The association between obstructive sleep apnoea (OSA) and motor vehicle crash (MVC)-related injury: A population based study

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The aim of this study was to assess the crash risk for drivers with a diagnosis of obstructive sleep apnoea (OSA) using population based linked data. The presence of OSA predicted increased risk of injury crash in patients with untreated OSA, but neither severity of OSA nor subjective sleepiness were consistently associated with increased risk. The increased risk is higher for commercial drivers than all other drivers. Since OSA approximately doubles crash risk and close to half of commercial drivers have OSA, this study lends support to the recommendation that commercial drivers be screened for OSA and participate in fatigue management training. These findings will assist clinicians, road safety researchers and licensing authorities in improving driving outcomes for people with OSA.

Obstructive sleep apnoea; driving crash-related injury; sleepiness; drowsy driving

This report is disseminated in the interest of information exchange. The views expressed here are those of the authors and not necessarily those of Curtin University or Monash University.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIST OF TABLES</td>
<td>vi</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>ix</td>
</tr>
<tr>
<td>EXECUTIVE SUMMARY</td>
<td>x</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>xvi</td>
</tr>
<tr>
<td>1. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>1.1 Aims and objectives</td>
<td>1</td>
</tr>
<tr>
<td>2. LITERATURE REVIEW</td>
<td>2</td>
</tr>
<tr>
<td>2.1 Background</td>
<td>2</td>
</tr>
<tr>
<td>2.2 What is obstructive sleep apnoea (OSA)?</td>
<td>3</td>
</tr>
<tr>
<td>2.2.1 Symptoms and risk factors for OSA</td>
<td>3</td>
</tr>
<tr>
<td>2.2.2 Prevalence: How common is OSA in the community?</td>
<td>4</td>
</tr>
<tr>
<td>2.2.3 Descriptors for daytime sleepiness</td>
<td>5</td>
</tr>
<tr>
<td>2.2.4 Excessive daytime sleepiness, OSA and crash risk</td>
<td>6</td>
</tr>
<tr>
<td>2.2.5 How is fatigue defined in road safety research?</td>
<td>6</td>
</tr>
<tr>
<td>2.3 Drowsy driving: How do sleep-related factors contribute to crash risk?</td>
<td>8</td>
</tr>
<tr>
<td>2.3.1 Environmental features and nature of drowsy driving crashes</td>
<td>9</td>
</tr>
<tr>
<td>2.3.2 Obstructive sleep apnoea and motor vehicle crashes</td>
<td>10</td>
</tr>
<tr>
<td>2.3.3 Insufficient sleep as a risk factor for drowsy driving</td>
<td>11</td>
</tr>
<tr>
<td>2.3.4 Professional drivers at risk of a drowsy driving crash</td>
<td>12</td>
</tr>
<tr>
<td>2.3.5 Fitness to drive in OSA</td>
<td>13</td>
</tr>
<tr>
<td>2.4 Summary</td>
<td>14</td>
</tr>
<tr>
<td>3. METHODS</td>
<td>15</td>
</tr>
<tr>
<td>3.1 Study Design</td>
<td>15</td>
</tr>
<tr>
<td>3.2 Data Collection</td>
<td>15</td>
</tr>
<tr>
<td>3.2.1 Databases</td>
<td>18</td>
</tr>
<tr>
<td>3.3 Statistical Analysis</td>
<td>20</td>
</tr>
<tr>
<td>3.4 Ethics approval</td>
<td>20</td>
</tr>
<tr>
<td>4. RESULTS</td>
<td>21</td>
</tr>
<tr>
<td>4.1 Characteristics of the cohort</td>
<td>21</td>
</tr>
<tr>
<td>4.2 Motor Vehicle Crash-Related Injury</td>
<td>22</td>
</tr>
</tbody>
</table>
4.2.1 Commercial Drivers ................................................................. 23
4.3 Risk Factors for Crash Related Injury ........................................ 24

5. DISCUSSION .................................................................................. 26
5.1 Strengths and Limitations ............................................................. 29
5.2 Implications of findings ................................................................. 30
5.3 Summary and recommendations .................................................. 31

6. REFERENCES .................................................................................. 33
LIST OF TABLES

Table 2.1: Motor vehicle crashes in subjects with OSA: Linked data studies^ ..................... 11
Table 4.1: Characteristics of the study population (N=2909 all cases)................................. 21
Table 4.2: OSA severity within the study population........................................................... 21
Table 4.3: Crash rates per 100 person-years in OSA group by age group............................. 22
Table 4.4: Summary of commercial drivers by occupation................................................. 23
Table 4.5: Risk factors for injury crash in people with OSA: Results from Negative Binomial Regression analysis ................................................................. 25
LIST OF FIGURES

Figure 2.1: A model of fatigue ................................................................. 8
Figure 3.1: Flow diagram describing how the case sample was generated .......... 17
Figure 4.1: Crash rates per 100 person-years in OSA group by age group ........ 22
Figure 4.2: Crash rates per 100 person-years for commercial versus non-commercial drivers ................................................................. 23
EXECUTIVE SUMMARY

Introduction
Sleep disorders are a common source of daytime fatigue and sleepiness\(^1\) with OSA the most prevalent condition. A recent systematic review has estimated that OSA affects approximately 9% to 38% of the population,\(^2\) and it is expected that the prevalence of OSA will rise as the population ages and the levels of obesity increase.\(^3,4\) The direct health care costs of sleep disorders including OSA in Australia in 2010 were $274 million for care of the disorders themselves and $544 million to care for associated comorbidities.\(^5\) Indirect financial costs were $4251 million, of which motor vehicle crashes (net of health costs) accounted for $465 million.\(^5\) It is conservatively estimated that 15% to 20% of all motor vehicle crashes are due to fatigue.\(^6\) Not surprisingly, it is likely that these costs will increase.

A real-world consequence of the chronic excessive daytime sleepiness and impaired vigilance associated with OSA is impaired driving and possible involvement in motor vehicle crashes due to difficulty in concentrating, forgetfulness, poor decision making and falling asleep while driving.\(^1\) Unfortunately, drowsy driving crashes are also more likely to result in major injury or fatality for a variety of reasons including no attempt is made to brake, the person drives off the road or higher speeds associated with these types of crashes.\(^7\) However, the relationship between the degree of OSA, the level of daytime sleepiness and crash risk remains unclear. Some studies report an increased crash risk,\(^8\) while other studies have reported no relationship.\(^9\) However a large population based study with a well characterised OSA cohort could provide definitive evidence of an association between OSA and crash risk.

Therefore the aim of this study is to assess the crash risk for drivers with a diagnosis of (OSA) using population based linked data. We believe these findings will assist clinicians, road safety researchers and licensing authorities in improving driving outcomes for people with OSA which will have policy implications at the local, national and international level.

Specifically, the proposed research answers the following hypothesis:

\(H^0:\) OSA, self-reported sleepiness and the severity of sleep apnoea does not increase the risk for a crash related injury (hospitalisation or injury not requiring hospitalisation).

\(H^1:\) OSA, self-reported sleepiness and the severity of sleep apnoea does increase the risk for a crash related injury (hospitalisation or injury not requiring hospitalisation).
The specific objectives of this research are to:

1. Describe the incidence of sleep apnoea-related injury crash.
2. Establish if the presence and severity of sleep apnoea and excessive daytime sleepiness are independent risk factors for crash related injury in participants with a diagnosis of OSA.
3. Assess the association between a diagnosis of obstructive sleep apnoea (OSA) and involvement in a crash related injury as the driver in the five years prior to a diagnosis of OSA after accounting for potential confounders such as demographic characteristics (age, gender, body mass index), co-morbid medical conditions, environmental exposures and socio-economic status.
4. Develop evidence-based recommendations to improve safety for drivers with OSA.

**Method**

A retrospective population based cohort study was undertaken using linked data from the Western Australian Data Linkage System and The Western Australian Sleep Disorders Research Institute Cohort (WASDRI) from 2002 to 2010. The WASDRI data was based on a large consecutive cohort of patients (n=26,000) who were referred for overnight sleep studies at a Western Australian sleep clinic from 1988 to 2014. They were also part of the Western Australian Sleep Health Study (n=3500) which collected additional information on driving status and occupation. These datasets were then linked to the Hospital Morbidity Data Collection (HMDC) and the Insurance Commission of Western Australia (ICWA) Injury Claims data to identify those who reported a crash related injury (crash requiring medical attention or admitted to hospital). The final cohort obtained from the WASDRI database used in the analysis included 2909 individuals of which 192 did not have sleep apnoea with the remaining participants (n=2717) having a confirmed diagnosis of OSA. All participants had a current driving licence.

**Statistical Analysis**

Statistical analysis was based on a summary dataset containing demographic and clinical variables for each individual and information on the number of injury crashes occurring in the five year period prior to the diagnostic of OSA.
Descriptive and univariate statistics were employed to describe the characteristics of the group with and without OSA. The outcome of interest was involvement as the driver in motor vehicle crash that resulted in an injury (hospitalised and non-hospitalised injury crashes).

Generalised linear modelling was undertaken to determine the association between an injury crash for drivers with OSA in the five years before a diagnosis of OSA. The following potential confounders were accounted for; severity of sleep apnoea, Epworth sleepiness score, presence of co-morbid health conditions, demographic factors (age, gender, residential location and an area based measure of socio-economic status), body mass index (BMI, obesity is a known risk factor for OSA), history of smoking, number of years driving and whether they were a commercial driver. Co-morbidity was measured from the HMDS using the Multipurpose Australian Comorbidity Scoring System (MACCS) which identifies 102 comorbid conditions. The number of co-morbid conditions were grouped into four categories, ranging from nil to ≥ 5 comorbidities. Location based on postcode was classified as regional, remote and metropolitan. Socioeconomic status was measured using the Australian Bureau of Statistics SEIFA score of disadvantage which was divided into five categories ranging from most disadvantaged to least disadvantaged. Commercial driving status was identified from occupation.

Results

Characteristics of participants

- 2,909 participants had a confirmed diagnosis of sleep apnoea
- Participants were predominantly male (n=1719, 59%), middle-aged (51.1 ± 13.0 years), and obese (BMI > 30 kg/m²), with mean years of driving of 30.1 years (SD=13.0 years)
- For the whole cohort, the severity of OSA was moderate (median apnoea hypopnea index 25.7, IQR 13.4 to 49.0)
- The majority (n=2071, 70%) of participants had moderate to severe OSA. Only 6.6% (n=192) had nil OSA, and 22.2% (n=646) had mild OSA.
- 16.4% reported moderate to severe excessive sleepiness (ESS ≥ 16), and the mean Epworth sleepiness score (ESS) was 9.8 (SD=5.6)
Summary of motor vehicle crash-related injury

- 9.2% (n=251) of the 2717 people with OSA had an injury crash in the five years prior to their diagnosis
- Of these, 220 (8.1%) had one crash, 27 (1.0%) had two crashes and four (0.1%) had three crashes
- Of the 251 crashes, 22 (9%) crashes required hospitalisation and 229 (91%) crashes caused injury but the people were not hospitalized
- The overall injury crash rate in the sleep apnoea cohort was 2.19 per 100 person-years
- Females: Crash rate was highest in the youngest age group (17-35 years) and declined with age
- Males: Crash rate declined up until the 55-64 year age group and then increased in those aged 65+ years

Commercial Drivers

- The injury crash rate in commercial drivers (4.65 crashes per 100 person-years) was approximately double that seen in non-commercial drivers (2.19 crashes per 100 person-years)

Risk Factors for Crash Related Injury

- The majority of the cohort (90%, n=2430) lived in the metropolitan area, 61.3% (n=1665) were male and 60.5% were obese
- 192 (6.6%) of individuals had nil OSA (AHI < 5), were not considered suitable as healthy controls and were removed from the analysis
- Results of the multivariate analysis found a significantly increased risk of an injury crash in those;
  - with moderate OSA in comparison to those with mild OSA (Risk ratio 1.53, p=0.02),
  - in commercial drivers compared to non-commercial drivers (Risk ratio 2.65, p<0.0001), and
  - in those with 5 or more comorbid conditions compared to those without a comorbid condition (Risk ratio 1.45, p=0.05)
- Age: Those in the 45-54 year age group (IRR 0.54, p=0.03) and in the 55-64 year age group (IRR 0.41, p=0.008) had a decreased risk of crashing in comparison to those aged 17-34 years.
Summary
This study found an increased risk of injury crash in patients with untreated OSA, but neither severity of OSA nor excessive sleepiness were consistently associated with increased risk. The increased risk is higher for commercial drivers than all other drivers. A previous study in WA found that heavy vehicle drivers diagnosed with OSA were over three times more likely to be involved in a crash compared to other heavy vehicle drivers. There are particular challenges for long haul truck drivers in WA with multiple factors contributing to increased risk; short average sleep duration (less than 7 hours); a high prevalence of OSA among this group of drivers, long monotonous driving and driving at night (especially between MN and 0600). Heavy vehicles are overrepresented in road deaths in Australia, with 20% of worker fatalities that have occurred during the past decade being truck and heavy vehicle drivers. Future research should focus on screening of commercial drivers for OSA and participation in fatigue management training.

Recommendations
From the findings of this study the following recommendations are made:

1. **That this pilot study be strengthened by analysis of the larger WASDRI cohort (n=26541 linked cases), with identification of drivers licence status, linkage to property damage crash data and application for an age and sex-matched control group. This further research would allow more comprehensive investigation of risk factors that may predict increased risk of injury crash in drivers with OSA.**

2. **That a fitness to drive tool be developed to provide a more robust assessment of safe driving ability in people with sleep disorders. The current gold standard test is conducted in a sleep laboratory and does not replicate real-life driving situations.**

3. **That priority be given to an evaluation of the Code of Practice for Fatigue Management for Commercial Vehicle Drivers (2004), to ensure it is appropriate for contemporary industry practices and latest research findings.**

4. **That further education be directed to target the general driving community encouraging responsibility for sleep health awareness.**
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1. **INTRODUCTION**

Obstructive sleep apnoea (OSA) causes significant health, economic and societal burdens. A real-world consequence of the chronic excessive daytime sleepiness and impaired vigilance associated with OSA is driving impairment which may lead to a crash. However there is inconsistent information available about the impact of OSA on driving outcomes including crash risk. It is expected that the number of drivers with OSA will increase over the next decade therefore it is paramount that their safety and that of the public is maintained as they continue to drive on Australian roads. With an estimated cost of approximately $4.34 million per fatal crash and serious injury crashes costing approximately $239,000, the management of fatigue-related crashes including OSA in Australia has become an urgent priority17.

1.1 **Aims and objectives**

The aim of this study is to assess the crash risk for drivers with a diagnosis of obstructive sleep apnoea (OSA) using population based linked data. We believe these findings will assist clinicians, road safety researchers and licensing authorities in improving driving outcomes for people with OSA which will have policy implications at the local, national and international level. Specifically, the proposed research will answer the following hypotheses:

H0: *OSA does not increase the risk of a crash related injury.*

H1: *OSA increases the risk of a crash related injury.*

The specific objectives of this research are to:

1. Describe the incidence of crash related injury in drivers diagnosed with OSA.
2. Establish if the presence and severity of sleep apnoea and excessive daytime sleepiness are independent risk factors for crash related injury for participants with a diagnosis of OSA.
3. Assess the association between a diagnosis of obstructive sleep apnoea (OSA) and involvement in an injury crash as the driver in the five years prior to a diagnosis of OSA, after accounting for potential confounders such as demographic characteristics, commercial driving status, location of residence, socioeconomic level, smoking exposure and co-morbid medical conditions.
4. Develop evidence-based recommendations to improve safety for drivers with OSA.
2. LITERATURE REVIEW

This chapter presents a summarised review of the published literature on obstructive sleep apnoea (OSA), driving and crash related injury. The review begins with background information about obstructive sleep apnoea (OSA), a common sleep disorder. This is followed by a summary of the literature describing the symptoms of excessive sleepiness and fatigue and their relationship to drowsy driving. Finally the relationship between OSA, driving and crash risk is examined.

2.1 Background

In 2015, 1209 people were killed on Australian roads and approximately 22,000 were seriously injured.¹⁸ The total economic cost for motor vehicle crashes is estimated to be in excess of $27 billion per year.⁵ Sleepiness at the wheel is the main cause for about 20% of all motor vehicle crashes,¹⁹ making it one of the largest identifiable causes of crashes. There is increasing recognition that sleep issues have a role to play in contributing to the road toll.²⁰

The most common medical cause of excessive daytime sleepiness (EDS) is obstructive sleep apnoea (OSA), a common breathing disorder of sleep that affects approximately 5 to 14% of the population.²¹ These symptoms of sleepiness and inattention mean that individuals with OSA may have an increased risk of involvement in a motor vehicle crash (MVC).²² Previous research found that drivers with OSA are two to seven times more likely to have a motor vehicle crash than those without sleep apnoea.²² Obesity is present in about 70% of subjects with OSA²³,²⁴ and has contributed to the rising prevalence of OSA²¹ and associated obesity-related crash risk over the past two decades.²⁵

A real-world consequence of the chronic excessive daytime sleepiness and impaired vigilance associated with OSA is driving difficulties.¹ The cognitive deficits seen in untreated OSA patients are reflected in patient’s reporting of difficulty concentrating, forgetfulness, poor decision making and falling asleep driving.²⁶ These cognitive changes affect tasks of daily living, as well as the potential higher risk of involvement in a motor vehicle crash.²⁷ Road trauma has increased over the past two years in the United States (US), Australia and New Zealand (NZ), however fatalities had been falling from 2011 onwards.²⁸ Over the same time frame, serious injuries have steadily risen. Road crashes are a leading cause of morbidity and mortality worldwide and predicted to be the fifth leading cause of death in 2030.²⁹ Given the
increased prevalence of both OSA and inadequate sleep in society, drowsy driving crashes are a likely contribution to the rising fatal and serious injury crashes globally.\textsuperscript{21,30}

2.2 What is obstructive sleep apnoea (OSA)?
Obstructive sleep apnoea is a common condition characterised by repeated episodes of closure of the upper airway during sleep.\textsuperscript{31} The body responds to obstructed breathing with reduced blood oxygen saturation and brain arousal from sleep.\textsuperscript{32} These repeated episodes of airway closure result in fragmented and non-refreshing sleep.\textsuperscript{32} The severity of OSA is usually quantified by the apnoea hypopnoea index (AHI), which is the total number of apnoeas and hypopnoeas per hour of sleep. A value of 5 or more breathing pauses (events/hour) is used to define OSA.\textsuperscript{33}

OSA is diagnosed by an overnight sleep study either in a laboratory or at home. The symptom of excessive daytime sleepiness is common in OSA but does not have to be present.\textsuperscript{33} Sleepiness may present as daytime fatigue or impaired concentration, both of which may impair driving, but would not necessarily result in an elevated sleepiness score. There is often a mismatch between the number of breathing pauses (AHI) and arousals and the degree of excessive daytime sleepiness. This suggests that sleepiness, in part, is independent of the number of breathing pauses and that other factors may play a role.\textsuperscript{34}

2.2.1 Symptoms and risk factors for OSA
Common indicators of OSA are snoring, witnessed apnoea, high blood pressure, frequency of urination overnight (nocturia) and daytime sleepiness.\textsuperscript{35} The risk factors most strongly related to OSA are obesity, male gender and advancing age.\textsuperscript{2,36-38} OSA affects up to 10\% of the middle-aged population and up to 50\% of adults over age sixty.\textsuperscript{21,39} Almost all OSA subjects snore\textsuperscript{40,41} and the most common complaint is daytime sleepiness or fatigue.\textsuperscript{40,42,43} Of particular relevance to crash risk are the signs and symptoms related to excessive sleepiness since this component of OSA has been identified as an important health-related risk in both private and commercial transportation.\textsuperscript{44-47}

Aside from sleepiness, several daytime symptoms relate to a facet of cognitive function that may contribute to crash risk; waking unrefreshed, drowsiness while driving, cognitive deficits, fatigue, lack of concentration and changes in mood.\textsuperscript{35} Aside from the obvious symptomatic
benefit to the patient when diagnosed and treated for OSA, it is important for the clinician to be able to identify at-risk sleepy individuals expeditiously, ideally at first presentation.48

2.2.2 Prevalence: How common is OSA in the community?

Epidemiological studies of OSA have revealed a high prevalence of undiagnosed sleep-disordered breathing in the general community,2,49 presenting a significant public health problem.50-52 OSA is most prevalent in males aged between 30 and 70 years, but occurs in all ages and both genders. Prevalence in men is double that of women, but post-menopause values for women are similar to men. Overall, OSA prevalence increases with age but plateaus in those aged 65 years and older.53

In the early 1990s the prevalence of OSA with sleepiness was reported in 2% of women and 4% of men, while OSA without sleepiness was found in 9% of women and 24% of men.54 This data was collected in the Wisconsin Sleep Cohort Study (WSCS), a longitudinal study of middle-aged adults, and similar values were verified in other populations in the US55,56 and Spain.57 There was concern about this large undiagnosed population in the community,49,50 due to the size of the problem and the proportion of people without overt symptoms. Although the clinical significance of OSA without overt symptoms is controversial, many studies have shown adverse health outcomes are associated with OSA regardless of the presence of daytime sleepiness.52,58 There is also increased likelihood of high blood pressure, heart disease, stroke, daytime sleepiness, motor vehicle crashes and decreased quality of life.52,58.

The most recent systematic review of the prevalence of OSA in the general population reported wide variation but a high prevalence overall. At an AHI of ≥5 events/hr, the overall population prevalence ranged from 9% to 38% and was higher in men.2 With respect to prevalence estimates in the Australian community, the Busselton Health Study commenced a longitudinal collection of sleep data in 1990.59 In Busselton, Western Australia, the prevalence of OSA has been estimated as follows; (i) in 1990 at 4.7% in men,59 (ii) in 2007 at 12.4% in men and 5.7% in women49 and (iii) in 2015 at 15.2% in men and 5.2% in women for OSA in participants without known OSA.60 Over the past 25 years the prevalence of OSA has increased in Busselton and is substantiated with the updated prevalence data for Wisconsin (13% of men, 6% of women).21 The most likely explanation for this increase is the ongoing obesity epidemic,21 since obesity is a strong causal factor for sleep-disordered breathing.
There is also strong evidence from an expanding number of epidemiological studies that untreated OSA is common in the community, with an increasing prevalence worldwide. The implication for road safety relates to the findings from several studies that people with OSA have higher motor vehicle crash rates, based on crash records as well as self-report information and poor performance on driving simulators.\textsuperscript{8,9,61} The excessive daytime sleepiness and reduced cognitive functioning secondary to OSA are also likely candidates for the increased risk of motor vehicle crashes.\textsuperscript{26} Driver sleepiness is one of the largest identifiable causes of motor vehicle crashes,\textsuperscript{62} but the sleepiness may stem from sources apart from sleep disorders such as lack of sleep or time of day. Sleepiness is difficult to measure, and many different terms are used to describe the phenomenon of sleepiness. The following section summarises some of the issues surrounding sleepiness descriptors.

2.2.3 Descriptors for daytime sleepiness

Many different terms have been used to describe the phenomenon of sleepiness in the scientific and road safety literature. The two most common are “excessive sleepiness” and “fatigue”. Multiple terms have arisen because not all sleepy individuals describe their symptoms as sleepiness \textit{per se}, but rather as a consequence of sleep loss such as fatigue, loss of energy, lethargy, weariness, memory lapses, lack of initiative, or difficulty concentrating.\textsuperscript{63-65} In clinical practice the term excessive sleepiness is defined “as a heightened propensity to fall asleep while involved in activities that require alertness”.\textsuperscript{66,67}

Certain terminology is favoured in specific research domains, such as occupational health and safety. With respect to the link between fatigue and safety, a recent literature review favoured the term fatigue, simply defined as “a biological drive for recuperative rest”.\textsuperscript{68} However fatigue may take several forms including sleepiness and mental, physical and/or muscular fatigue depending on the nature of its cause.\textsuperscript{69} In 2005 Philip \textit{et al.} presented a distinction between fatigue and sleepiness, based upon work by Grandjean;\textsuperscript{70} “Fatigue increases with sustained activity and can be eliminated with rest but not necessarily sleep, whilst sleepiness is the subjective need to sleep that cannot be eliminated through rest from activity alone.”\textsuperscript{69} Thus sleep is required to alleviate sleepiness, but will not necessarily relieve fatigue. In this review the term excessive sleepiness is used to define the physiological problem of disabling sleepiness in relation to the sleep disruption due to the medical condition of OSA.
2.2.4 Excessive daytime sleepiness, OSA and crash risk

The most common daytime symptom in OSA is excessive daytime sleepiness.⁴⁰ OSA is the second most common cause of excessive daytime sleepiness aside from insufficient sleep, but not all OSA subjects report this symptom.⁶⁶ Self-perceived excessive sleepiness is absent in more than half of individuals with OSA, even among those with severe OSA.²¹,⁷¹ There is a poor correlation between sleepiness symptoms and OSA severity (as measured by the number of breathing pauses).³ This poor correlation is partially due to the difficulty of measuring sleepiness accurately. Thus OSA can be present without overt sleepiness, and symptoms may be represented by another “fatigue” descriptor, such as fatigue or tiredness.⁵⁴,⁷² Many of the neurobehavioural deficits associated with OSA (such as reduced attention, concentration, vigilance, manual dexterity and visual motor skills) have important impacts on driving ability and as such have been extensively investigated.²⁶ An important unresolved question is whether people with OSA but without overt sleepiness are at increased motor vehicle crash risk.⁷³

It has long been recognised that chronic excessive daytime sleepiness can be ignored by subjects simply because of an inability to distinguish normal from abnormal.⁷⁴ This phenomenon of under-reported sleepiness in OSA subjects (especially prior to treatment) was first noted by Dement in 1981.⁷⁵ It has been attributed to a loss of the normal frame of reference for alertness as a result of prolonged excessive sleepiness. It has also been suggested that the internal calibration of feeling ‘refreshed’ was gradually reset over many years of untreated OSA.⁶⁵,⁷⁵ This is particularly evident in cases where excessive daytime sleepiness is denied at presentation, but a successful trial of treatment resets the baseline of refreshing sleep and perception improves.⁶⁵,⁷⁴ Further evidence of adaptation to chronic sleepiness in OSA is found in the results from laboratory-based sleep deprivation studies in healthy subjects. After one night of sleep deprivation alert individuals were able to accurately estimate their sleepiness, in contrast to OSA subjects.⁷⁶

2.2.5 How is fatigue defined in road safety research?

Fatigue is a form of driver inattention and a noted risk factor for crash involvement and resulting injury.⁷⁷ There has been considerable focus on fatigue though it is sometimes interchangeably referred to as drowsiness, sleepiness or tiredness.⁷⁸-⁸⁰ In the road safety context, fatigue is defined by the biological drive for recuperative rest; it may not be observable but can produce measurable effects.⁶⁸ Fatigue impacts on the likelihood of drivers committing errors, the
magnitude of errors committed, and the variability of the errors\(^{81}\) which combined can increase crash risk.\(^{68,81}\)

Unfortunately ‘fatigued’ or ‘drowsy driving’ is increasingly common especially among driver groups such as long distance truck drivers\(^{81,82}\) and younger age drivers.\(^{81}\) Other community surveys of self-reported drowsy driving (without crashing) have produced varying estimates, ranging from 11% of US drivers\(^{83}\) to 25% of French drivers\(^{84}\) in the preceding 12-months, and 69% in the preceding five years for a sample of over 1,500 Australian drivers.\(^{85}\)

Despite fatigue or sleepiness being widely acknowledged as a contributing factor in motor vehicle crashes, there is limited evidence from population-based investigations to quantify the magnitude of the problem, particularly in Australia.\(^{86}\) There is a problem estimating the incidence of fatigue among crash involved drivers because of the lack of objective, measureable biological evidence unlike when considering other potential causes of driver impairment such as alcohol or illicit drugs.\(^{87}\) At present there is no universally accepted, standardised operational definition to support the valid and reliable determination of fatigue among crash involved drivers.\(^{68,80,88}\)

### 2.2.5.1 Model of fatigue

The fatigue condition is complex and represents more than just a tendency to ‘fall asleep’.\(^{89}\) A model of fatigue has been developed by May and Baldwin to account for the various causal factors that contribute to driving performance decrements and crash risk (Figure 2.1).\(^{90}\)
The fatigue model has three components, two of which are driving task-related (TR) and the third sleep-related (SR). As depicted in Figure 3.1, the driving task is proposed to be a cause of fatigue if it either overloads (Active Task Related Fatigue) or under stimulates (Passive Task Related Fatigue) the driver in relation to demands. Importantly, both active and passive task-related fatigue can worsen sleep-related fatigue (see Figure 2.1).

The focus of this project is the sleepiness and cognitive impairment caused by OSA and as such, the following section will address drowsy driving in relation to sleep loss. A real-world consequence of the chronic excessive daytime sleepiness and impaired vigilance associated with OSA is driving difficulties.

2.3 Drowsy driving: How do sleep-related factors contribute to crash risk?

Drowsy driving is an important contributor to motor vehicle crashes and fatalities, with sleepiness accounting for up to 20% of crashes on monotonous roads, especially highways. Driving is a complex task undertaken by most people on a daily basis demanding perception, judgement and adequate response time. It is an applied task requiring attention and vigilance,
both of which are impaired by insufficient or poor quality sleep. Thus, an important outcome of inadequate sleep is driver sleepiness and an increased risk of involvement in a crash. Estimates of the proportion of crashes attributable to driver sleepiness vary tenfold from 1 to 3% in the US,\textsuperscript{46} to 20% in NZ\textsuperscript{91} and 30% in Australia.\textsuperscript{92}

In the US, self-reported drowsy driving is regularly surveyed and the prevalence of it has ranged from 51% of respondents to a peak of 60% in the 2005 National Sleep Foundation poll.\textsuperscript{93} Self-reported falling asleep while driving were also high, with 13% of respondents reporting an episode at least once per month.\textsuperscript{93} Those who reported snoring (suggestive of OSA) or usually sleeping $\leq 6$ hours per day were also more likely to report falling asleep while driving. In a recent sleep health survey conducted in Australia, driving while drowsy at least every month was reported by 29% of participants, 20% have nodded off while driving, and 5% have had a crash in the past year because they dozed off.\textsuperscript{30} Thus these trends of drowsy driving suggest that the public health burden of sleepiness-related crash/injury is likely increasing.

2.3.1 Environmental features and nature of drowsy driving crashes

It remains a challenge to accurately ascribe driver sleepiness as the cause of a crash due to the lack of easily applied onsite measurement tools for sleepiness. However, there are distinct patterns to sleep-related crashes by type of crash and time of day. Sleep-related crashes are more likely to occur mid-afternoon and at night, when drivers are sleepy.\textsuperscript{94} In addition, drowsy driving crashes often involve a single vehicle leaving the road, with no evidence of braking.\textsuperscript{94} Rear-end and head-on crashes are also likely to be sleep-related.\textsuperscript{95} Finally, drowsy driving resulting in a motor vehicle crash is more likely to result in major injury or fatality since no attempt is made to brake.\textsuperscript{7} Mulgrew \textit{et al.} were the first group to demonstrate the greater impact of OSA on crashes involving injury, postulating that sleepiness-related crashes may be related to failure to brake, driving off the road or higher speeds.\textsuperscript{91,94} Identification of these features of drowsy driving crashes has contributed to the estimation that fatigue and sleepiness may account for up to 20% of MVCs in the general population.\textsuperscript{91}
2.3.2 Obstructive sleep apnoea and motor vehicle crashes

Obstructive sleep apnoea is the most common sleep disorder that causes excessive daytime sleepiness,\(^{48}\) and is thus a risk factor for both drowsy driving and fall-asleep MVCs. It has been heavily researched with respect to MVCs due to the high prevalence of OSA among professional drivers (ranging from 26 to 50\%).\(^{74,96}\) Recently Meuleners et al. found that heavy vehicle drivers with a diagnosis of OSA were over three times more likely to be involved in a crash compared to other heavy vehicle drivers in Western Australia (WA).\(^{12}\) In addition, many OSA patients report sleep-related crashes and near-misses to their clinicians, raising obvious concern.\(^1\)

Research in both clinical cohorts of OSA patients\(^{22}\) and community-based samples of drivers\(^{97}\) found that OSA is associated with a two to three times increased risk for motor vehicle crashes. A meta-analysis examining impairment and crash risk associated with ageing and disease found that OSA had the highest relative risk [RR: 3.71 (95% CI: 2.1, 6.40), \(p < 0.001\)] of all conditions considered.\(^{98}\) There have been two systematic reviews of OSA and driving risk, the most recent being commissioned in the US to assist with the development of guidelines and standards for commercial motor vehicle drivers.\(^{9,99}\) It was confirmed that the mean crash rate ratio associated with OSA is likely to fall in the range of 1.21 to 4.89, however prediction of risk in an individual is imprecise.\(^9\) Not all patients have crashes, and as many as two thirds may never have a crash.\(^{100}\) Thus identifying those people with untreated OSA at greatest risk remains a challenge, and is further heightened because crashes put lives other than the driver with OSA at risk.

The systematic review by Tregear et al. assessed the role of disease severity and daytime sleepiness and found that the risk of a crash for drivers with OSA was associated with increased sleepiness in half of the studies reviewed.\(^{99}\) However, the relationship between the degree of OSA (as measured by the apnoea hypopnoea index (AHI)), the level of daytime sleepiness (as measured by the Epworth Sleepiness Score (ESS)) and crash risk remains unclear. Some studies report an increased crash risk with high ESS\(^{101-103}\) and AHI scores,\(^{99,100}\) while other studies have reported no relationship.\(^7,9,22\) Studies by Mulgrew et al.\(^7\) and Shiomi et al.\(^{104}\) found that even low AHI scores (indicative of mild OSA), were associated with an increased crash risk. However, a recent Swedish study strengthened the evidence for an elevated crash risk for individuals with OSA by using an objective measure of a crash (police reports), assessing crash risk using both prospective and retrospective techniques and comparing the OSA cohort to a non-OSA cohort.\(^{105}\) Disease severity (AHI) did not predict crash risk, but severe excessive
daytime sleepiness (ESS ≥16), short habitual sleep time (≤ 5h/night) and the use of hypnotics were associated with an increased crash risk. An important novel finding was that therapy (continuous positive airways pressure [CPAP]) use ≥ 4h/night was associated with a reduction in crashes, confirming the results of a CPAP therapy meta-analysis.

Several studies of undiagnosed OSA and objectively measured motor vehicle crashes (police report) also suggest a strong association (see Table 2.1), with odds ratio for a crash ranging from 1.97 to 8.1 (95% CI 1.2 to 26.5). Although the data from these population studies does support undiagnosed OSA in crashes as a risk factor, it should be noted that the confidence intervals for the odds ratios are wide. Neither severity of OSA nor self-assessed sleepiness was consistently associated with increased crash risk. The lack of finding sleepiness as an explanatory variable is concerning since it suggests that drivers with OSA may not perceive performance impairment and so not take precautions when driving.

Table 2.1: Motor vehicle crashes in subjects with OSA: Linked data studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Clinic patients (Y/N)</th>
<th>No of subjects#</th>
<th>Odds ratio (95% CI) for MVC</th>
<th>Mean Crash Rate # (no/driver/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young 1997</td>
<td>N</td>
<td>913 (221)</td>
<td>3.4 (1.4 to 8.0)</td>
<td>0.049*</td>
</tr>
<tr>
<td>Barbe 1998</td>
<td>Y</td>
<td>60</td>
<td>2.3 (0.97 to 5.33)</td>
<td>0.18 (0.03)*</td>
</tr>
<tr>
<td>Teran-Santos 1999∆</td>
<td>N</td>
<td>254 (29)</td>
<td>8.1 (2.4 to 26.5)</td>
<td>NA</td>
</tr>
<tr>
<td>George 1999</td>
<td>Y</td>
<td>1163 (582)</td>
<td>1.9 (1.5 to 2.2)</td>
<td>0.09 (0.14)</td>
</tr>
<tr>
<td>Mulgrew 2008</td>
<td>Y</td>
<td>783 (643)</td>
<td>1.9 (1.2 to 2.8)^</td>
<td>0.12 (0.23)*</td>
</tr>
<tr>
<td>Karimi 2015</td>
<td>Y</td>
<td>1478</td>
<td>2.45^</td>
<td>NA</td>
</tr>
</tbody>
</table>

^ Modified from George 2004; # Number with apnoea/hypopnoea index (AHI) ≥5 shown in parentheses; # Numbers in parentheses represent ± SD; *calculated; ∆ Case-control study; ^Relative Risk; NA = not available; MVC = motor vehicle crash; CI = confidence interval.

2.3.3 Insufficient sleep as a risk factor for drowsy driving

Drowsy driving can be due to the excessive sleepiness associated with untreated sleep disorders. However sleep deprivation, circadian rhythm changes due to shift work, fatigue, sedating medications and consuming alcohol when tired also contribute to drowsy driving risk. Of the several risk factors for drowsy driving, the greatest is likely to be sleep loss due to insufficient or poor quality sleep. The scale of sleep loss in society has been
investigated over the past 30 years by annual sleep health polls (since 1991) in the US, and more recently in Australia. Evaluation of sleep habits has shown that frequent sleep difficulties, daytime fatigue, sleepiness and irritability are highly prevalent (20 - 35%) in society. Since drowsiness slows reaction time, causes inattention and impairs decision making, there is a clear mechanism for sleep loss to contribute to increased crash risk.

The most common contributors to fall-asleep crashes are working multiple jobs, night shift work and sleep duration of less than 5 hours, all of which are linked to insufficient sleep. In broad terms, the sleepiness contributing to drowsy driving can be caused by societal factors (such as work schedules, round-the-clock access to technology and family responsibilities), environmental influences (sedating medications and alcohol), untreated sleep disorders, or a combination of these factors. Since OSA is the most common of the sleep disorders and is highly prevalent among truck drivers, the relationship to drowsy driving and crashes has gained increased attention as discussed in the following section.

2.3.4 Professional drivers at risk of a drowsy driving crash

Heavy vehicles are overrepresented in road deaths, with 20% of worker fatalities that have occurred in Australia during the past decade being truck and heavy vehicle drivers. There has been particular focus on commercial drivers since the prevalence, severity and public health impact of crashes involving commercial vehicles is high. Long-haul commercial drivers are especially vulnerable to drowsy driving due to short average sleep duration (less than 7 hours) and a high prevalence of OSA among this group of drivers. In the US in 2009, there were 1,547,797 police-reported motor vehicle crashes resulting in an injury or fatality, of which 63,197 involved large trucks and buses. Of the single-vehicle heavy truck crashes, 18% of involved drivers admitted to having fallen asleep behind the wheel, with 50% assessed as fatigue-related. In 2009, the cost of commercial motor vehicle crashes was estimated at US$7,200,000 for a fatal crash and US$331,000 for an injury crash. In Australia in 2011, the federal government estimated that road trauma cost our economy $27 billion per year, a serious impact on our productivity. Thus both the human and economic cost of motor vehicle crashes is high and unfortunately increasing.

Over the past 10 years, several studies have been conducted in commercial drivers to establish the prevalence of OSA. Commercial drivers are vulnerable to the development of OSA due to the sedentary nature of the work, irregular work shifts, monotonous long-hours of driving and poor access to healthy food on shift, all factors that contribute to obesity. In Australia,
Howard et al. found that 60% of commercial motor vehicle (CMV) drivers had sleep disordered breathing and 24% were excessively sleepy. Most studies have found a much higher prevalence of OSA in CMV drivers than the general population (5%). A study of heavy vehicle drivers diagnosed with OSA found they were over three times more likely to be involved in a crash compared to other heavy vehicle drivers in WA. A study of truck drivers in Brazil also reported a prevalence of risk of 11.5%. Further work in Australia with long-haul truck drivers has demonstrated that 41% of 517 participants were likely to have OSA. A recent report by the National Truck Accident Research Centre (2015) noted that Queensland followed by Western Australia was the worst performing jurisdiction in Australia for major truck crashes. In 2013 Western Australia evidenced the highest proportion of crashes attributed to fatigue (30%). Taken together most studies examining the presence of OSA in commercial drivers have reported a prevalence in the range of two to six times that of the general community. This data highlights the need to assess for OSA risk in all patients who drive professionally.

2.3.5 Fitness to drive in OSA

For most people, driving is an essential part of modern life. A survey of OSA patients attending sleep clinics in the UK found that 82% held a current driving licence, 62% drove a vehicle, and 22% drove for a living (or held a commercial motor vehicle licence [16%]). Thus an important role for sleep clinicians is the assessment of driving risk. Several international guidelines help determine fitness to drive in both private and commercial drivers, providing specific guidance regarding management of excessive sleepiness and OSA. High-risk drivers are defined as those with severe daytime sleepiness (an ESS score $\geq 16$) and a history of motor vehicle crashes or near-misses caused by inattention or sleepiness.

Current Australian fitness to drive guidelines (Assessing Fitness to Drive: for commercial and private drivers) recommend that sleepy individuals should be advised to avoid or limit driving, and not drive at all if they are considered as high risk. Sleepy drivers and those with suspected OSA should be referred to a sleep specialist for evaluation and treated. However there is no compelling evidence to restrict driving in OSA patients when there has not been a crash or equivalent event, since studies suggest up to two-thirds of drivers do not have a crash.

OSA is highly prevalent among commercial motor vehicle drivers, and as such screening for OSA has been promoted for this group. Since OSA is treatable and treatment reduces crash risk, the potential benefits of OSA screening in commercial motor vehicle drivers...
are high. Substantial effort over the past 10 years has led to the development of a more consistent framework to manage OSA screening, testing and treatment of commercial motor vehicle drivers.\textsuperscript{127} In 2008 portable sleep monitoring was approved partially on the basis to provide better access to diagnostic testing.\textsuperscript{116} Although the guidelines in place are provided for commercial drivers, private drivers have the same risk, so expeditious diagnosis and treatment of OSA is equally important in this group.\textsuperscript{48} The challenge for sleep physicians and road safety professionals is the management of crash risk, since prediction of risk in an individual is imprecise. This study has the potential to characterise OSA risk factors that may predict increased risk of driving crash-related injury in people with sleep apnoea.

2.4 Summary

Driving is a complex task requiring alertness, vigilance, complex higher cortical function and motor skills. The most obvious cause for impaired driving in OSA patients is excessive daytime sleepiness, but the literature is inconsistent.\textsuperscript{128} Recent data from neuroimaging techniques have shown significant changes to brain structure and metabolism in OSA patients.\textsuperscript{129} Thus the effects of neural, cognitive and daytime functional impairments, in addition to excessive daytime sleepiness, may contribute to increased risk of motor vehicle crashes in OSA.\textsuperscript{26,128}

One of the major concerns with drowsy driving crashes is that they result in more severe injury or death due to the fall-asleep nature of the crash as no attempt is made to brake.\textsuperscript{7} Sleep disorders, especially OSA are highly prevalent in the community.\textsuperscript{58,130} Sleep loss, sleep disorders, and shift work cause impaired alertness, which adversely affects performance and safety.\textsuperscript{130} OSA is associated with increased crash risk\textsuperscript{9} but not all people with OSA crash. Neither sleepiness nor severity of OSA consistently predict increased risk of crash.\textsuperscript{73} There is a high prevalence of OSA among commercial drivers so particular interest has been paid to this group as truck and bus crashes are calamitous, expensive and impact on the public.\textsuperscript{14} There is an imperative to better understand the nature of the increased driving risk associated with OSA. This would help identification of those at particular risk so that targeted preventative measures can be implemented.\textsuperscript{131}
3. METHODS

3.1 Study Design

A retrospective population based cohort study was undertaken using linked data from the Western Australian Data Linkage System (WADLS) and the Western Australian Sleep Disorders Research Institute Cohort (WASDRI) from 2002 to 2010. The WASDRI data was from a large consecutive cohort of patients (n=26,000) who were referred for overnight sleep studies at a Western Australian sleep clinic from 1988 to 2014 (referred to as the WASDRI cohort)\textsuperscript{132}.

3.2 Data Collection

This study relies on the analysis of data from existing administrative health databases (WADLS) and a customised sleep database (WASDRI). The WADLS was established in 1995 and is one of only a small number of comprehensive, whole population data linkage systems in the world. It constitutes a powerful source for conducting health services and outcomes research on an entire population within an Australian setting. Previous studies involving linked administrative health data by members of the research team have demonstrated enormous potential to investigate disease aetiologies, identify factors influencing health, and utilisation of health services.\textsuperscript{133, 134}

The main advantages of this approach are:

1. It is far more time and cost-effective than studies relying on primary data collection and data entry.
2. It avoids problems that result when individuals are lost to follow-up, thereby providing advantages over other prospective research designs in terms of identifying clinical populations and ensuring adequate sample size.
3. Privacy of the medical and health records is fully protected and research is only permitted on totally de-identified data, as probabilistic matching techniques will be used for the linkage adhering to “best-practice” guidelines.
3.2 Data Sources

3.2.1 Identification of the study population with OSA and those without OSA

The WASDRI database contains information on those who have a diagnosis of OSA and those referred to the clinic but who were found not to have a diagnosis of OSA. Further information was collected on a subset of this cohort, including possession of a current driving licence and driving exposure which was available from the West Australian Sleep Health Study (WASHS) cohort. These datasets were linked to the Hospital Morbidity Data Collection (HMDC) and the Insurance Commission of Western Australia (ICWA) Injury Claims Data to identify those who sustained an injury related crash (hospitalised due to a crash or injured but not hospitalised due to a crash).

The final cohort obtained from the WASDRI database who were retained for the analyses were 5149 individuals (Figure 3.1). Of this group 4666 participants (91%) were confirmed to be drivers with a current valid driving license. Individuals whose age was invalid when licensed were excluded (n=397), leaving 4,269 participants. A further 607 individuals were excluded due to missing clinical data (n=3662). Those without a matching root number (for linked data) were excluded (n=263). Finally, those older than 75 years and/or with <10 years driving experience were excluded, and of the remainder, individuals were included if their questionnaire data was collected within 2 years of their diagnostic sleep study (n=490 excluded). This left 2909 people of which 192 did not have sleep apnoea and 2717 people did have a confirmed diagnosis of OSA (Figure 3.1).
Figure 3.1: Flow diagram describing how the case sample was generated

*WASHS, WA Sleep Health Study; # PSG, polysomnography (sleep study)
3.2.1 Databases

*The West Australian Sleep Disorders Research Institute (WASDRI) Database:*

The WASDRI database includes all patients who underwent sleep studies from January 1989 to December 2016. The WASDRI database is the largest sleep cohort database nationally and internationally. It consists of longitudinal data of patients from both metropolitan and rural regions attending the only public sleep clinic in WA. The database contains approximately 30,000 polysomnography (PSG, sleep study) records for around 27,000 patients. The diagnosis of OSA is confirmed by scoring the sleep study to generate the apnoea hypopnoea index (AHI). This is defined as the number of apnoeas and hypopnoeas recorded per hour of sleep. The AHI represents an index of sleep disruption. The severity of OSA is defined according to the following AHI categories: ‘normal’ (AHI <5); ‘mild OSA’ (AHI >=5 and less than 15 events per hour); ‘moderate OSA’ (AHI>=15 and < 30 events per hour); and ‘severe OSA’ (AHI>= 30 events per hour). The Epworth Sleepiness Scale (ESS) was also administered to all participants. It is an eight point instrument that assesses the likeliness of dozing in passive and active day time situations. It is used as a proxy measure of daytime sleepiness. It produces a score between 0 (least sleepy) to 24 (most sleepy) with excessive sleepiness >= 16, sleepy >=10 and <=15; and not sleepy <10.

The WASDRI database also contains detailed information on age, gender, BMI, neck circumference, oxygen saturation, time spent with oxygen saturation < 90%, arousal index, sleep behaviour, smoking history, physical activity, consumption of alcohol and caffeinated drinks, comorbid conditions, medications, blood pressure, treatment information, and the number of years driving.

*West Australian Sleep Health Study (WASHS) cohort:*

The WASHS is a prospectively collected sample of well-characterized OSA patients collected from late 2005 to mid-2010 who were reviewed at the West Australian Sleep Disorders Research Institute (WASDRI). In addition to sleep and other routinely collected clinical data, this database contains a self-reported questionnaire and blood-derived data (biochemistry and genetic). The WASHS study recruited all new consenting patients referred to WASDRI for a presumed sleep disorder, the majority for snoring and/or OSA (91%). Within the questionnaire (n=55 questions), information has been collected on sleep behaviour, driving history, physical activity, alcohol consumption, smoking history, family and past medical history and co-
morbidity of OSA (such as hypertension, diabetes, and cardiovascular outcomes). Sleep physicians use this questionnaire as their primary clinical tool to obtain clinical information to assist in the diagnosis of sleep disorders. Measurements of variables predictive of OSA were made and include height, weight, body mass index, neck circumference and crowding of the upper airway (using visual scales of Mallampati score and oropharyngeal grade). Questionnaire data is subsequently stored as part of the patient’s medical record for future reference.

**Hospital Morbidity Data Collection (HMDC):**
This is one of the core datasets of the WADLS and comprises details of all hospital (public and private) admissions since 1970. This data was used to identify those involved in a motor vehicle crash that resulted in a hospitalisation. Participants were defined as being hospitalised for an injury due to a motor vehicle crash as the driver if the primary diagnosis was an injury coded between S00.0 to T98.3 (Chapter XIX, ICD-10-AM) and a primary external cause code for a motor vehicle crash (V10-V79, V83-V86) in their hospital records. Drivers were identified by the fifth digit of the ICD code. This is either 0 or 4 for codes V10-V29 and 0 or 5 for codes V30 onwards. Records where the injured person was not specified were also selected, but only used if they matched an Insurance Commission of WA record which specified the injured person was the driver. These records were those with a fifth digit of 2 or 9 for codes V10-V29 and 3 or 9 for codes V30 onwards.

**Insurance Commission of Western Australia (ICWA) Injury Claims Data:**
The Insurance Commission of WA is the sole compulsory third party Insurer for submitting a claim due to motor vehicle personal injuries in WA. The Insurance Commission of WA database contains crash information for individuals who submit claims for compensation following a crash in which they were injured and required medical treatment. This may include crashes resulting in hospitalisation or non-hospitalised injury. Crash information includes the data and location of the crash, whether the injured person was a driver, passenger, cyclist or pedestrian, vehicle type, type of crash, nature and severity of injury and nature of the compensation.

The final dataset used in the analysis was created from the above four datasets. This dataset contained demographic and clinical variables for each individual as well as information on the number of crashes occurring in the five year period prior to the diagnosis of OSA taking place.
3.3 Statistical Analysis

Descriptive and univariate statistics were employed to describe the characteristics of the cohort with and without OSA. The outcome of interest was involvement as the driver in a motor vehicle crash that resulted in an injury (hospitalised and non-hospitalised injury crashes).

Generalised linear modelling with a negative binomial distribution was undertaken to determine the association between a crash for drivers with OSA in the five years before a diagnosis of OSA after accounting for potential confounders such as severity of sleep apnoea, Epworth sleepiness score, presence of co-morbid health conditions, demographic factors (age, gender, residential location and an area based measure of socio-economic status), BMI (obesity is a known risk factor for OSA), history of smoking, number of years driving and whether they were a commercial driver or not. Co-morbidity was measured from the HMDC using the Multipurpose Australian Comorbidity Scoring System (MACCS) which identifies 102 comorbid conditions.\textsuperscript{10} The number of co-morbid conditions were grouped into four categories; 0 comorbidities, 1-2 comorbidities, 3-4 comorbidities and 5+ comorbidities. Location based on postcode was classified as regional, remote and metropolitan. Socioeconomic status was measured using the Australian Bureau of Statistics SEIFA score of disadvantage which was divided into five categories ranging from most disadvantaged to least disadvantaged.\textsuperscript{11} Commercial driving status was identified from the variable occupation.

3.4 Ethics approval

The research was undertaken with the reciprocal approval of the Human Research Ethics Committee, Curtin University; approval number HRE2017-0447 (10\textsuperscript{th} July 2017). The lead HREC for this project was the Department of Health, Government of WA, Human Research Ethics Committee; approval number 2016/33. This study was conducted in accordance with the guidelines of the Declaration of Helsinki.
4. RESULTS

4.1 Characteristics of the cohort

Questionnaire, polysomnography (PSG, sleep study) and crash data were available for 2,909 patients. The cohort was predominantly male (n=1719, 59%), middle-aged (51.1 ± 13.0 years), and obese (BMI > 30 kg/m²), and the mean number of years of driving was 30.1 years (SD=13.0 years) (Table 4.1). The mean Epworth sleepiness score (ESS) was 9.8 (SD=5.6), with 16.4% reporting moderate to severe excessive sleepiness (ESS ≥ 16). The median apnoea hypopnoea index (AHI) was 25.7 events per hour (Interquartile range 13.4 to 49.0) representing moderate obstructive sleep apnoea (OSA), (Table 4.1).

Table 4.1: Characteristics of the study population (N=2909 all cases)

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td>51.1 ± 13.0</td>
</tr>
<tr>
<td>Sex, M/F (%)</td>
<td>59/41</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>32.6 ± 7.7</td>
</tr>
<tr>
<td>Years driving</td>
<td>30.1 ± 13.0</td>
</tr>
<tr>
<td>AHI, events/h</td>
<td>25.7 (13.4-49.0)</td>
</tr>
<tr>
<td>ESS, score</td>
<td>9.8 ± 5.6</td>
</tr>
</tbody>
</table>

Data are presented as mean ± SD or median (interquartile range). BMI, body mass index; AHI, apnoea hypopnoea index; ESS, Epworth Sleepiness Score.

The severity of OSA was characterised by standard criteria and distribution of cases by category is presented in Table 4.2. OSA was diagnosed in 93% of cases, with 43% having severe OSA (>30 breathing pauses per sleep hour), [Table 4.2].

Table 4.2: OSA severity within the study population

<table>
<thead>
<tr>
<th>OSA severity</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nil</td>
<td>192</td>
<td>6.6</td>
</tr>
<tr>
<td>Mild</td>
<td>646</td>
<td>22.2</td>
</tr>
<tr>
<td>Moderate</td>
<td>808</td>
<td>27.8</td>
</tr>
<tr>
<td>Severe</td>
<td>1263</td>
<td>43.4</td>
</tr>
<tr>
<td>Total</td>
<td>2909</td>
<td>100.0</td>
</tr>
</tbody>
</table>

OSA, obstructive sleep apnoea
4.2 Motor Vehicle Crash-Related Injury

Two hundred and fifty one of the 2,717 people with obstructive sleep apnoea had an injury crash in the five years prior to their diagnosis. Of these, 220 participants (8.1%) had one crash, 27 (1.0%) had two crashes and four (0.1%) had three crashes. Of the 251 crashes, there were 22 (9%) crashes that required hospitalisation and 229 (91%) crashes with people who were injured but not hospitalised. The overall injury crash rate in the sleep apnoea cohort was 2.19 per 100 person-years, (Table 4.3). The crash rate was highest in the youngest age group and declined with age in females (Table 4.3). The crash rate in males declined up until the 55-64 year age group and then increased in those aged 65+ years (Figure 4.1).

Table 4.3: Crash rates per 100 person-years in OSA group by age group for WASHS cohort (n=2909 people)

<table>
<thead>
<tr>
<th>Age group</th>
<th>Males</th>
<th>Females</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>17-35</td>
<td>3.50 (2.32-4.67)</td>
<td>3.81 (2.34-5.27)</td>
<td>3.63 (2.71-4.54)</td>
</tr>
<tr>
<td>35-44</td>
<td>2.64 (1.90-3.38)</td>
<td>2.92 (1.92-3.91)</td>
<td>2.75 (2.15-3.34)</td>
</tr>
<tr>
<td>45-54</td>
<td>1.81 (1.23-2.40)</td>
<td>2.10 (1.37-2.83)</td>
<td>1.94 (1.48-2.39)</td>
</tr>
<tr>
<td>55-64</td>
<td>1.37 (0.87-1.87)</td>
<td>1.91 (1.20-2.62)</td>
<td>1.59 (1.18-2.00)</td>
</tr>
<tr>
<td>65+</td>
<td>2.09 (1.38-2.80)</td>
<td>1.35 (0.64-2.06)</td>
<td>1.80 (1.28-2.31)</td>
</tr>
<tr>
<td>Total</td>
<td>2.12 (1.82-2.43)</td>
<td>2.28 (1.89-2.67)</td>
<td>2.19 (1.95-2.43)</td>
</tr>
</tbody>
</table>

Figure 4.1: Crash rates per 100 person-years in OSA group by age group for WASHS cohort (n=2909 people)
4.2.1 Commercial Motor Vehicle (CMV) Drivers

Of the 2717 people with OSA, 156 were commercial drivers (Table 4.4). Of these, 64% were bus or truck drivers, 23% were taxi drivers and 17% were delivery or courier drivers (Table 4.4).

The injury crash rate in commercial motor vehicle drivers (4.65 crashes per 100 person-years, 95% CI 3.21 to 6.09) was approximately double that seen in non-commercial drivers (2.03 crashes per 100 person-years, 95% CI 1.79 to 2.27). The rate for female commercial drivers appears high at 8.89 crashes per 100 person-years (95% CI 0.18 to 17.6), but is based on only four crashes.

Table 4.4: Summary of commercial drivers by occupation

<table>
<thead>
<tr>
<th>Occupation - Driver</th>
<th>Number</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus/Coach</td>
<td>18</td>
<td>11.5</td>
</tr>
<tr>
<td>Truck</td>
<td>82</td>
<td>52.5</td>
</tr>
<tr>
<td>Taxi</td>
<td>23</td>
<td>14.7</td>
</tr>
<tr>
<td>Delivery</td>
<td>7</td>
<td>4.5</td>
</tr>
<tr>
<td>Courier</td>
<td>10</td>
<td>6.4</td>
</tr>
<tr>
<td>Driver - general</td>
<td>15</td>
<td>9.6</td>
</tr>
<tr>
<td>Locomotive</td>
<td>1</td>
<td>0.6</td>
</tr>
<tr>
<td>Total</td>
<td>156</td>
<td>100</td>
</tr>
</tbody>
</table>

Figure 4.2 Crash rates per 100 person-years for commercial versus non-commercial drivers
4.3 Risk Factors for Crash Related Injury

Table 4.5 shows the distribution of risk factors in the cohort (first column), and the associated crash risks. The majority of the cohort lived in the metropolitan area (n=2430, 90%), 61.3% (n=1665) were male and 60.5% (n=1632) were obese. There were 192 individuals not diagnosed with OSA (AHI<5) who were not considered suitable as healthy controls, as they had been referred to the sleep service for investigation of a symptomatic sleep disorder. For this reason, those with nil OSA were removed from the analysis, and the reference category for the OSA severity comparison was the mild category, (Table 4.5).

The results of the multivariate analysis found a significantly increased risk of 53% for an injury crash in those with moderate OSA in comparison to those with mild OSA (incidence rate ratio 1.53, 95% CI 1.07-2.21, p=0.02). A significant increase of 45% was found in those with 5 or more comorbid conditions compared to those without a comorbid condition (incidence rate ratio 1.45, 95% CI 1.00-2.09, p=0.05). Additionally, commercial drivers had a significantly increased risk of almost three times compared to non-commercial drivers (incidence rate ratio 2.65, 95% CI 1.75-4.00, p<0.0001), after adjustment for other potential risk factors. Those in the 45-54 year age group (RR 0.54, 95% CI 0.30-0.95, p=0.03) and in the 55-64 year age group (RR 0.41, 95% CI 0.21-0.79, p=0.008) had a decreased risk of crashing in comparison to those aged 17-34 years. Level of sleepiness as classified by the Epworth Sleepiness Score, gender, location of residence, number of years driving experience, relative disadvantage, BMI category and smoking history did not contribute to the risk of having an injury crash for those with a diagnosis of OSA (Table 4.5).
Table 4.5: Risk factors for injury crash in people with OSA: Results from Negative Binomial Regression analysis

<table>
<thead>
<tr>
<th>Factor</th>
<th>No. of people N=2717 (%)</th>
<th>Incidence rate ratio from univariate model</th>
<th>Incidence rate ratio from multivariate model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OSA Severity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mild</td>
<td>646 (23.8)</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Moderate</td>
<td>808 (29.7)</td>
<td>1.44 (1.04-2.01) *</td>
<td>1.53 (1.07-2.21) *</td>
</tr>
<tr>
<td>Severe</td>
<td>1263 (46.4)</td>
<td>1.15 (0.93-1.58)</td>
<td>1.16 (0.80-1.69)</td>
</tr>
<tr>
<td><strong>Epworth sleepiness score</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not sleepy</td>
<td>1529 (56.3)</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Sleepy</td>
<td>734 (27.0)</td>
<td>1.30 (0.97-1.75)</td>
<td>1.29 (0.96-1.72)</td>
</tr>
<tr>
<td>Excessively sleepy</td>
<td>453 (16.7)</td>
<td>1.29 (0.91-1.83)</td>
<td>1.27 (0.90-1.80)</td>
</tr>
<tr>
<td><strong>Age group</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17-34yrs</td>
<td>289 (10.6)</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>35-44yrs</td>
<td>548 (20.2)</td>
<td>0.75 (0.50-1.13)</td>
<td>0.76 (0.49-1.19)</td>
</tr>
<tr>
<td>45-54 yrs</td>
<td>681 (25.1)</td>
<td>0.55 (0.36-0.83) *</td>
<td>0.54 (0.30-0.95) *</td>
</tr>
<tr>
<td>55-64 yrs</td>
<td>688 (25.3)</td>
<td>0.42 (0.27-0.65) **</td>
<td>0.41 (0.21-0.79) *</td>
</tr>
<tr>
<td>65-79 yrs</td>
<td>511 (18.8)</td>
<td>0.49 (0.31-0.77) *</td>
<td>0.49 (0.23-1.04)</td>
</tr>
<tr>
<td><strong>Sex</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>1052 (38.7)</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Male</td>
<td>1665 (61.3)</td>
<td>0.99 (0.76-1.29)</td>
<td>0.87 (0.65-1.16)</td>
</tr>
<tr>
<td><strong>Location of residence</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metropolitan</td>
<td>2430 (90.0)</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Regional</td>
<td>175 (6.5)</td>
<td>0.74 (0.42-1.32)</td>
<td>0.87 (0.48-1.57)</td>
</tr>
<tr>
<td>Remote</td>
<td>96 (3.5)</td>
<td>0.60 (0.26-1.42)</td>
<td>0.66 (0.28-1.57)</td>
</tr>
<tr>
<td><strong>Comorbid conditions</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>797 (29.3)</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>1-2</td>
<td>702 (25.8)</td>
<td>1.21 (0.88-1.66)</td>
<td>1.30 (0.92-1.84)</td>
</tr>
<tr>
<td>3-4</td>
<td>539 (19.8)</td>
<td>1.04 (0.73-1.49)</td>
<td>1.14 (0.77-1.68)</td>
</tr>
<tr>
<td>5+</td>
<td>679 (25.0)</td>
<td>1.25 (0.91-1.73)</td>
<td>1.45 (1.00-2.09) *</td>
</tr>
<tr>
<td><strong>Commercial driver</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>2494 (93.8)</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Yes</td>
<td>165 (6.2)</td>
<td>2.32 (1.55-3.46) **</td>
<td>2.65 (1.75-4.00) **</td>
</tr>
<tr>
<td><strong>No. of years driving</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;=20 yrs</td>
<td>681 (25.1)</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>21-30 yrs</td>
<td>687 (25.3)</td>
<td>0.60 (0.43-0.85) *</td>
<td>0.76 (0.49-1.16)</td>
</tr>
<tr>
<td>31-40 yrs</td>
<td>713 (26.2)</td>
<td>0.62 (0.44-0.87) *</td>
<td>0.98 (0.57-1.68)</td>
</tr>
<tr>
<td>41-70 yrs</td>
<td>636 (23.4)</td>
<td>0.50 (0.34-0.72) *</td>
<td>0.75 (0.38-1.48)</td>
</tr>
<tr>
<td><strong>Disadvantage</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 (Most disadvantaged)</td>
<td>573 (21.1)</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>2</td>
<td>532 (19.6)</td>
<td>1.29 (0.85-1.98)</td>
<td>1.12 (0.73-1.72)</td>
</tr>
<tr>
<td>3</td>
<td>485 (17.9)</td>
<td>1.26 (0.81-1.94)</td>
<td>1.19 (0.76-1.84)</td>
</tr>
<tr>
<td>4</td>
<td>606 (22.3)</td>
<td>1.47 (0.98-2.20)</td>
<td>1.38 (0.92-2.08)</td>
</tr>
<tr>
<td>5 (Least disadvantaged)</td>
<td>521 (19.2)</td>
<td>1.36 (0.89-2.07)</td>
<td>1.37 (0.89-2.12)</td>
</tr>
<tr>
<td><strong>BMI category</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal/underweight</td>
<td>306 (11.4)</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Overweight</td>
<td>758 (28.1)</td>
<td>1.24 (0.76-2.03)</td>
<td>1.26 (0.77-2.06)</td>
</tr>
<tr>
<td>Obese</td>
<td>1632 (60.5)</td>
<td>1.39 (0.88-2.20)</td>
<td>1.35 (0.84-2.17)</td>
</tr>
<tr>
<td><strong>Smoking history</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never smoked</td>
<td>1132 (41.7)</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Ever smoked</td>
<td>1585 (58.3)</td>
<td>1.06 (0.82-1.38)</td>
<td>1.02 (0.78-1.33)</td>
</tr>
</tbody>
</table>

*, p value < 0.05; **, p value < 0.001
5. DISCUSSION

This large population based linked health data study investigated the relationship between OSA, excessive daytime sleepiness (as measured by Epworth sleepiness score) and crash related injury in a cohort of sleep clinic patients.

The study found that people with a confirmed diagnosis of OSA (AHI > 5 events per hour) sustained crash related injuries at a rate of 2.19 per 100 person-years. For comparative purposes, the injury crash rate in 17-79 year old drivers in the West Australian population in 2010 was 0.44 per 100 person-years (Data source: Main Roads IRIS database and DoT Licensing data with approval). These results are consistent with a large Canadian study that also used objective crash data.7 Mulgrew et al. were the first group to report that the relative risk was much greater for crashes associated with personal injury (than for property damage only) in untreated OSA subjects.7 Compared with controls, patients with OSA had a 3.0 to 4.8-fold increased rate of MVC causing injury. For mild, moderate and severe OSA, the injury crash rate was 3.0, 3.0 and 4.0 per 100 person-years7, compared with our overall crash rate of 2.19 per 100 person-years in our cohort. A recent Swedish study also reported more common injury-related crashes in OSA patients when compared with the control population (OR 1.9, 95%CI 1.18-3.18, p<0.01).105 Past studies of crash rate associated with OSA have reported on all crash types (not just injury crashes).22 In well-designed linked data studies, reported crash rates have ranged from 5.097 to 18.0137 per 100 person-years, however sample sizes varied.7,105,123

The study also examined the association of two primary OSA-related factors (OSA severity and excessive sleepiness) and the risk for an injury related crash for a cohort with a confirmed diagnosis of OSA. Interestingly, a significantly increased risk of an injury-related crash was found in those with moderate OSA, but not severe OSA, in comparison to those with mild OSA. This finding reflects the inconsistent association of the severity of OSA with an increased crash risk in previous research. Most studies have found an increased risk of 2 to 7 times for a MVC (all crash types) in people with OSA.7,9 However, the characteristics that are associated with an increased risk in people with OSA are less clear and may include severity of OSA, daytime sleepiness, oxygen dips during sleep and obesity. Both Young and Mulgrew found that any degree of OSA (AHI ≥ 5 events/h) increased the crash risk in people with untreated OSA in both community and clinic samples.7,97
The poor relationship between severity of OSA (as defined by apnoea hypopnoea index) and the degree of daytime sleepiness has long been recognized.\cite{138,139} It remains unclear why one person with moderate sleep apnoea may be sleepy whereas another may be asymptomatic.\cite{71,140} Since disease severity does not correspond well with symptomology, it is not surprising that an association between the risk of an injury related crash in people with moderate OSA but not severe OSA was found in this study. This finding may also be accounted for by self-regulation of driving in those with severe OSA due to awareness of drowsiness and difficulty driving safely. This concept is aligned with the current Australian Fitness to Drive guidelines that identify high risk individuals as: those with moderate to severe excessive daytime sleepiness (Epworth Sleepiness Score 16-24), those with a history of self-reported sleepiness while driving, and those who have had a crash caused by inattention or sleepiness.\cite{18}

Previous research examining crash risk in OSA found a strong association between sleepiness and increased rate of self-reported near-misses in untreated OSA patients.\cite{8} In the current study there was no association between Epworth sleepiness score (ESS) and crash related injury (Table 4.5). However Karimi et al. found that excessive daytime sleepiness (ESS ≥ 16) did predict increased risk of crashes (all crash types) among OSA patients (OR 2.13, 95%CI 1.26-3.61, p=0.005).\cite{105} Their study used all crash types (both property damage and injury crashes) which increased the number of crash events and so may have provided support for this finding. In the large study by Mulgrew neither severity of OSA nor subjective sleepiness predicted increased crash risk for any crash type.\cite{7}

This study adjusted for several other confounding variables including age, sex, location of residence, comorbid conditions, years driving, socioeconomic disadvantage, BMI category and smoking exposure for those with confirmed OSA. Commercial drivers with OSA were 2.65 times (p<0.0001) more likely to have an injury related crash than other drivers with OSA. This finding is consistent with recent research reported by the ESADA study (a European multi-centre cohort study) that is designed to address potential risk factors in drivers with suspected OSA.\cite{141} Frequent driving (driving distance ≥ 15,000 kms/y) was associated with an increased risk of a crash among OSA patients.
Three Australian studies have examined the relationship between sleepiness, sleep-disordered breathing and crash risk factors in commercial vehicle drivers.\textsuperscript{12,14,15} Most recently Meuleners et al. reported that heavy vehicle drivers who spent more than 50% of the trip driving between midnight and 5.59 am were four times more likely to crash.\textsuperscript{15} Howard et al. reported that 60% of commercial vehicle drivers had sleep-disordered breathing, and that 24% of drivers had excessive sleepiness.\textsuperscript{14} Sharwood et al. found using an at-home diagnostic test that 41% of long-distance heavy vehicle drivers were likely to have OSA.\textsuperscript{119} The current study supports these findings and lends support to the recommendation that commercial drivers be screened for OSA and participate in fatigue management training. The current Australian Fitness to Drive guidelines are particularly relevant for commercial vehicle drivers, given that OSA approximately doubles crash risk and close to half of commercial drivers have OSA.\textsuperscript{14,119,124,142}

Increased risk for a crash related injury was also related to those with 5 or more comorbidities including a diagnosis of OSA. Previous studies have identified comorbidities as predictors of older driver performance and driving pattern.\textsuperscript{143} Increased crash risk in older drivers relates to functional impairments, comorbidities and polypharmacy rather than age alone.\textsuperscript{144} However, compared with younger drivers, older drivers have lower rates of crash involvement because fewer older subjects keep their licence and those who do self-regulate and drive fewer miles.\textsuperscript{145} A recent study of OSA related crash risk in Sweden included both comorbidities and medication use in their research.\textsuperscript{105} Hypnotic use (OR 2.07, 95\%CI 1.07-3.98, p=0.03) but not comorbidities was an independent predictor associated with MVCs among OSA patients. Since factors associated with increased crash risk in OSA have proven difficult to identify, recent studies have included more potential drowsy driving confounders into models.

A significant relationship between age group and risk of injury related crash in the cohort of OSA patients was also found, consistent with known trends in road safety statistics. Those in the 45-54 year age group and in the 55-64 year age group (all had OSA) reported a decreased risk of crashing in comparison to those aged 17-34 years. The increased risk of involvement in injury crash by driver age and gender has been reported in a meta-analysis by Vaa.\textsuperscript{98}

Predictors of increased MVC risk for untreated OSA remain unclear and generate a clinical challenge in sleep medicine, road safety and public health for management of driving risk. In
the current study, OSA severity was associated with an increased risk of an injury related crash in cases with moderate OSA (p=0.02) but not severe compared with mild OSA. Against logic the symptom of severe EDS (ESS ≥ 16) did not predict increased risk for injury crashes.

5.1 Strengths and Limitations

This study found an increased risk of an injury related crash in patients with a confirmed diagnosis of OSA which is consistent with the other comparable study by Mulgrew et al. that reported a three to five-fold increase in relative risk of crash with personal injury in OSA cases.7 Our study extends current knowledge with the following strengths.

1. The results are based on verified and objective data that combined information from linked administrative health data records (hospital morbidity), government insurance records (injury crash) and an injury related crash.
2. Only the crash records of the driver at the time of the crash were included in the analysis.
3. All participants had OSA diagnosed using the gold standard Type 1 polysomnography, in addition to information collected on sleep variables, a validated measure of self-reported sleepiness (ESS), lifestyle factors, comorbidities and medication use.
4. Our study has utilised the largest sample size (n=2717) for confirmed diagnosis of OSA and injury crash (objective data) to our knowledge.

However there are limitations to the study.

1. The study would have been strengthened with a set of age and sex-matched controls without OSA or any other sleep related disorders for comparison.
2. Information for property damage crashes was not available. Most previous studies have analysed data for all crash types since crashes are rare events. Therefore the estimates of crash involvement for people with OSA are likely to be conservative since we have only reported on injury crashes.
3. A further limitation is the lack of a measure of driving exposure, however we have used a surrogate measure which was the number of years driving in our analysis. The inclusion of detailed information on medication use and sleep variables would also allow better adjustment for potential confounders in any subsequent analyses which is undertaken.
4. Most published data supporting increased crashes in OSA are from studies of patients referred to a sleep clinic.9 It may be that our finding of increased risk of injury-crash is biased toward those people who are symptomatic and sought referral to a sleep clinic for
advice. However, Teran-Santos et al. found in a well-designed case-control study of drivers who received emergency treatment as a result of involvement in a traffic crash that there is a strong association between OSA and crash risk (OR 7.2). The magnitude of their results was similar to that of Young et al. who found that drivers with moderate OSA were significantly more likely to have multiple crashes in a period of five years (OR 7.3) than drivers without OSA. Both studies have drawn cases with OSA from a community sample and found a strong association between OSA and increased crash risk in a sample free of clinic bias. Thus impaired drivers with OSA were not over represented in clinic populations supporting the generalizability of our findings.

5.2 Implications of findings
In this study the presence of OSA predicted the increased risk of an injury related crash in patients with confirmed OSA. The development of a fitness to drive tool would allow sleep physicians to better assess efficacy of treatment and pronounce fitness to drive with confidence. Treatment of OSA with continuous positive airways pressure (CPAP) is highly effective, and reduces crash risk. However, Karimi et al. have shown recently that crash risk reduction is confined to patients who comply with therapy for at least 4 hours per night. Paradoxically patients with lower therapy compliance had an increased crash frequency, suggesting that incomplete therapy use is linked to high crash risk. This finding creates a dilemma for the physician with respect to determination of fitness to drive. The current gold standard test (Maintenance of Wakefulness test) is conducted in a sleep laboratory and in no respect replicates real-life driving situations. Thus clinicians managing OSA need to advise patients about driving risk but there are no validated tools nor robust objective data about which factors are important. Recently Ghosh et al. have reported that more advanced PC-based simulators appear to be a credible test of real-life driving, with 25% of people with moderate OSA failing. In addition to the simulator results, the group identified driving questions that identified people likely to fail, but concluded that no single factor was sufficiently robust by itself to predict driving risk. In Australia currently a Cooperative Research Centre for Alertness Safety and Productivity is actively developing tools to predict and measure alertness. Until such time as more robust data is available, development of a fitness to drive tool using the driving simulator at C-MARC would significantly benefit sleep physicians bearing responsibility for management of drivers with sleep disorders, especially OSA.
5.3 Summary
These results for sleep clinic patients with OSA can be used to both guide clinical management and inform public health policy with respect to driving crash risk. The data supports the finding that participants with confirmed diagnosis of OSA have an increased risk of injury crash. The increased risk is higher for commercial drivers than all other drivers, possibly due in part to increased driving exposure. Although higher driving exposure may be offset by greater driving experience in professional drivers, these factors are correlated. In long haul truck drivers multiple factors contribute to increased crash risk; short average sleep duration (less than 7 hours), a high prevalence of OSA among this group of drivers, long monotonous driving and driving at night (especially between MN and 0600). Since heavy vehicles are overrepresented in road deaths in Australia, research should focus on screening of commercial drivers for OSA and participation in fatigue management training.

The findings of this study would be strengthened by analysis of the larger WASDRI cohort (n=26541 cases), with identification of drivers licence status and application for an age and sex-matched control group. Linkage to property damage crash data would also add weight to the evidence for increased crash risk. Analysis of this large OSA cohort using population based linked data would allow comprehensive assessment of crash risk in drivers with a diagnosis of sleep apnoea in a large sample that is unique internationally due to its size and the amount of data collected (inclusive of sleep study). Since OSA is the medical condition with the highest risk of crash, and prevalence is increasing, such research has the potential to address the burden of fatality and serious injury on our roads, lessening the burden on the Australian health care system.

Recommendations
From the findings of this study the following recommendations are made:

1. That this pilot study be strengthened by analysis of the larger WASDRI cohort (n=26541 linked cases), with identification of drivers licence status, linkage to property damage crash data and application for an age and sex-matched control group. This further research would allow more comprehensive investigation of risk factors that may predict increased risk of injury crash in drivers with OSA.

2. That a fitness to drive tool be developed to provide a more robust assessment of safe driving ability in people with sleep disorders. The current gold standard test is conducted in a sleep laboratory and does not replicate real-life driving situations.
3. That priority be given to an evaluation of the Code of Practice for Fatigue Management for Commercial Vehicle Drivers to ensure it is appropriate for contemporary industry practices and latest research findings.

4. That further education be directed to target the general driving community encouraging responsibility for sleep health awareness.
6. REFERENCES


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