving") is the traditional and most reliable indicator of decreased alertness while driving (Otmani, Pebayle, Roge, & Muzet, 2005; Verster & Roth, 2011). One study demonstrated that patients with severe OSA commit driving violations more frequently than age-matched control subjects during real world driving tests, suggesting greater inattention and thus, potentially, higher motor vehicle accident risk (Philip et al., 2014). Another study indicated that naturalistic driving-related performance in individuals with OSA, who are less sleepy, still does not readily translate into safer driving (Aksan et al., 2013; Tregear, Reston, Schoelles, & Phillips, 2009; Vakulin et al., 2011). However, there are few studies on driving violations in non-commercial drivers with OSA (none since 2014); those that do exist have focused mainly on crash risk (Barger et al., 2015; George, 2007; Tregear, Reston, Schoelles, & Phillips, 2009, 2010). In addition, access to official driving records is difficult to obtain. One challenge is that official driving records only report violations committed and caught by officials; these may be very few over a five-year span (as we have found) and thus limits statistical analysis.

The objective of the present study was to evaluate self-reported driving violations as a proxy measure of real-world driving quality and to assess if it could be a more useful research tool than either driving simulation data or official driving records. Specifically, we explored whether self-reported driving violations can be used as an accurate assessment of driving risk. We approached this question with the following steps:

(1) We obtained official government-based driving records—including violations and accidents— for both participants with OSA as well as for healthy control subjects;
(2) For this study, we adapted the governmental list of driving violations and administered it as the Driving Violations Inventory (DVI), a self-report measure that asks participants to record which of the official list of violations had been committed during the previous 5 years;
(3) We administered a validated monotonous driving simulator task to measure driving performance directly;
(4) Data from the self-report measure were compared with official driving records, obtained from governmental sources and with driving simulator results.

2. Methods

2.1. Ethics approval

The present study was part of a larger investigation on OSA and risky driving carried out in our laboratory (Libman et al., 2016; Rizzo et al., 2017) 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. We were granted permission by the *Société de l'assurance automobile du Québec* (SAAQ)—the provincial body regulating driver's licenses, in Quebec, Canada—to obtain driving records for all participants. Potential participants were informed about all aspects of the study, including obtaining official government driving records.

2.2. Participants

We recruited 58 individuals who were non-commercial drivers, (mean age = 50.78, SD = 11.13) through a sleep clinic,. Of these, 29 (15 females, 14 males) were newly diagnosed with OSA, between the ages of 25 and 65. We selected adults under the age of 65 in order to avoid the many health conditions that are more prevalent in the over 65 age group. A comparison sample of 29 individuals (Control Group), matched for age and biological sex, with no complaints of fatigue, sleepiness or sleep problems was either recruited at the sleep clinic (e.g. accompanying partners, family members, friends) after sleep apnea was ruled-out (n = 10), or from the community through posters (n = 19). We verified that the different recruitment approaches yielded no differences on sleep parameters, quality of life, psychological profiles or driving parameters, i.e. control participants recruited from sleep clinics were not statistically different from control participants recruited from the community.

Potential participants were informed of all aspects of the study and screened for eligibility. Exclusion criteria were: inability to function in English or French, not having a valid driving license for at least 5 years, severe or acute medical or psychiatric condition, and cardiovascular disease with end-organ effects (e.g., heart attack, stroke, and congestive heart failure). To rule out the presence of fatigue or sleepiness, Control Group participants were administered the 7 item Sleep Disorder subscale of the Sleep Symptom Checklist (SSC), and were administered the *Breabon MediByte*® home monitoring device to confirm the absence of OSA (Apnea-Hyponea Index less than 5). We evaluated all control participants at baseline. All participants completed a questionnaire battery related to driving behavior and psychological adjustment; we obtained official accident and driving violations records for all participants. Participant demographics results are available in Table 1.

2.3. Procedure

Participants with OSA were made aware of the study by their sleep specialist at their follow-up appointment after their polysomnography sleep study. They were asked for consent to have a member of the research team contact them to explain the study and request their participation. Control participants were contacted directly by the researchers.

All potential participants were sent two copies of the information and consent form, a questionnaire package, and a self-addressed stamped envelope to return completed materials to our laboratory.

When the completed questionnaires were returned, we verified that we had permission to retrieve the 5-year accident record from the SAAQ records for all the participants, both with OSA and their age- and biological sex-matched participants without OSA.

When OSA is diagnosed, the usual treatment offered is continuous positive airway pressure (CPAP). Once the sleep specialist prescribes treatment, it usually takes several weeks to arrange meetings with a sleep medicine technician to choose a device that suits the patient. This time interval allowed us to complete all assessments for the OSA group before CPAP treatment began.

2.4. Measures

Polysomnography (PSG). Unrelated to this study's protocol, participants suspected of having OSA were prescribed an overnight sleep study by a sleep medicine physician. Nocturnal PSG was used to obtain sleep parameter scores (i.e., frequency of nocturnal arousals, total sleep time, sleep onset latency, wake after sleep onset, and sleep efficiency) as well as OSA related- factors (i.e., nocturnal profile of oxygen saturation (O2%), apnea hypopnea index (AHI) and respiratory event -related arousal from sleep). Participants were monitored in a supervised, participating sleep laboratory from 10:00 PM to 7:00 AM. Monitoring included: electroocularogram (EOG), electroencephalogram (EEG), bilateral anterior tibialis and chin electromyogram (EMG), electrocardiogram (ECG), pulse oximetry, nasal and oral airflow with thermistor and nasal pressure cannulae, microphone for snoring, and respitrace bands for measurement of respiratory effort. Apnea events and associated arousals were scored manually per scoring rules established by the American Academy of Sleep Medicine. An apnea event was defined as cessation of breathing lasting 10 s or more. Hypopneas were scored when there was a 30% or more decrease in airflow, with 3% or more oxygen desaturation or a subsequent cortical arousal. Scoring sleep began at lights out and stopped when the participant arose in the morning. The sleep laboratory is certified by the American Academy of Sleep Medicine and uses standardised methods of evaluation. We analyzed the following information from the participants' polysomnography records: basal oxygen saturation (SpO2%), respiratory distress index (RDI), and apnea hypopnea index (AHI).

Home Polysomnography Assessment (Braebon, MediByte©). Type 3 portable monitor for screening of OSA in Control participants. This device has been compared with overnight laboratory polysomnography and found to provide a close estimate of the apnea/hypopnea index (AHI) as well as excellent diagnostic sensitivity and specificity for OSA in a sample of patients with suspected OSA (Driver et al., 2011). This device records pulse oximetry, nasal airflow with nasal pressure cannulae, microphone for snoring, and respitrace bands for measurement of respiratory effort. Records underwent automated scoring which was validated by visual inspection of the raw data disclosed in 10-minute epochs. Healthy control group participants underwent home sleep recording to screen for the presence of OSA. Participants slept at home and, on a night without any unusual upper respiratory tract symptoms such as acute nasal congestion, recorded the time between when they turned off the lights to go to sleep and the time they awoke in the morning. Respiratory disturbance indices were adjusted for any time spent with invalid recording or persistent movement suggesting wakefulness.

Demographics: Background Information Form (Libman, 1989; Libman, Creti, & Fichten, 1987; Libman & Fichten, 1987). This measure collects information on biological sex, age, marital status, living conditions, and employment.

Driving Violations Inventory. Inventory of 32 driving violations listed by the SAAQ (Sdlaa, 2018). Participants are asked to indicate how often they committed each of the violations on a six-point scale (0 = never; 5 = nearly all the time). Cronbach's alpha is 0.94. (Inventory presented in Fig. 1).

Table 1
Means and standard deviations of driving habits.

	OSA		Controls			
	M	SD	M	SD	t	p
Number of years since obtaining driver's license	29.96	11.95	32.54	10.27	−0.86	0.39
Number of kilometers per year	19,168	23,119	12,422	9970	1.44	0.16
Number of hours of driving per week	6.28	1.42	6.2	1.57	0.18	0.86

For each item below, please indicate how often this has happened in the past five (5) years.	**0 =** ***never*** **1 =** ***hardly ever*** **2 =** ***occasionally*** **3 =** ***quite often*** **4 =** ***frequently*** **5 =** ***nearly always***					
1. Excessive Speeding by 11 to 20 km/h	0	1	2	3	4	5
2. Excessive Speeding by 21 to 30 km/h	0	1	2	3	4	5
3. Excessive Speeding by 31 to 45 km/h	0	1	2	3	4	5
4. Excessive Speeding by more than 45k/h	0	1	2	3	4	5
5. Excessive speeding through road work	0	1	2	3	4	5
6. Prohibited passing on the left	0	1	2	3	4	5
7. Prohibited passing on the right	0	1	2	3	4	5
8. Prohibited passing in a lane reserved for oncoming traffic	0	1	2	3	4	5
9. Accelerating when being passed	0	1	2	3	4	5
10. Passing a bicycle too closely in a travel lane	0	1	2	3	4	5
11. Zigzagging to pass	0	1	2	3	4	5
12. Failure to obey a red traffic light	0	1	2	3	4	5
13. Failure to obey a stop sign	0	1	2	3	4	5
14. Failure to come to a mandatory stop at a level crossing	0	1	2	3	4	5
15. Failure to stop before turning right at a red traffic light (where permitted)	0	1	2	3	4	5
16. Passing a school bus	0	1	2	3	4	5
17. Failure to obey the order or signal of a peace officer, school crossing guard or flag person	0	1	2	3	4	5
18. Prohibited driving in reverse	0	1	2	3	4	5
19. Prohibited crossing of a line marking off lanes	0	1	2	3	4	5
20. Speeding or reckless driving	0	1	2	3	4	5
21. Driving for a wager or stake or in a race	0	1	2	3	4	5
22. Prohibited use of a tunnel by a vehicle carrying dangerous substances	0	1	2	3	4	5
23. Driving at a speed too fast for weather or road conditions	0	1	2	3	4	5
24. Tailgating	0	1	2	3	4	5
25. Sudden braking without cause	0	1	2	3	4	5
26. Failure to yield to pedestrians and cyclists at an intersection	0	1	2	3	4	5
27. Failure to yield to oncoming traffic	0	1	2	3	4	5
28. Failure to wear a seat belt	0	1	2	3	4	5
29. Failure of a driver involved in an accident to do his or her duty	0	1	2	3	4	5
30. Driving with the presence of alcohol in the body	0	1	2	3	4	5
31. Failure to provide a breath sample	0	1	2	3	4	5
32. Driving while using a hand-held device that includes a telephone function	0	1	2	3	4	5

Fig. 1. Driving violations inventory.

Official driving records. Official driving records from the SAAQ. 32 driving violations to be recorded by the law enforcement officer. For each individual, the record includes the number of violations, information on demerit points and frequency of driving violations. The record contains data on accidents - their frequency and a severity rating (not severe to deadly). We obtained these records for all study participants covering the 5 years previous to baseline evaluation, and again at re-test 6 months later.

Driving Simulator (Thiffault & Bergeron, 2003a, 2003b). Driving simulation tests were conducted at the Université de Montréal's driving simulator laboratory. The simulator consisted of a complete automobile, including fully functional pedals and dashboard, a high-resolution projector, and a large screen. Simulated highway images were designed using actual Canadian geometric route design standards. The moving images were generated by a compatible computer. During a simulation test, the location of the pedals and the location and speed of the vehicle were recorded. A potentiometer attached to the steering column allowed detailed recording of steering wheel movements (Thiffault & Bergeron, 2003b). Data were analyzed at three time periods: after 20, 40, and 60 min. Three measures were obtained for each of the three time periods (mean lateral position, mean speed, and mean orientation of steering wheel (lower scores indicate better performance).

2.5. Analyses

A Mann-Whitney U test was conducted to compare self-reported driving violations and officially recorded driving violations. Correlations were also performed to verify whether higher (i.e. worse) scores on the DVI were associated with higher experimental or simulator standard deviation values for lateral position in the driving simulator. We also performed a Fisher's exact test to evaluate which driving violations in the DVI were more reported by each of the groups. Finally, a discriminant analysis was used to test the hypothesis that participants with OSA would differ significantly from individuals without OSA on self-report items in the DVI. We also performed a Wald test in the context of logistic regression where we allowed for the program to determine whether items from the DVI revealed that a certain predictor variable was significant or not. We then performed a discriminant analysis to verify whether the DVI is an appropriate tool for identifying participants with OSA. Finally, correlations were performed on a subset of participants (OSA groups n = 13, Control group n = 7) who were available to complete the monotonous driving simulation task to verify whether higher (i.e. worse) scores on the DVI would be associated to higher experimental or simulator standard deviation values for lateral position in the driving simulator task. Attrition for this section of the analyses was related to participant availability and whether they experienced motion sickness during the task.

3. Results

Participants in both groups reported significantly more violations than were officially recorded: Individuals with OSA reported 7.35 times and control subjects reported 12.65 times more violations than in their officially recorded file. However, given the non-normal nature of our data distribution, a Mann-Whitney test indicated that there were no differences between individuals with OSA (Mdn = 8) and control (Mdn = 7) subjects for self-reported driving violations, $p = .591$, and official registry recorded violations (Mdn = 0; Mdn = 0, respectively), $p = .124$. Frequency counts revealed that the OSA group reported a total of 250 driving violations; the Control group reported 253 driving violations. Frequency counts from official driving records revealed 34 official driving violations for the OSA group, and 20 driving violations for the Control group. Odds ratio analyses indicated that the difference between groups was not statistically significant ($\chi^2(1, N = 58) = 3.43$, $p = .064$, odds ratio = 0.058).

Binary data comparisons on self-reported violations between groups revealed that 3 items from the DVI showed differences between the OSA and Control groups with a p-value lesser than 0.1. First, there is a trend for control participants endorsing item 14—Failure to come to a mandatory stop at a level crossing ($p = 0.070$), where the odds of an individual with OSA reporting this violation is less than the odds of a control participants reporting this violation (odds ration 0.26). On the other hand, item 25—Sudden braking without cause (Fisher's exact test $p = 0.003$)—showed that the odds of an individual with OSA reporting this item are 6.8 times higher than that of a control participant (95%CI 2.0–22.9). However, item 30—Driving with the presence of alcohol in the body (Fisher's exact test $p = 0.024$)—showed that the odds of an individual with OSA endorsing this driving violation are less than that of a control participant (odds ratio 0.22, 95%CI 0.07–0.75). Entered explanatory variables item 14 ($p = .027$), item 25 ($p = .005$) and item 30 ($p = .294$) showed that they correctly predicted 69% of group memberships for all subjects. The test showed a model that correctly predicted 82.8% of group memberships. The variables retained by the Wald test in this model were item 2 ($p = .014$), item 14 ($p = .003$), item 23 ($p = .034$) and item 25 ($p = .002$).

To verify whether the DVI is an appropriate tool for identifying participants with OSA, we performed a discriminant analysis using the inventory's scores for all participants. The overall Chi-square test was significant (Wilks $\lambda = 0.330$, Chi-square = 44.851, df = 29, Canonical correlation = 0.818, $p < .05$); 91.2% of the cases were correctly reclassified into their original categories. In other words, of the 29 cases that were predicted to be in the OSA group, 26 were correctly predicted, and 3 were incorrectly predicted.

Analyses on the driving simulator data revealed that for participants with OSA, the overall number of self-reported violations was strongly correlated with the standard deviation lateral position variable of the driving simulator, $r(13) = 0.64$, $p < .05$ (Table 2). There was no such association for Control participants (Table 3). Moreover, there were no significant associations between the number of official driving violations and experimental standard deviation lateral position for either group. The standard deviation of lateral position is significantly higher for participants with OSA ($M = 0.653$, $SD = 0.062$) than

Table 2
Correlations between driving violations and lateral position for OSA group (n = 13).

	Lateral position	Self-reported driving violations
Self-reported driving violations	0.638*	
Actual driving violations	0.385	0.067

* The correlation is significant at the 0,05 level (bilateral).

Table 3
Correlations between driving violations and lateral position for Control group (n = 7).

	Lateral position	Self-reported driving violations
Self-reported driving violations	−0.002	
Actual driving violations	−0.293	0.006

*The correlation is significant at the 0,05 level (bilateral).

for Controls (M = 0.588, SD = 0.039); $t(18) = 2.539$, $p = .034$ (see Table 4 for means). A previous report has suggested that the last 20 min of the hour-long task may account for those differences, where participants with OSA may possibly be particularly sensitive to longer driving periods (Libman, Bergeron, & Creti, 2016). A larger sample size would be needed to verify this.

4. Limitations

Although data on accidents were collected, the number was too low to be considered for statistical analyses (5 total, for n = 58). The data presented in this paper are more a reflection of drivers' aptitudes and potential risk of committing driving violations than of actual accident or crash risk.

Also, Control participants were matched for age and biological sex. While matching is intended to reduce confounding, we also wanted to benefit from a gain in efficiency. The linear regression may have yielded a significant model, but, in reality, a higher percentage of men are diagnosed with OSA (Deol, Lee, Kandula, & Kanaya, 2018). Though, more studies are beginning to show that women with OSA are being overlooked (Bailes et al., 2017).

In the driving simulator task, a deterioration over time was demonstrated for participants with OSA after 40 min of driving. Due to the low number of participants, we did not elaborate on this but it would be interesting to verify with a larger sample in the future.

Lastly, the DVI is a self-reported measure. Our data shows that all participants reported several times more driving offenses than the number of offenses found in their driving records; It is likely that outside of an experimental confidentiality context, individuals may be more reluctant to disclose driving misbehaviors. It is known that self-reported data is a reflection of participants' response styles, response sets and memory (Harrison, 1997).

5. Discussion and conclusions

The DVI, is a novel measure that mirrors all possible violations listed by an official government driving agency. Our findings indicate that, it is accessible, meaningful, and. may be a simple tool to help identify a risky driver who is likely to weave while driving. The latter is an acknowledged potential warning sign of driving performance and accident risk (van Loon, Brouwer, & Martens, 2015).

Identifying drivers with OSA who may be at risk of dangerous driving is a challenge for primary care practitioners. Questioning the driver or the driver's passenger about frequency of sudden braking or weaving might indicate that further evaluation is needed. Our data suggest that drivers with OSA may need more frequent rest stops to maintain driving quality.

Notably, all participants, with and without OSA, reported significantly more driving violations than recorded in their official driving files; no differences were found in the number of driving violations between participants with OSA and control subjects. This is a reminder that driving records represent only a percentage of driving violations - those that are witnessed

Table 4
Means and standard deviations of driving violations and lateral position.

	OSA		Controls	
	Means	SD	Means	SD
Self-reported driving violations (DVI)	8.62	5.07	8.72	7.16
Actual driving violations (SAAQ)	1.17	1.36	0.69	1.17
Lateral Position (driving simulator)	0.65	0.06	0.59	0.04

by a law enforcer. Participants with OSA did report 41% more driving violations than did individuals without OSA. This difference was found not statistically significant, but further evaluation in the context of a larger sample is indicated.

Acknowledgements

We would like to thank the *Braebon Medical Corporation* for kindly providing us with a complimentary MediByte® device for screening our research participants. We also thank the *Réseau de recherche en sécurité routière* (RRSR), *Société de l'assurance automobile du Québec* (SAAQ), *Fonds de recherche en santé du Québec* (FRSQ) and *Fonds de recherche du Québec - Société et culture* (FRQSC) for funding this research. None of the authors had any financial conflict of interest with the present study.

Funding

Réseau de recherche en sécurité routière (RRSR), Société de l'assurance automobile du Québec (SAAQ), Fonds de recherche en santé du Québec(FRSQ) and Fonds de recherche du Québec – Société et culture (FRQSC) provided financial support through the 2012 Actions Concertées program (ref.: 2012-OU-14614). The sponsors had no role in the design or conduct of this research.

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.

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.

Informed consent

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

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trf.2018.12.015.

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