

Efficacy of proxy definitions for identification of fatigue/sleep-related crashes: an Australian evaluation

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Abstract

Fatigue/sleepiness is recognised as an important contributory factor in fatal and serious injury road traffic incidents (RTIs), however, identifying fatigue/sleepiness as a causal factor remains an uncertain science. Within Australia attending police officers at a RTI report the causal factors; one option is fatigue/sleepiness. In some Australian jurisdictions police incident databases are subject to post-hoc analysis using a proxy definition for fatigue/sleepiness. This secondary analysis identifies further RTIs caused by fatigue/sleepiness not initially identified by attending officers. The current study investigates the efficacy of such proxy definitions for attributing fatigue/sleepiness as a RTI causal factor. Over 1,600 Australian drivers were surveyed regarding their experience and involvement in fatigue/sleep-related RTIs and near-misses during the past five years. Driving while fatigued/sleepy had been experienced by the majority of participants (66.0% of participants). Fatigue/sleep-related near misses were reported by 19.1% of participants, with 2.4% being involved in a fatigue/sleep-related RTI. Examination of the characteristics for the most recent event (either a near miss or crash) found that the largest proportion of incidents (28.0%) occurred when commuting to or from work, followed by social activities (25.1%), holiday travel (19.8%), or for work purposes (10.1%). The fatigue/sleep related RTI and near-miss experience of a representative sample of Australian drivers does not reflect the proxy definitions used for fatigue/sleepiness identification. In particular those RTIs that occur in urban areas and at slow speeds may not be identified. While important to have a strategy for identifying fatigue/sleepiness related RTIs proxy measures appear best suited to identifying specific subsets of such RTIs.

Key words: Driver behaviour, sleep related crash, near miss crash, road traffic incident

This research grant was made possible as the result of a funding grant by the NRMA-ACT Road Safety Trust and the Roads and Traffic Authority, New South Wales. This work has been prepared exclusively by the authors and is not endorsed or guaranteed by the Trust.

1. Introduction

Fatigue/sleepiness road traffic incidents (RTIs) are one of the most preventable types of RTI in the developed world. However the extent of this problem is often understated. The importance of fatigue/sleep-related driving as a contributory factor in fatal and serious injury RTIs is well established within Australia (ATSB, 2006; Dobbie, 2002) and internationally (Åkerstedt, 2000; Connor et al., 2002; Dinges, 1995; Horne & Reyner, 1995). Fatigue/sleepiness accounts for up to 20.0% of population attributable risk (Connor et al., 2002) and is on par with the contribution of alcohol related factors to RTI (Australian Transport Council, 2011).

The percentages of RTIs attributed to fatigue/sleepiness have varied across different studies. For example, in the United States driver fatigue/sleepiness has been identified as a causative factor in one to three percent of all RTIs (Lyznicki, Doege, Davis, Williams, & Fabrizio, 1998). In the United Kingdom, Horne and Reyner (1995) reported that 16.0% of all RTIs were sleep related and 20.0% of motorway RTIs were due to fatigue/sleepiness. In more recent times there has been a consensus within the literature that the proportion of all RTIs related to fatigue/sleepiness is in the order of 20.0% (Connor et al., 2002; Garbarino, Nobili, Beelke, De Carli, & Ferrillo, 2001). Moreover, the study by Connor et al. (2002) provides sound evidence of the role of fatigue/sleepiness in RTIs. This stringent case controlled study found the population attributable risk for fatigued/sleepy driving to be 19.0%; that is, a cessation of all fatigue/sleep-related crashes would result in a 19.0% decrease in the total number of RTIs.

Determinations as to the involvement of fatigue/sleep-related factors can only be arrived at indirectly, and tend to rely on subjective police reports. Within Australia, as with many other jurisdictions, the attending police officer is responsible for identifying causal factors at an RTI and one option available is 'fatigue/sleep-related'. Given that there is no objective method for identifying the involvement of fatigue/sleepiness in RTIs, as there is for other factors such as alcohol use or speeding, researchers and crash investigators therefore often rely upon evidence of erratic driving immediately prior to the crash to indicate the involvement of fatigue/sleepiness. These indicators include crossing the centre line, running off the edge of the road and the frequency of lane excursions, as well as driver behaviour in the days leading up to the crash. Police attribution of fatigue/sleepiness in RTI reports is, in some instances, the only data available. In some Australian jurisdictions (including Queensland, New South Wales and Western Australia), police check a box on the crash report form to indicate that fatigue/sleepiness was considered to be a contributing factor in the crash. The figures derived from such coding are considered to be an underestimate of the true number of fatigue/sleep-related crashes (Attewell, Lock, Dobbie, & Walker, 2001).

In response to concerns of underestimation of the contribution of fatigue/sleepiness to crashes by self-report and subjective police reports, five of the eight Australian jurisdictions and the national Australian Transport Safety Bureau (ATSB) have developed proxy measures

of fatigue/sleep-involvement which can be applied post-hoc to all RTIs in a police report databases, these definitions are displayed in table 1.

Insert table 1 here

In general, these proxy measures use characteristics that have been repeatedly found by research studies to be associated with fatigue/sleepiness to identify crashes that are likely to be fatigue/sleep-related. For example, studies have shown that drivers are much more likely to fall asleep at the wheel between midnight and 6am (or 2am and 6am) and fatigue/sleep-related crashes are more likely to involve a single vehicle running off the road (Horne & Reyner, 1995; Pack, Maislin, Staley, Pack et al., 2006). Whilst these proxy definitions have been shown to provide sound estimations as to the extent of fatigue/sleep-related crashes (e.g., Dobbie, 2002) other studies have identified proxy definitions to be of limited value. A study by Crummy, Cameron, Swann, Kossmann, and Naughton (2008) employed the ATSB operational definitions used by Dobbie (2002) for identification of a fatigue/sleep related crash. These definitions had been developed following investigations into the characteristics of fatal RTI's in which fatigue/sleepiness was identified as an important contributing factor by police, witnesses or coronial report (Attewell et al., 2001). However, only 25.0% of Crummy et al. (2008) participants that had actually had a fatigue/sleep-related crash were correctly identified by the ATSB proxy definition. Crummy et al. (2008) concluded that the ATSB definitions on sleepy and fatigued driving were too narrow and would benefit from further expansion. This statement supports the argument put forward by Åkerstedt (2000), that proxy definitions are too rigid and typically underestimate the prevalence of fatigue/sleep-related crashes.

Assigning the primary cause of the crash to fatigue/sleepiness is difficult as the nature of many RTIs are often multifactoral (Shinar, 1978, 2007), and there is no objective and reliable test for measuring driver fatigue/sleepiness either before or after an RTI (Pack et al., 1995). A number of papers have reported data on time-of-day of RTI for fatigue/sleep attributed RTI. In these studies, either an observer criteria has been applied (e.g., a decision by police at scene that fatigue/sleepiness was a contributing factor), or another data criterion has been applied (e.g., a single vehicle crash occurring on a rural, high speed road; see Horne & Reyner, 2001; Horne & Reyner, 1995). It is on the basis of such work that the current proxy definitions have been developed. However, not all fatigue related crashes occur on high speed rural roads. A study conducted by Gunatillake, Daly and Anderson (2003), investigated the characteristics of police reported fatigue/sleep related RTIs in urban areas with speed zones of 60km/h or less. The results showed that a considerable number of crashes attributed to fatigue/sleep resulted in fatalities or required hospitalisation of the driver. In a similar vein, an investigation of RTIs occurring in speed zones of 60 km/h or less was conducted using data extracted from Queensland Transport's road crash database over a six year period (Armstrong, Smith, Steinhardt, & Haworth, 2008). The results indicated that

almost a quarter of the crashes attributed to “fatigue/fell asleep” resulted in a fatality or hospitalisation due to hitting an object or a parked vehicle, or colliding with another vehicle head-on. It should be noted that all of the low speed crashes examined in these studies would not meet the ATSB proxy definition, given that it recognises only those crashes occurring on roads with speed limits of 80 km/h or above.

Currently, the proxy definitions are predominantly informed by research conducted on data from actual RTIs. However, to develop proxy definitions capable of identifying all fatigue/sleep related RTIs it is important to consider all incidents including those where their police were not involved. An alternative approach to understanding fatigue/sleep-related RTIs is to gather self-report data from drivers regarding their involvement in RTIs or “near misses” due to fatigue/sleepiness. A number of investigations (National Sleep Foundation, 2008; Pennay, 2008) have been conducted in which drivers have been surveyed in regard to their experience of fatigue/sleepiness and their involvement in motor vehicle crashes. Most of these surveys have used a rather narrow definition of fatigue/sleepiness, such as “falling asleep at the wheel” and subsequently results may be underestimates of the broad range of effects on crash involvement.

Although reporting biases due to social desirability and recall bias can affect the accuracy of self-reported incidence rates (Neugebauer & Ng, 1990; Wählberg, Dorn, & Kline, 2010) self-report remains a vital component for the evaluation of near-misses. Research has highlighted the relationship between near misses (also referred to as close calls) and actual RTIs, most notably in a study involving over 35,000 drivers (Powell et al., 2007), in which participants who reported at least one fatigue/sleep-related near-miss incident were 1.13 times more likely to also report involvement in a fatigue/sleep-related RTI compared to drivers who did not report a near-miss. Further, participants who reported four or more fatigue/sleep-related near-miss incidents had twice the risk of involvement in a fatigue/sleep-related RTI than those who had no-near miss events. The authors of this study argue that fatigue/sleep-related near-misses can serve as a metric to predict drivers at risk of a fatigue/sleep-related crash (Powell et al., 2007). An earlier study focusing on the experiences of drivers with a sleep disorder (Engleman et al., 1996) noted that following an intervention, near-misses decreased in line with the observed reduction of actual RTIs, providing further support for the premise that fatigue/sleepy near miss-events are precursors to an actual incident. As crashes are relatively rare events, proxies for RTI involvement have also been used in transport and road safety research to better understand actual risk (Bureau of Transportation Statistics, 2001; Harris & Mackie, 1972; Williamson, Feyer, Friswell & Leslie, 1994).

Self report data has potential to be informative for investigation into fatigue/sleep related RTIs because it is generally acknowledged that drivers are aware of their increasing fatigue/sleepiness. Awareness of prior sleepiness has been repeatedly reported over the last

three decades in on-road studies (Lisper, Laurellm & Van Loon, 1986; Akerstedt et al., 2013), and in driving simulators (Reyner & Horne, 1998; Horne & Baulk, 2004; Filtness, Reyner & Horne 2012). For example, Horne and Baulk (2004) undertook a series of driving simulator studies and found that among young drivers, subjective sleepiness was significantly correlated to physiological signs of sleepiness; a finding that has also been confirmed amongst older drivers (Filtness et al., 2012). Furthermore, it has been found that awareness of fatigue/sleepiness is apparent for an average of 45 minutes prior to a driving incident when measured as part of a driving simulator study and within controlled laboratory conditions participants can accurately their self rated fatigue/sleepiness and task performance when subject to sleep deprivation (Reyner & Horne 1998). The ability to accurately monitor increasing fatigue/sleepiness means that the person themselves is very 'qualified' to report about occasions when they were fatigued, which is particularly poignant when investigating near-misses. However, despite awareness of increasing fatigue/sleepiness people are generally unable to identify the exact point at which they will fall asleep (Kaplan et al., 2007) and people who are awoken within a minute or two of falling asleep may not acknowledge that they were asleep (Bonnet & Moore, 1982). The conflicting situations of, (1) having awareness regarding increasing sleepiness but (2) an inability to identify the point of sleep onset has consequences for investigating self reported fatigue/sleepiness related near-misses and RTIs. Consequently, while participants may find it hard to answer the question 'Have you had an accident because of falling asleep while driving?' they should have ability to answer the question 'Have you had an accident when driving because you were sleepy?'

The current study sought to survey a large, representative sample of Australian drivers with two specific aims:

- 1) To obtain a truer rate of fatigue/sleep -related incidents (including both near-misses and RTIs).
- 2) To assess if proxy definitions used, within Australia, to identify fatigue/sleep related RTIs encapsulate drivers actual experience of fatigue/sleep related incidents.

It is hypothesised that current police reports may under estimate the frequency of fatigue/sleep incidents, in part due to use of stringent proxy definitions.

2. Materials and methods

2.1 Participants

The sample comprised 1, 609 individuals with an equal proportion of males ($n = 805$) and females ($n = 804$). To be considered eligible for inclusion in the survey, participants had to be aged 17 years or older, hold a valid drivers licence, and state that they drove a motor vehicle (either private or work related) more than one hour per week. In order that, the geographical size and population distribution within Australia not bias results, recruitment of

participants was stratified based on the proportion of passenger vehicles registered within a targeted geographical region. For instance within the state of New South Wales (NSW) more participants were recruited from the Sydney region than the Murray regions because there are more passenger vehicles registered in Sydney. Additionally, the sample was stratified according to age and gender. In the final study sample half of the participants were aged 30 years or less.

2.2 Materials

The Driving Fatigue Questionnaire (DFQ) utilised in this study was developed by the authors. The DFQ is comprised of three sections, with questions relating to (1) demographics, (2) fatigue/sleep RTIs, and (3) general sleep health. The demographic section recorded age, gender, education level completed, employment details (e.g., shiftwork), and typical driving routines. The fatigue/sleep related driving incidents section assessed the prevalence of fatigue/sleep-related driving incidents within the sample, the presence or usage of fatigue/sleepiness countermeasures, the characteristics of drivers involved in fatigue/sleep related incidents, and any contributing factors. A third section examined respondents' general sleep health by quantifying individual's perceived quality of sleep and noting any associated sleep problems, average hours of sleep during the working week, feelings of sleepiness and fatigue during the day, and whether the individual had been diagnosed with sleep apnoea.

Development of the fatigue/sleepiness specific DFQ questions was informed by review of peer reviewed scientific literature. One component of this review identified characteristics of fatigue/sleepiness (e.g. slower reaction time, difficulty concentrating etc) and driver response to fatigue (e.g. changing drivers, having a nap) in order that appropriate illustration and definitions be provided with the questions. Additionally, information regarding the nature and outcome of fatigue/sleep related RTI were obtained from both review of scientific literature and of the Queensland State Government – Transport and Main Roads 2012 Road Crash Glossary. This latter information shaped questions relating to RTI and near-miss events.

The DFQ was thoroughly tested with minor wording changes made during pilot testing. Pilot testing was conducted over two consecutive days following the same call procedure outlined in section 2.3. Consequently all pilot participants were selected from the potential participant pool and met the same selection criteria. Pilot testing facilitated interviewer training to ensure proficiency at survey delivery and allowed participant's responses to be scrutinised for comprehension and validity. The most notable change was that the term 'accident' was introduced as pilot participants found this easier to understand than 'RTI' or 'crash'. Additionally, further definition was provided for the symptom – "Increased variation in speed" and one question was removed due to similarity with a previous question.

The survey was administered in the form of a structured interview. For the majority of questions there was an applicable list of options which the interviewer read to participants for them to select their answer from, however, there was always an option for 'Other Specify'.

2.3 Procedure

In line with ethical protocols, the collection of data utilised a telephone survey methodology administered by an independent data collection agency. Participants were sourced from the Association of Market and Social Research Organisations Random Digit Dialing system. The approach used the Computer Assisted Telephone Interview (CATI) system with a team of 31 experienced interviewers, trained to conduct the survey. The call routine for the current study consisted of: calls occurring on weekdays being made in the late afternoon and early evenings between 16:30 and 20:30 and; on weekends, interviews conducted between 9:00 and 17:00. On initiation of the call the interviewer read an explanatory statement to the potential participant and obtained verbal informed consent. This approach provided an overall response rate of 78.7%.

2.4 Data Analysis

Results are reported as percentages with descriptive statistics where applicable. Following data collection logistic regression analysis was discounted due to insufficient number of participants reporting a fatigue/sleep related RTI. Therefore, descriptive analysis was conducted on the factors associated with RTIs rather than parametric tests of statistical significance, in order to determine whether the characteristics of the fatigue/sleep RTIs would fit within the proxy definitions.

3. Results

3.1 Incidence of driver fatigue/sleepiness

Analyses of self-reported past behaviours in this sample of Australian drivers found that driving while fatigue/sleepy was common. Overall, 66.9% of participants reported having felt fatigued/sleepy while driving in the last 5 years ($n = 1,077$) and 65.9% continued to drive occasionally or always after having experienced symptoms of fatigue/sleepiness ($n = 1,060$). The most common symptoms of fatigue/sleepiness experienced while driving, as reported by participants, were yawning (83.4%), needing to change position frequently (58.8%), frequent eye blinks (51.5%) and difficulty in concentrating on driving (50.6%). When asked what they had done to make themselves feel more alert, a majority of participants reported stopping the vehicle (58.1%), however almost half (46.2%) also reported that they continued to drive, despite being aware of fatigue/sleepiness.

3.2 *Fatigue/sleepiness related RTIs*

In terms of RTIs, defined as *'where the vehicle was damaged or someone got hurt or the police were called'*, only 2.4%¹ of participants reported they had experienced an RTI due to driving when fatigued/sleepy in the past five year period (range 1-3).

Table 2 provides a breakdown of the time of day in which the most recent² fatigue/sleep-related RTI occurred and shows that more crashes occurred between 9pm and midnight than at any other time of day. Proxy definitions including time of day exclude all RTIs outside of 10pm to 6am and 2pm to 4pm as not due to fatigue/sleepiness.

Insert Table 2 here

In regard to the type of road environment in which the most recent fatigue/sleep-related RTI occurred, the largest proportion were reported as occurring on motorways with a speed limit of 100 to 110 km/h (45.0%) followed by roads in built-up areas with a speed limit between 80 and 50 km/h (30.0%) and on local/neighbourhood streets with a speed limit of 50 km/h (25.0%). Proxy definitions including road environment exclude all RTIs on roads with speed limits below 80 km/h as not being fatigue/sleep related.

The percentage of crashes per time of day and speed environment for most recent fatigue/sleep-related RTI is shown in Table 3.

Insert Table 3 here

An analysis of the outcomes of the most recent fatigue/sleep-related RTI was conducted with the results provided in Table 4. The most common outcome, as reported by respondents, was a head-on crash with a stationary object, followed by side-swiping a stationary object. Proxy definitions including outcomes identify only head on conclusions when neither vehicle were over taking, run off the road and inappropriate lane crossing as being fatigue/sleep related.

Insert Table 4 here

3.3 *Fatigue/sleepiness related near-misses*

In order to undertake a thorough investigation of the factors associated with fatigue/sleep-related driving incidents, an analysis of the prevalence of near miss events was conducted. As part of this investigation, a near miss event was defined as *'a near-accident where you*

¹ Based on valid responses from 1,518 participants

² $N = 20$ for most recent fatigue-related crash

were driving or if you drove outside of your designated lane because you were fatigued/sleepy.' Over 16%³ (16.7%; $N = 254$) of participants reported they had experienced one or more near-miss events in the past five year period. Examination of the outcomes revealed that startled awake (55.1%) was the most common outcome of the most recent near miss event, followed by drifted/ran off the road (23.6%), wandered/drifted into other lane (14.6%) and wandered/drifted off onto shoulder (14.6%) respectively.

3.4 Combined fatigue/sleepiness related RTIs and near-misses

In-line with previous research, incidents representing actual RTIs and near-misses were combined to facilitate the next stage of the analysis. The factors associated with the most recent 'incident' (either near-miss or RTI) showed that the largest proportion of incidents (28.0%) occurred when commuting to or from work, followed by social activities (25.1%), holiday travel (19.8%), or for work purposes (10.1%). In regard to the location relative to intended destination, it was found that the largest proportion of incidents (20.8%) occurred less than five kilometres from the intended destination, followed by between five and 10 kilometres (16.9%), between 11 and 20 kilometres (13.0%), between 21 and 50 kilometres (12.1%), with the remainder occurring greater than 50 kilometres from the intended destination.

Some interesting results were found when assessing how long the participant had been driving when the most recent fatigue/sleep-related incident occurred. While the distributions were reasonably even, it is interesting to note that 11.1% of the incidents occurred less than 10 minutes into the journey and approximately half (49.8%) of the incidents occurred less than one hour into the commencement of the driving task.

Analysis of the type of road environment in which the incident occurred revealed that the largest number of incidents were reported as occurring on motorways with a speed limit of 100 to 110 km/h (42.0%); followed by country roads with a speed limit of 100 km/h (28.0%). That is, approximately two-thirds of reported incidents occurred on roads with a speed limit of 100 km/h or greater. However, it must be noted that many reported incidents also occurred on roads in built up areas with a speed limit of less than 80 km/h (18.8%) and on local/neighbourhood streets with a speed limit of 50 km/h (11.1%).

An examination of time of day in which the most recent crash or near miss occurred was undertaken with the results shown in Table 5. When measured in groupings of three hours, the period from 3pm to 6pm recorded the highest number of incidents. A relatively large proportion was also found to occur between 12am to 6am, with 15.4% of incidents occurring during this period.

Insert Table 5 here

³ Based on valid responses from 1,518 participants.

Finally, alcohol consumption and prescription medications were examined as some proxy definitions would exclude fatigue if either were identified. It was found that 8.2% of those who reported an incident had consumed any alcohol in the 12 hours prior to their involvement. Additionally, 10.1% of those involved in an incident took a prescription medication in the previous 12 hours. However, when asked if the prescription medication was one that made them feel fatigued/sleepy or less alert none of the participants claimed taking it did so.

3.5 General sleep health

The current study also examined the participant's perceptions of their sleep habits and health. Almost one third (31.9%) reported having mild problems in getting to sleep or staying asleep, while 5.1% reported having severe difficulties. The remainder of the sample (63.0%) reported having no difficulties getting to sleep or staying asleep. Further, over two thirds (69.6%) of individuals reported feeling tired occasionally or frequently despite a full night's sleep. However, of concern is the finding that 39.1% of participants reported getting less than seven hours of sleep each day in an average working week and a small percentage of the sample reported having been diagnosed with sleep apnoea (3.1%). Finally, when asked to rate their quality of sleep, 12.1% rated it as excellent, 41.1% rated it as good, 37.8% rated it as average and 9.0% rated it as poor.

4. Discussion

The current study aimed to investigate fatigue/sleep-related incidents in a large, representative sample of Australian drivers and use this information to assess the appropriateness of proxy definitions used within Australia to classify fatigue/sleepiness as a causal factor of RTI. The extent to which the sample was stratified to ensure equal representation of male and female participants, key age groups and other demographic factors enhances the validity of the study findings in this context. From a total of 1,609 interviews, it was found that 19.1% reported having a near miss or crash due to driving when tired. Furthermore, in terms of driving when fatigued/sleepy, over 65.0% of participants reported they had done so in the last 5 years, with a high proportion (65.9%) reporting that they continued to drive occasionally or regularly after experiencing symptoms of fatigue/sleepiness. This percentage is comparable to other self-report investigations (Nordbakke & Sagberg, 2007; Vanlaar et al., 2008); further highlighting the fact that sleepy or fatigued driving is a major road safety issue requiring further empirical investigation.

Overall, the responses regarding a fatigue/sleep-related crash in the previous five year period do not fit neatly within the NSW, QLD or ATSB proxy definitions for a fatigue/sleep crash (approximately 55.0% in the current study). Furthermore, of the responses received, only 45.0% of the participants stated that the police were involved as a result of the most recent fatigue/sleep-related crash. This suggests that, regardless of the proxy definitions,

incidents resulting from fatigued/sleepy driving remain under-reported, and especially so when they do not involve multiple vehicles or injuries.

Over 16.0% of participants reported having a near-miss as a result of being fatigued/sleepy whilst driving. This demonstrates that these participants had awareness of fatigue/sleepiness prior to the near-miss, as has been reported by laboratory studies (Reyner & Horne 1998). However, despite the awareness that they were fatigued/sleepy these participants have allowed fatigue/sleepiness to reach a level that has been causal to a near-miss. As such, the effectiveness of driver education programs may be enhanced by better driver recognition of the early signs of fatigue/sleepiness and an increased focus on advance trip planning that incorporates adequate rest stops consequently never fatigued enough to have a near-miss. It is possible that these results may underestimate the true number of near misses experienced due to fatigue/sleepiness. Identification of the exact point of falling asleep is hard to accurately achieve (Kaplan et al., 2007) and despite ability to recognise increasing fatigue/sleepiness some people fail to equate this with a belief that they may actually fall asleep (Reyner & Horne 1998)

4.1 Characteristics of fatigue/sleep-related incidents

4.1.1 Road Speed

Approximately two-thirds of the fatigue/sleep-related incidents occurred on roads with speed limits of 100 km/h or greater. This finding supports previous research that has found highway driving involves higher occurrences of fatigue/sleep-related crashes (e.g., Dobbie, 2002; Horne & Reyner, 1995; Sagberg, 1999). However it is noteworthy that almost a fifth of the incidents occurred on roads in built up areas with a speed limit of less than 80 km/h with over 10.0% also occurring on local/neighbourhood streets. This is not surprising as all journeys will have a component of driving on lower speed roads; drivers intending to drive on motorways would usually have to drive through built up areas initially, in addition to drivers whose journeys are exclusively on these types of roads. However, examination of the road environment and time of day revealed that crashes, particularly on high speed roads can occur outside periods associated with high circadian sleep incidences.

4.1.2 Time of day

A myriad of research has investigated the time of day that fatigue/sleep-related incidents occur (see Ingre, Kecklund, Åkerstedt & Kecklund, 2004; Pennay, 2008), with increases in fatigue/sleep-related incidents occurring during the two phases of increased sleep propensity in the circadian rhythm (Pack et al., 1995). Previous research has suggested that fatigue/sleep-related incidents are most likely to occur in the nocturnal period between midnight and 6am (Pennay, 2008). Accordingly fatigue/sleep-related incidents were expected to be most prevalent during this time. However, in this study only 15.4% incidents

occurred between midnight and 6am, a figure comparable with most other time periods. The diurnal period in the circadian rhythm cycle is between 2pm to 4pm and as such fatigue/sleep-related incidents were expected to slightly rise during this period. Notably, in this study the largest proportion of incidents occurred between 3pm and 6pm, with just under a quarter of the incidents occurring during this period.

4.1.3 Outcome

Proxy definitions including outcomes identify only head on conclusions when neither vehicle were over taking, run off the road and inappropriate lane crossing as being fatigue/sleep related. However, the most common outcome, as reported by respondents, was a head-on crash with a stationary object, followed by side-swiping a stationary object. These results confirm the short coming of proxy definitions previously reported by others (Crummy et al., 2008); a collision with a stationary object is a common aspect of fatigue/sleep related incidents not identified within the proxy definitions.

4.1.4 Features not present – alcohol

Consumption of alcohol within 12 hours of the incident was relatively rare amongst respondents. According to some proxy definitions a positive reading for alcohol consumptions negates that the incident cannot be fatigue related. The results of the current study suggest that using such a definition will exclude a small number of fatigue/sleep related incidents from being identified. Nevertheless, the combining effect of fatigue/sleepiness and alcohol should not be underestimated as laboratory studies have demonstrated alcohol and fatigue/sleepiness in combination to have a great impact on incidents than either factor alone (Horne, Reyner, & Barrett 2003).

4.1.5 Characteristics of fatigue/sleep related incidents not included in proxy definitions

The analysis of the purpose of the journey in which fatigue/sleep-related incidents (sleep related crashes and near misses) were reported, showed that the largest proportions of incidents occurred when commuting to or from work, followed by social activities, holiday travel and for work purposes. It is arguable that for most drivers commuting to and from work and travelling to social activities generally involves travelling shorter distances and may be less likely to occur on monotonous roads. However, these findings can be better understood in relation to the different speed limits in place where incidents were reported.

The current study also investigated journey length and distance of the intended destination from the location of the drivers' most recent fatigue/sleep-related incident. Notably, the largest proportion of incidents occurred less than five kilometres from the intended destination, followed by a distance of between five and 10 kilometres. Taken together, these findings demonstrate that just over a third of the incidents occurred within 10 kilometres of the intended destination. These results show that a substantial proportion of the reported incidents occurred toward the end of the journey, indicating that while drivers may be more prone to feeling fatigued/sleepy at this time, they may continue to drive due to the relatively

close proximity of their final destination. The driver's focus may be directed towards thoughts of the destination or proceduralised driving due to familiarity with the location (Charlton & Starkey, 2011) rather than the task of safely completing the journey. Further research is needed to confirm the extent to which these behaviours are present. Accordingly driver education could place greater emphasis on the particular vulnerability of drivers to fatigue/sleep-related crashes toward the end of journeys.

Analysis of the timing of an incident in relation to the duration of a journey provided interesting results. Although a large proportion of incidents occurred toward the end of the journeys, 11.1% of incidents occurred less than 10 minutes into the journey. At this early stage of a journey it is unlikely that these drivers would attribute fatigue/sleepiness to the duration or length of the journey. Additionally, there would have only been a small time frame for the driver to experience the subjective symptoms of fatigue/sleepiness. This suggests that fatigue/sleep-related crashes do not only occur after long periods of driving, and that embarking upon journeys while fatigued/sleepy may also be dangerous. Future research utilising a driving simulator could investigate levels of fatigue/sleepiness and occurrences of sleep related incidents during short trip durations and could provide greater insight into this interesting finding. However, such investigations would need to recognise the reduced arousal levels present among simulated drivers as opposed to on-road driving (see Philip et al., 2005).

4.2 General sleep health

A subjective assessment of the participants' general sleep health can provide insights into the occurrence of fatigue/sleep-related driving incidents. Just under two-thirds of the sample reported no difficulties in getting to sleep or staying asleep. Additionally, most of the participants rated their sleep quality as good or average. This is a welcome finding, given that obtaining regular good quality sleep should reduce the likelihood of feeling fatigued/sleepy while driving. However, almost a third of the participants reported mild problems in getting to sleep or staying asleep. Additionally, a small proportion reported having severe difficulties getting to sleep or staying asleep.

People who report difficulties getting to sleep, staying asleep or obtaining an optimal level of sleep may be more prone to symptoms of sleepiness and subsequent driver fatigue/sleepiness (Papadakaki et al., 2008). Drawing on the finding that a third of the participants reported mild or severe difficulties getting to sleep or staying asleep, it may be hypothesised that there are a substantial number of drivers at considerable risk of experiencing sleep-related symptoms whilst driving. To examine this contention, future research might explore the relationship between levels of sleep disruption and prevalence of sleep-related symptoms whilst driving. Given the possibility that individuals may experience varying levels of sleep disruption during different periods of their lives, it is important to

educate all drivers (not just those with current sleep disruption problems) of the effects of fatigue/sleepiness on driving ability.

Another area of concern was the finding that over two-thirds of the sample reported feeling tired occasionally or frequently after a full night sleep. It is possible that even though these drivers may get a full night sleep occasionally, on average they are not getting their required amount of sleep. This is supported by the finding that 39.1% of participants reported getting less than seven hours of sleep each day in an average working week. Van Dongen, Maislin, Mullington, and Dinges (2007), found that relatively moderate levels of sleep deprivation (i.e., 6 hours or less per night) over a 14 day period produced reductions in psychomotor performance that were equivalent to levels observed after being completely sleep deprived for up to two nights. As such, it may be necessary to educate drivers about the effect of continuous partial sleep deprivation on their own sleepiness levels and the subsequent impact on their driving performance.

4.3 Limitations

As with all studies there are a number of limitations which need to be acknowledged. A stratified sampling technique was used to recruit participants to ensure that participants represented a relevant sample of society. This robust method has generate results which can be inferred across the general population, however, by recruiting in this manner the number of fatigue/sleep related incidents for analysis is smaller than if a targeted recruitment technique had been adopted. A likely consequence is that the number of incidents reported between midnight and 6am was relatively small in this study despite being widely reported as the time of day in which fatigue/sleep related incidents are most common. It is important to note that in regard to their regular driving patterns, participants were not questioned on whether they ever drive between midnight and 6am. It follows therefore that participants who rarely drive during this period have a lower likelihood of becoming involved in an incident between midnight and 6am. Additionally, it could be assumed that a greater proportion of the sample drive between 3pm and 6pm than between midnight and 6am. This would explain the greater proportion of incidents occurring between 3pm and 6pm. That is, the higher instances of incidents reported here may be due to a greater volume of drivers on the road between 3pm and 6pm. Accordingly, interpreting these findings should be done within the context of the study as it would be wrong to infer that drivers are more likely to be driving whilst fatigued/sleepy between 3pm and 6pm than midnight and 6am. An alternative approach which may be considered by future research would be to recruit only those drivers who had experienced a fatigue/sleep related incident. A similar survey technique could then generate sufficient data to allow logistic regression analysis. Such information has potential to contribute towards new understandings of driving events caused by fatigue/sleepiness.

4.4 Conclusions

Results support the hypothesis that current police reports may under estimate the frequency of fatigue/sleep incidents, in part due to use of stringent proxy definitions. In relation to Aim 1 fatigue/sleep-related RTIs or near misses are reported by nearly 20% of survey respondents, however, in almost half of these incidents the police were not notified. In relation to Aim 2 the incidents and the details reported by participants in this study do not fit neatly within the proxy definitions for a fatigue/sleep crash. By using proxy definitions not all of the driver's actual experience of fatigue/sleep-related RTIs is encapsulated. In particular, those occurring at lower speeds are not considered.

Examination of the proxy definitions (table 1) reveals that the ATSB definition is the narrowest, followed by the Queensland definition and then the NSW definition. For example, a quarter of the sleep related crashes reported in the current study are outside the proxy definition as used by the ATSB. Furthermore, proxy measures are used by different organisations and for different purposes among the different jurisdictions. The operational definition employed by the ATSB quite clearly states that this was not designed to measure the absolute number of fatigue/sleep-related crashes, but rather to serve as an indicator that would be useful in monitoring these crashes and comparing trends over time or between regions (Dobbie, 2002). However, aspects of the ATSB definition have been incorporated into jurisdictions with the purpose of defining a fatigue/sleep related incident.

Identifying the limitations of current proxy definitions is not intended to suggest such definitions as worthless. On the country, police officers report difficulty in identifying fatigue/sleep related RTIs, in part due to lack of training (Radun et al., 2013). Having a proxy definition is likely to mean more fatigue/sleep related RTIs will be correctly identified than by reliance on police officer reports alone. However, given the nature of the current study proxy measures may be better suited to identifying subsets of fatigue/sleep related RTIs that involve falling asleep at the wheel (occurring predominately in rural locations) as opposed to other RTIs that may occur when less severe levels of fatigue/sleepiness are present (particularly in urban areas).

5. References

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6. Tables for inclusion (five in total)

Table 1: Outline of proxy definition by Australian agency or jurisdiction

	Time of day	Road speed	Outcome	Features not present	Reporting officer consideration
Australian Transport Safety Bureau (ATSB)	Midnight to 6am, 2pm to 4pm	≥ 80 km/h	Single vehicle	Pedestrian, unlicensed driver, blood alcohol concentration > 0.05%	NA
Queensland (QLD)	2pm to 4pm, 10pm to 6pm	≥100 km/h	Single vehicle	NA	Fatigue to be contributory
New South Wales (NSW)	NA	NA	Travel onto incorrect side of road, Head on collision with oncoming vehicle (not overtaking), Run off road	Excess speed, Another relevant factor which may affect manoeuvre	Driver described as asleep or drowsy
Victoria (VIC)	NA	NA	NA	NA	Involuntary and progressive withdrawal of attention. Witness accounts of fatigue
Western Australia (WA)	NA	NA	Travel onto incorrect side of road, Head on collision with oncoming vehicle (not overtaking), Run off road	Excess speed, Another relevant factor affecting loss of control (alcohol, road condition, tyre blow out, sun glare, side wind, headlights, driver condition, broken screen)	Fatigue stated as likely cause
Tasmania (TAS)	NA	NA	NA	NA	Reports of inattentiveness, drowsiness or falling asleep

Table 2: Percentage of reported road traffic incidents occurring at various times of day

Time of day	Percentage
12am-3am	10.0%
3am-6am	15.0%
6am-9am	15.0%
9am-12pm	5.0%
12pm-3pm	10.0%
3pm-6pm	15.0%
6pm-9pm	10.0%
9pm-12am	20.0%

Table 3: Number of road traffic incidents reported by time of day and speed environment

Time of Day	Speed limit		
	100 to 110km/h	<80km/h	50km/h
12am-3am	5.0%	5.0%	0%
3am-6am	5.0%	5.0%	5.0%
6am-9am	15.0%	0%	0%
9am-12pm	0%	5.0%	0%
12pm-3pm	5.0%	0%	5.0%
3pm-6pm	0%	10.0%	5.0%
6pm-9pm	5.0%	5.0%	0%
9pm-12am	10.0%	0%	10.0%

Table 4: Road traffic incidents outcomes

Outcome	Percentage
Collided with centre lane divider	10.8%
Collided with median strip	-
Had a head on crash with stationary object (such as tree or roadside furniture)	37.8%
Had a head on crash with another road user travelling in the opposite direction	-
Had a side-swipe crash with stationary object (such as tree or roadside furniture)	27.1%
Had a side-swipe crash with another road user travelling in same/opposite direction	13.5%
Had a rear-end crash	10.8%

Table 5: Time of day of incidents (near-miss + road traffic incidents) as a percentage

Time of day	Percentage
12am-3am	8.2%
3am-6am	7.2%
6am-9am	13.5%
9am-12pm	9.2%
12pm-3pm	13.5%
3pm-6pm	23.7%
6pm-9pm	12.1%
9pm-12am	12.6%