SLEEPINESS AND OTHER DRIVING RISKS IN YOUNG ADULTS

Final Report

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Executive Summary

This project aimed to investigate the impact of sleepiness and stress on the driving behaviours of young adults (aged 18-25 years). The primary objective was to generate evidence to inform practical and effective interventions to reduce the sleepiness-related road crash risk of young adults. The study sample comprised 83 young adult drivers aged between 18 and 25 years old, sampled from two metropolitan centres in the Australian Capital Territory (ACT) and Queensland (QLD) in Australia. Data were collected prospectively across a 7-day period using a combination of questionnaires, daily sleep diary, stress and driving related diaries, 24-hour ambulatory assessment of both sleep-wake activity (using actigraphy) and stress (using electrocardiography), and in-vehicle monitoring technologies.

The project sought to address the following research questions; (1) to determine the impact of sleepiness on on-road driving performance in young adults; (2) to contribute to evidence on young adults' exposure to driving while sleepy, and (3) to determine interactions between sleepiness and stress related driving risk factors in young adults.

Results indicated that participants were generally meeting current recommendations for sleep duration (between 7-9 hours each night), believed that their sleep quality was 'fair', and did not experience significant subjective sleepiness, nor stress, while driving at times of the day associated with greater crash risk. However, objective risky driving performance was negatively associated with habitual objective sleep duration, suggesting that individuals with shorter sleep were more prone to drive in a risky manner. In contrast, higher subjective sleepiness was associated with less risky driving, suggesting that young drivers may adopt self-regulatory strategies in certain situations. This finding was mirrored in questionnaire data, where participants reported differences in their driving behaviour while sleepy (e.g. by

avoiding other ‘unsafe’ behaviours such as speeding or distractions), compared to driving when not sleepy.

Road crashes remain a leading cause of mortality and morbidity for young adults, and sleepiness is a major contributor to those crashes. These new findings provide robust knowledge to inform potential new interventions to reduce sleep-related road crashes.

Acknowledgements

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The work has been prepared exclusively by the research team and is not endorsed by the NRMA-ACT Road Safety Trust.

Project Research Output and Awards

Rossa, K.R., Sullivan, K.A., & Smith, S.S (2016) *Prospective Measurement Of Daily Sleep, Stress, And Affect In College Students*. SLEEP 2016, 30th Annual Meeting of the Associated Professional Sleep Societies, Denver, Colorado, USA. ‘People’s Choice’ award for best poster presentation.

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Preface

This project was approved by the Queensland University of Technology Human Research Ethics Committee (1400000877) as meeting the requirements of the National Statement on Ethical Conduct in Human Research. Cross Institutional approval was also provided by the University of Canberra Human Research Ethics Committee.

An Occupational Health and Safety risk assessment for this project was completed and approved by the Queensland University of Technology.

Introduction

Young adult drivers (those aged 18-24 years) are over-represented in road crash injuries and associated fatalities around the globe. Across the majority of countries that make up the Organisation for Economic Cooperation and Development (OECD), young adult road users have significantly higher rates of death per population than do both young (<15 years old) and middle aged (≥70 years old) road users combined (Bureau of Infrastructure, Transport and Regional Economics [BITRE], 2015a). In Australia, young adults accounted for nearly twice the annual number of road deaths (8 deaths per 100 000) when compared to drivers of all other ages in 2014 (4.9 deaths per 100 000; BITRE, 2015b). Whilst it is clear that a wide range of factors might contribute to increased crash risk in this age group (including inexperience, peer influences, and other factors), the influence of sleepiness on young driver behaviour is yet to be well addressed.

Sleepiness is a primary contributor to serious injury and fatal road crashes (Australian Transport Council [ATC], 2011; Akerstedt, 2000; Bunn, Slavova, Struttmann, & Browning, 2005; Connor et al., 2002; Gonçalves et al., 2015). In Australia, it is estimated that approximately 20-30% of fatal road crashes occur as a result of sleepiness-related factors, a crash rate comparable to that of speeding and drink driving (approximately 30-34% of crashes respectively; ATC, 2011). This figure may be an under-estimate of the contribution to crashes from sleepiness, due to the current lack of objective measures of on-road sleepiness (as are available for drink and drug driving), and the difficulty and methodological constraints involved in police crash reporting (Filtness, Armstrong, Watson, & Smith, 2015; Grigo & Baldock, 2011; Radun, Ohisalo, Radun, Wahde, & Kecklund, 2013). Drivers crash more often when they are sleepy because sleepiness slows information processing, decision making and reaction speed, and reduces attention and vigilance (Durmer & Dinges, 2005; Smith, Horswill, Chambers, & Wetton, 2009; Van Dongen, Maislin, Mullington, & Dinges, 2003). The degree of impairment of driving associated with sleepiness is very comparable to that of moderate alcohol intoxication (Fairclough & Graham, 1999; Reid & Dawson, 1997). Sleepiness acts to increase driver distraction and to reduce hazard perception (Anderson & Horne, 2013; Smith et al., 2009); two factors that are critical for safe driving, but are under-developed skills in the young driver (Williams, 2003). Thus sleepiness is not only a direct contributor to crash risk, but contributes towards crash risk indirectly by compounding the risks associated with other dangerous driving behaviours.

Young adults are at particular risk for sleepiness-related crashes due to a combination of environmental and biological factors that impact on the quality of their sleep and upon their opportunities for sleep. During puberty, the circadian system (the internal 'body clock') undergoes a phase delay, whereby the clock shifts to later bedtimes and later wake times (Carskadon, Acebo, & Jenni, 2004; Crowley, Acebo, & Carskadon, 2007). This biological delay in sleep-wake timing may continue into young adulthood (Carskadon, Wolfson, Acebo, Tzischinsky, & Seifer, 1998). Certain lifestyle habits associated with young adulthood, such as the use of stimulants to promote wakefulness (Taylor & Bramoweth, 2010), increased mobile phone use at night (Cain & Gradisar, 2010), or later bedtimes on weekends coupled with early morning educational or vocational commitments (Gradisar, Gardner, & Dohnt, 2011), may also impact upon the sleep timing system. This in turn leads to increased daytime sleepiness, and associated impairment of basic cognitive functions that cause poor attention and reduced vigilance (Dorrian, Rogers & Dinges, 2005; Van Dongen et al., 2003). The interactions between biological and lifestyle influences on sleep mechanisms are not perfectly understood; however, current evidence suggests that young adults may very often not be getting sufficient duration, quality, or regularity of sleep. This confluence of factors leading to increased sleepiness may be especially dangerous in the context of road safety.

The degree of sleep loss sufficient to cause measurable deficits in cognition and driving performance may vary from individual to individual; however, obtaining fewer than 6 hours of sleep per night causes impairments in attention, reaction time, and processing speed (Van Dongen et al., 2003). Young adults (particularly university students) regularly experience shorter sleep, with 21% reporting sleeping less than 6 hours per night (Steptoe, Peacey, & Wardle, 2006), 20% of students reporting *no sleep* at night at least once a month, and a third rating their sleep quality as 'poor' every night (Lund, Reider, Whiting, & Prichard, 2010).

When compared to older drivers, young drivers are over-represented in sleepiness-related crashes (Horne & Reyner, 1995; Pack et al., 1995; Phillips & Sagberg, 2013; Williams, 2003), and they are more likely to drive whilst sleepy (Smith, Carrington, & Trinder, 2005). A recent sleep health population survey of 2330 young adults in the United States, found that 44% had reported *unintentionally* falling asleep during the day, and 4.5% had reported nodding off or falling asleep *while driving* in the past month (CDC, 2014). In NSW, it was found that young drivers who slept less than 6 hours per night were more likely to crash (particularly between 8pm and 6am) when compared to drivers who slept more than 6 hours per night (Martiniuk, Senserrick, Lo, et al., 2013). Another study comparing the influence of different crash risk factors on fatal and injury-sustained crashes in young drivers (<25 years old), found that young *sleepy* drivers had a crash and injury risk that was two to three times higher than young drivers who were *not* sleepy. This increased risk was nearly double that which could be attributed to alcohol, night time driving, or distraction-related crashes (Lam, 2003).

The impact of sleepiness on all-cause crashes can also be seen in a more general way by assessing the diurnal pattern of crash data. Typically, most sleepiness-related crashes occur at times of day that follow the human circadian trajectory of alertness; that is, increasing rates of crashes in the night time and early hours of the morning, as well as an increase during the mid-afternoon hours (Åkerstedt & Kecklund, 2001; Connor et al., 2002; Horne & Reyner, 1995; Smith, Armstrong, Steinhardt, & Haworth, 2008). However, due to the unique influence of biological and environmental factors on young adult sleep, their risk of sleepiness-related crashes may potentially be higher at *any time of day* in both urban and rural environments (Obst, Armstrong, Smith, & Banks, 2011).

It is clear from these data that sleepiness is a strong predictor of young driver crash involvement at a *population* level. However in order to mitigate the sleepiness related crash risk of young drivers, it is necessary to quantify the extent to which everyday sleepiness undermines driving performance in young drivers on a *daily* level. A better understanding of the nature of sleepiness in young adults and its influence on young driver behaviour may be the first step in building an intervention program aimed at reducing young driver sleepiness, and thereby reducing the associated injury and mortality risks. To date, the majority of studies assessing young driver sleepiness have relied on analyses of retrospective crash reports, or upon self-reported survey (cross-sectional) data. The exact nature and extent of sleep disturbance on driving in young adults in 'real-time' is yet to be demonstrated. To the best of our knowledge, virtually no prospective evidence exists assessing both sleep and driving in young drivers using *objective* measures. This information is critical to determine if remedies should target the amount or timing of sleep needed for safe driving, or should target other trip parameters such as the timing or duration of driving.

Study Aims

This study utilised a multi-method approach consisting of in-vehicle monitoring technologies to measure driving performance, 24-hour ambulatory assessment of sleep-wake and stress behaviours, as well as sleep and driving diaries and questionnaires in order to understand the relationship between sleepiness, stress and driving related risks in young adults.

The primary aims of this study were to;

(1) Determine the impact of sleepiness on on-road driving performance in young adults;
(2) To contribute to evidence on young adults' exposure to driving while sleepy, and
(3) To determine interactions between sleepiness, stress, and other driving risk factors in young adults.

Method

Design

The study employed a prospective, mixed-methods naturalistic approach to assess the effects of daily variations in sleep and stress on driving performance in young adults. Continuous, day-to-day ambulatory assessment of sleep, stress and driving were collected over the course of 7 days.

Participants

Eighty three young adult drivers aged 18 to 25 years old took part in this study (mean of 21±2 years, 60% female). Participants were recruited from Canberra (ACT), Brisbane (QLD), and surrounds. A combination of advertisement and word of mouth recruitment strategies were used from within community, media, university and TAFE environs. Participants were eligible if they held a current Australian driver's license at any level greater than the Learner license phase and drove regularly (>1hr per week). Participants were ineligible if they had any of the following; current medically diagnosed sleep or mental health disorders, significant health problems affecting daily functioning, night-shift work related employment, or if they had crossed more than 2 time-zones within the past 2 weeks.

Materials

A focussed set of measurement methods were utilised in this study, to provide objective and subjective estimates of sleep-wake states, stress, and driving performance.

Sleep measurement: Actigraphy.

Objective assessment of sleep-wake states was determined using wrist-worn accelerometers (i.e. actigraphy; GENEActiv Original, ActivInsights Ltd). The actigraph is a wrist-watch device that records ambient light (Lux) and movement onto on-board memory in 1-minute epochs. Actigraphy provides a non-invasive and objective method of measuring habitual sleep and activity levels in naturalistic settings (Sadeh & Acebo, 2002). Actigraphy is comparable to polysomnography as a valid and reliable measure of sleep-wake parameters, particularly for sleep onset and wake times (Rupp & Balkin, 2011). Specific sleep dimensions extracted for this study included sleep duration, sleep timing, and night-to-night variations in sleep.

Sleep measurement: Daily diaries.

Daily subjective sleep diary reports were used to supplement objective actigraphy data. Sleep items were based on the Consensus Sleep Diary (Carney et al., 2012) a standardized list of questions that identify sleep-related function, and the Karolinska Sleepiness Scale (Akerstedt & Gillberg, 1990). The Consensus Sleep Diary includes questions pertaining to sleep timing, duration, and quality (rated on a 5 point scale where 1 = ‘very poor’ and 5 =

‘excellent’) each night. The Karolinska Sleepiness Scale (KSS) is a 9 point scale measuring subjective sleepiness. The KSS has been validated against standard laboratory polysomnography. Responses vary on a scale from 1 = ‘extremely alert’, to 9 = ‘very sleepy, great effort to keep awake, fighting sleep’. Items pertaining to daily stress, substance use and regulatory emotional functioning were also included in the daily sleep diary. The primary parameters extracted for analysis were bed-time and wake-time, sleep duration, sleep quality and sleepiness.

Driving measurement: Accelerometry.

On-road driving performance was assessed using small, sensitive, 3-dimensional accelerometers (GP1L, SENSR Inc.) fitted to the participant’s vehicles. These devices objectively record vehicular forces of acceleration and provide an ecologically meaningful assessment of driving performance. Risky driving indices extracted for analysis included elevated g-force events in the lateral (hard left and right turns) and longitudinal planes (hard accelerations and braking). Previous research suggests that elevated g-force events in these dimensions are associated with higher crash risk in young drivers (Lee, Simons-Morton, Klauer, Ouimet, & Dingus, 2011; Simons-Morton, Cheon, Guo, & Albert, 2013; Simons-Morton et al., 2011; Simons-Morton, Zhang, Jackson, & Albert, 2012).

Driving measurement: Driving diaries.

Daily driving diaries were used to supplement data collected from the objective driving measures. Driving time, purpose, and duration were recorded for each trip across the week. Participants were also asked to rate their level of sleepiness, stress, how mentally demanding they found the drive (i.e. how much effort and concentration was required), and their distractibility (i.e. how much they felt their attention wavering during the drive as a result of mind wandering, phone distraction, passenger distraction etc.) on a numbered scale for each driving trip.

Stress measurement: Electrocardiograms

Small wearable electrocardiograms (ECG; *E-Motion Faros, MegaElectronics Pty Ltd*) were used to measure participants' heart rate and heart rate variability (HRV). Some physiological changes associated with the perception of a stressor may include increases in sympathetic activity associated with increased heart rate, whereas parasympathetic influences work within the stress-reactivity framework to lower heart rate (Thayer, Åhs, Fredrikson, Sollers, & Wager, 2012; Ursin & Eriksen, 2004).

Other driving risk measurement: Baseline questionnaire

A questionnaire battery including validated and standardized measures of psychological distress (*Kessler 6*; Kessler et al., 2002), stress (*Perceived Stress Scale*; Cohen, Kamarck, & Mermelstein, 1983), sensation seeking (*Brief Sensation Seeking Scale;* Hoyle, Stephenson, Palmgreen, Lorch, & Donohew, 2002), and general risk taking (*Youth Risk Behavior Survey*; CDC, 2013) was completed by participants online at the beginning of the study. The battery also included a young driver behaviour questionnaire specifically developed for this study. This questionnaire addressed a number of risky young driver behaviours established previously (Scott-Parker, Watson, King, & Hyde, 2012; Williams, 2003), and risky driver avoidance situations (Baldock, Mathias, McLean, & Berndt, 2006).

Procedure

Interested participants were screened via telephone interview according to the eligibility criteria. If eligible, participants were provided with a detailed package of information about their involvement in the study, and asked to return a signed consent form to indicate their willingness to participate. Recruited participants were sent an e-mail link to the baseline questionnaire to complete online. They were also informed that they would need to attend the university campus on two occasions; (1) to install monitoring equipment in their vehicle, and on their person, and (2) to remove the installed equipment following one week of data collection. During the initial equipment installation and setup session, the research assistant explained the use and nature of the study equipment. Participants' vehicles were fitted with accelerometers, and the participants themselves were fitted with actigraphs and electrocardiograms, and given their daily sleep and driving diaries. Participants were instructed that they would need to re-charge their electrocardiograms at home. They were provided with a charging cable and instructions about how to do this. Participants were instructed to 'continue life and driving as normal' while filling in their sleep and driving diaries each day for one week. Following 7 days of data collection, participants returned to the campus to return the study equipment. Participants were compensated $150 (AUD) for their time.

Results

Sample demographic and license characteristics.

Demographic and license characteristics of the sample are detailed in Table 1. The majority of the sample was comprised of university students residing in the ACT, who had been driving on an open license for a period of 1-3 years. Normative data suggest that levels of perceived psychological distress and/or stress experienced by the sample were within the ‘normal’ ranges (Cohen & Williamson, 1988; Kessler et al., 2002), and that sensation seeking propensity was comparable to that reported in a previous validation study of healthy youth (Hoyle et al., 2002).

Table 1.

Demographic, mood, stress and personality characteristics of study participants

Demographic Characteristics	***N = 80***
Mean years of age* (*SD*)	21.28 (2.39)
Gender*	
Female	60%
Male	40%
Highest level of education completed	
PhD/Masters	4%
Bachelor degree	25%
Diploma	6%
Year 12	64%
Year 10	1%
Current student status	
Full-time	85%
Part-time	2.5%
Not a student	12.5%
Residential location	
ACT	69%
QLD	31%
License status	
Provisional 1	24%
Provisional 2	19%
Open	57%
Number of years license held	
<1 year	26%
1-3 years	46%
3-5 years	20%
>5 years	8%
Mood and Personality Characteristics	***M* (*SD*)**
Kessler Psychological Distress Scale Score	11.3 (4.5)
Perceived Stress Scale Score	15.5 (6.5)
Brief Sensation Seeking Scale Score	3.3 (.7)

Note. **N* = 83

Sleep characteristics: Actigraphy and sleep diary data.

Sleep-related characteristics are displayed in Table 2. On average, participants' self-reported sleep time was 8 hours and 12 minutes per night (± 44 minutes). Average subjective sleep quality was rated as '*fair*' (3.5) across the week, with participants reporting their average daily sleepiness as between '*alert*' and '*neither alert not sleepy*'. Actigraphy-based estimates of objective sleep parameters were highly correlated with subjective diary data (wake-time r^2 = .79, bed-time r^2= .83, sleep duration r^2=.*60*).

Table 2

Participant sleep-related characteristics across 7 day study period.

	Sleep Diary *M* (*SD*)	Actigraphy *M* (*SD*)
Bed-time*	23:37 (01:05)	23:26 (00:54)
Wake-time*	07:49 (00:57)	07:50 (00:49)
Sleep duration*	08:12 (00:44)	08:24 (00:54)
Subjective sleep quality	3.5 (.51)	
Subjective sleepiness	4.5 (1.0)	

Note. * = bivariate correlations between self-reported and objective sleep metrics significant at p <.001.

Driving characteristics: Driving diary

The number of hours and kilometres spent driving, including trip purpose and frequency of drives at times of day associated with greater crash risk (e.g. peak hour 1 (7-9am), during the circadian dip in alertness (2-4pm), peak hour 2 (4-6pm) and night driving (10pm-6am)) are displayed in Table 3. Driving diary reported subjective sleepiness, stress, distractibility and mental demand required per trip at those times are reported in Table 4.

Table 3.

Diary reported driving characteristics and proportion of sample participating in drives during times of day associated with highest crash risk

Driving characteristic	***M* (*SD*)**	**% of sample**
Number of kilometres driven per week		
0-200 km		46.3
200-400 km		38.8
400-800 km		13.8
>800 km		1.3
Number of minutes driving per week		
Total	558.8 (256.7)	100
Peak Hour 1 (7-9am)	76.2 (57.6)	13.6
Circadian dip (2-4pm)	71.2 (62.6)	12.7
Peak Hour 2 (4-6pm)	103.5 (56.8)	18.5
Night driving (10pm-6am)	26.2 (40.3)	4.7
Number of driving trips per week		
Total	23.8 (8.2)	100
Peak Hour 1 (7-9am)	3.0 (2.0)	12.6
Circadian dip (2-4pm)	3.0 (2.0)	12.6
Peak Hour 2 (4-6pm)	4.5 (2.0)	18.9
Night driving (10pm-6am)	1.1 (1.4)	4.6
Average number of driving trips for the purpose of;		
Work	5.1	21.1
Social	5.2	21.8
Sport	3.5	14.5
Uni/TAFE	3.4	14.1
Shopping	3.0	12.8
Appointment	0.7	3.1
Leisure	3.0	12.6

The majority of the sample reported driving between 0-200km in a typical week, with at least 50% of their driving occurring at times of the day associated with higher crash risks. Work, social, and sport related drives occupied the majority of trip purposes across the week.

Table 4.

Self-reported ratings of sleepiness, stress, distractibility and mental demand at risky driving times across the day.

Risky Driving Time	***M* (*SD*)**	**% of sample reporting '*high*' or '*very high*' rates of each construct***
Subjective sleepiness		
Peak Hour 1 (7-9am)	4.2 (1.5)	15.4
Circadian dip (2-4pm)	3.8 (1.4)	12.3
Peak Hour 2 (4-6pm)	4.0 (1.4)	12.7
Night driving (10pm-6am)	5.7 (1.7)	56.9
Overall	4.5 (0.9)	24.3
Subjective stress		
Peak Hour 1 (7-9am)	2.1 (0.8)	4.2
Circadian dip (2-4pm)	1.9 (0.7)	0
Peak Hour 2 (4-6pm)	1.9 (0.6)	0
Night driving (10pm-6am)	1.7 (1.0)	4.6
Overall	1.9 (0.6)	4.4
Subjective distractibility		
Peak Hour 1 (7-9am)	2.0 (0.7)	0
Circadian dip (2-4pm)	2.2 (0.8)	0
Peak Hour 2 (4-6pm)	2.2 (0.6)	0
Night driving (10pm-6am)	2.4 (1.1)	13.6
Overall	2.3 (0.6)	13.6
Subjective mental demand		
Peak Hour 1 (7-9am)	2.1 (0.7)	2.8
Circadian dip (2-4pm)	2.0 (0.7)	2.7
Peak Hour 2 (4-6pm)	2.0 (0.7)	1.3
Night driving (10pm-6am)	2.2 (1.0)	4.5
Overall	2.1 (0.6)	2.8

Note. Subjective *sleepiness* was rated on a 9-point scale from 1 = extremely alert, to 9 = very sleepy, great effort to stay awake, fighting sleep; Subjective *stress* was rated on a 5-point scale from 1 = not stressed at all, to 5 = extremely stressed; Subjective *distractibility* and *mental demand* were rated on a 5 point scale from 1 = very low, to 5 = very high. *='High' or 'very high' sleepiness was indicated by a score of 6 or above on the 9 point sleepiness scale.

On average, participants reported feeling approximately "*rather alert*" while driving during the day, with '*some signs of sleepiness'* being reported while driving at night. Subjective stress, distractibility and mental demand required for driving remained at '*very low*' to '*low*' across the day.

Risky driving characteristics

Driver behaviour and attitudes were assessed using the baseline questionnaire. Three participants failed to complete the questionnaire. Data from the remaining 80 participants are presented in subsequent tables. The proportion of participants reporting having engaged in particular sleepy or risky driving behaviours are reported in Table 5. Nearly 9% of the sample reported having fallen asleep while driving in the past year. One participant reported experiencing a near-hit as a result of falling asleep behind the wheel. No instances of crash as a result of falling asleep were reported.

Approximately 12% of the sample reported driving when they suspected that they were over the legal blood alcohol limit to drive, and nearly 9% of the sample reported being a passenger in a vehicle driven by someone else who may have been drunk.

The majority of participants (over 80%) reported using their mobile to call, text, or email while driving in the past month. Hands-free devices were used only '*rarely*' in these cases.

Table 5

Sleepy and risky driving characteristics of sample

Driving characteristics	***n***	**% of sample**
Sleepy Driving		
Number of participants who fell asleep while driving in the *past year*	7	8.8
Number of participants who fell asleep while driving and experienced a near hit or crash in the *past year*	1	1.2
Drink Driving (past 30 days)		
Number of participants who drove a car while believing *they* were over the legal BAC limit	10	12.3
Number of participants who rode in a car being driven by *someone else* they believed was over the legal BAC limit	7	8.6
Mobile phone use (past 30 days)		
Number of participants who used their mobile phone while driving*	65	81.3
Frequency of risky driving behaviours engaged in during past month^{+}	***M* (*SD*)**	
Frequency of driving while finding it difficult to stay awake $^{\#}$	1.7 (.7)	
Frequency of texting while driving	3.3 (1.4)	
Frequency of calling someone while driving	3.1 (1.5)	
Frequency of hands-free use during calls	3.6 (1.9)	

Note. BAC = Blood alcohol concentration; *= Use of mobile phone in general to call/text/email. $^{+}$=Frequencies were measured on a 6-point Likert scale where 1 = never and 6 = always. $^{\#}$ = Near sleep driving frequency measured on a 7-point Likert scale were 1 = never and 7 = every time.

Sleepy driving behaviours and attitudes

Paired samples t-tests were conducted on driver avoidance items in the baseline questionnaire in order to assess perceived differences in behaviour and attitudes towards driving under 'normal' conditions versus driving while sleepy. The results of these comparisons are presented in Table 6.

Participants reported behaving differently under a number of driving conditions as a result of perceived sleepiness. Participants were *more likely* to avoid driving with passengers, driving at night, and driving in general if they were already feeling sleepy. Participants also reported that they were *less likely* to drive in general, and *less likely* to avoid wearing a seatbelt, if they were already feeling sleepy.

Table 6.

Means, standard deviations and paired t-test results comparing driver avoidance behaviours under normal and sleepy conditions.

Driver avoidance item	**Under normal conditions** ***M*** **(*SD*)**	**When feeling sleepy** ***M*** **(*SD*)**
To what extent do you avoid:		
Driving with one or more passengers in the car	1.9 (1.4)	2.8 (1.7)*
Driving while under the influence of alcohol	5.0 (1.8)	4.9 (1.9)
Driving while under the influence of illicit drugs	4.9 (2.0)	4.9 (2.0)
Driving (while sleepy)	3.6 (1.1)	3.0 (1.5)*
Letting emotions affect your driving style	3.4 (1.5)	3.7 (1.7)
Wearing a seatbelt	2.6 (2.3)	1.5 (1.5)*
Driving at night (10pm-6am)	2.7 (1.6)	3.8 (1.7)*
Driving over the speed limit	4.1 (1.4)	4.2 (1.6)
Distractions (e.g. mobile phone use/talking with passengers etc)	3.8 (1.3)	4.3 (1.6)*

Note. Driver avoidance items were rated on a 6-point Likert scale where 1 = “never avoid”, and 6 = “always avoid”; * Paired samples t-test is significant, p<.001.

Participant's attitudes and beliefs about sleepy driving are displayed in Table 7. In general, the majority of participants believed that individuals should not drive whilst sleepy, and understood that sleepy driving may impact on their judgement and ability to drive safely. In contrast, sleepy driving was not viewed to be as dangerous as drink/drug driving, with the majority of participants reporting little impairment to their decision making and distractibility following sleepiness.

Table 7.

Attitudes and beliefs about sleepy driving

Attitude	*M* (*SD*)	% of sample reporting 'agree' or 'strongly agree'
Driving while sleepy impacts on my ability to drive safely	2.4 (1.0)	81%
A driver should not drive if he or she is sleepy	3.7 (.8)	63%
I make bad driving decisions if I drive while sleepy	3.0 (1.0)	30%
Driving under the influence of alcohol or drugs is more dangerous than driving while sleepy	3.9 (1.0)	66%
My judgement is impaired if I drive while sleepy	2.6 (1.0)	80%
Sleepy driving is more dangerous than speeding	3.6 (1.0)	56%
I tend to get easily distracted if I drive while sleepy	3.0 (1.0)	38%

Note. Attitudes/beliefs were rated on a 5-point Likert scale where 1 = "strongly disagree" and 5 = "strongly agree".

Objective driving performance and sleepiness

Accelerometry data from 8 participants was missing due to technical failure. Data from the remaining 75 participants is presented in the following analyses.

Over the course of 7 days, participants recorded an average of 124 hard acceleration events (>.35g), 115 hard braking events (≤ -0.45g), 149 hard left turning events (≤ -0.05) and 129 hard right turning events (≥0.05g). In order to investigate the relationship between objective risky driving performance indicators and sleepiness, a composite 'risky driving' variable was created out of the 4 individual risky driving indicators (hard braking/accelerating, and hard left/right turning) to use in subsequent analyses. This composite was based on methods described in previous papers (Simons-Morton et al., 2013; Simons-Morton et al., 2011; Simons-Morton et al., 2012).

Due to the non-normal distribution of the data, two outliers were removed and the data underwent log transformations to ensure normal distribution for analysis. Partial correlations controlling for age (i.e. an index of inexperience) were conducted in order to test the association between objective risky driving and sleep related variables (see Table 8).

Results indicate that objective 'risky' driving performance (i.e. drivers who experienced a greater number of hard braking/accelerating/turning events) was significantly and positively associated with length of time driving each week (an exposure effect), and negatively associated with objective sleep duration (i.e. *higher* incidents of risky driving were associated with *shorter* sleep durations) overall.

However, risky driving performance was also *negatively* associated with subjective ratings of sleepiness during risky driving times (i.e. individuals who reported feeling more sleepy were less likely drive in a risky manner).

Table 8.

Partial correlations+ between driving performance and sleep related variables

Driving and Sleepiness Indicators	1.	2.	3.	4.	5.	6.
1. Risky driving performance (accelerometers)	1					
2. Number of minutes driven per week (driving diaries)	**.55***	1				
3. Bed-time	.19	-.08	1			
4. Wake-time	-.12	-.02	**.48****	1		
5. Sleep duration	**-.32***	-.01	**-.57****	**.46****	1	
6. Subjective sleepiness at risky driving times#	**-.35***	-.28	-.18	-.24	-.01	1

Note. +Age included as control variable; Due to the high correlation between objective and subjective sleep-timing factors (bed-time, wake-time and duration), only objective sleep estimates were used in correlation analysis. # Risky driving times = average subjective ratings during peak hour 1 (7-9am), circadian dip (2-4pm), peak hour 2 (4-6pm) and night driving (10pm-6am); *p≤.05, **p≤.01

Sleepiness and stress related driving risk factors

Non-parametric correlation analyses were run to assess associations between sleep and stress related driving risk factors (see Table 9). Subjective 'trait' levels of stress as assessed by the Perceived Stress Scale were significantly associated with perceived 'state' levels of subjective stress while driving. Subjective stress and mental demand were significantly associated during risky driving times. Also, the degree to which participants felt they were distractible while driving was significantly associated with their objective bed-times (i.e. the later the habitual bedtime the more distractible the driver), and negatively associated with habitual sleep duration (i.e. the shorter the habitual sleep duration the more distractible the driver). No other significant associations between sleepiness or stress related driving risk factors were observed.

Table 9.

Bivariate correlations between sleepiness and stress related driving risk factors

Sleepiness and stress Indicators	1.	2.	3.	4.	5.	6.	7	8
1. Bed-time	1							
2. Wake-time	**.39****	1						
3. Sleep duration	**-.49****	**.48****	1					
4. PSS+	-.05	.11	.08	1				
5. Subjective sleepiness at risky driving times#	-.21	-.17	-.01	.14	1			
6. Subjective stress at risky driving times	.08	-.05	-.11	**.34***	.07	1		
7. Subjective mental demand at risky driving times	.07	-.04	-.11	.07	.29	**.37***	1	
8. Subjective distractibility at risky driving times	**.41***	.14	**-.51****	.23	.05	.20	.27	1

Note. + =Perceived Stress Scale; # Risky driving times = average subjective ratings during peak hour 1 (7-9am), circadian dip (2-4pm), peak hour 2 (4-6pm) and night driving (10pm-6am); *p≤.05, **p≤.01

Discussion

The primary aims of this study were to;

(1) Determine the impact of sleepiness on on-road driving performance in young adults;

(2) To contribute to evidence on young adults' exposure to driving while sleepy, and;

(3) To determine interactions between sleepiness, and stress related driving risk factors in young adults.

The majority of young drivers in this study were meeting the current National Sleep Foundation guidelines for sleep duration (i.e. sleeping between 7 to 9 hours per night) and did not appear to be habitually sleep deprived. Although approximately 50% of drives were occurring at times of day associated with greater risk of crashes, and during periods where high subjective sleepiness would be expected, self-reported driving diary data suggested that drivers were not significantly sleepy nor stressed while driving at these times. These young drivers also reported low levels of distractibility, and did not find driving mentally taxing.

However, approximately 8% of the sample *were* sleeping less than 7 hours per night, which may constitute a real-world safety risk to these young drivers and the public. Previous studies have modelled subjective sleepiness rating against real world crash risk (Akerstedt et al., 2008), and found that for every 1 unit increase in subjective sleepiness on the KSS, the odds of sustaining a crash *multiply* by 1.72 (i.e. crash risk increases *exponentially* as subjective sleepiness increases). Thus, whilst feeling '*rather alert*' during daytime-driving may seem innocuous, the subsequent increase to feeling '*some signs of sleepiness'* when driving at night (as exemplified by changes in KSS scores in this study) equates to nearly a 3.5 fold increase in the odds of sustaining a crash. A better understanding of the way in which small changes in sleepiness may serve to undermine driving performance could be a stepping point in the planning of targeted public education campaigns aimed at reducing sleepiness-related road crash risk.

The objective driving data collected in this study suggested a significant negative association between risky driving performance and habitual sleep duration. These data suggest that individuals who are sleeping less are driving more dangerously. There was also a trend suggesting that high subjective sleepiness at times of day associated with increased crashes (e.g. at morning peak hour, afternoon alertness dip, afternoon peak hour, and night time) was associated with *fewer* instances of risky driving. It is unclear why this may be the case. This is the first study to assess objective naturalistic driving performance and sleepiness in young adults, and it is possible that there are factors at play that have not been accounted for in these preliminary analyses. There may be a difference in the way in which objective and subjective estimates of sleepiness relate to driving performance, and in the way objective changes in sleepiness are perceived by the driver. It is also possible, that completing the driving diary and reporting on subjective sleepiness contributed to a heightened sense of 'self-awareness' while driving.

Sleepy driving attitudes revealed in the questionnaire suggest that the majority of young drivers understand that sleepy driving is dangerous and should be avoided. However there appears to be a lack of understanding about the cognitive deficits associated with sleepiness (i.e. poor decision making and increased distraction), with many young drivers believing these faculties to be undisturbed as a result of sleepiness. Sleepy driving was also viewed as less dangerous than drink/drug driving, identifying a need for further education to shift perspectives of risk in this group.

Limitations

The present study had a number of limitations. As a naturalistic study, it is possible that some variables influencing the results could not be controlled or specified. However we attempted to be as robust as possible in terms of ensuring a targeted age range, strict eligibility criteria, use of objective measures, and by standardising instructions and materials across participants.

Another limitation is that the sleep and driving related variables were averaged across the week. This approach provides good measurement stability, but there is some evidence to suggest that young adults in particular may demonstrate large weekend to weekday variability, and day-to-day variability in sleep timing (Klerman & Dijk, 2005) depending on life circumstances. Current evidence supports differences in performance as a result of 'habitual' or 'chronic' sleep deprivation, and the effects of 'acute' or 'once-off' sleep deprivation (Rossa, Smith, Allan, & Sullivan, 2014; Van Dongen et al., 2003). Sleep is a dynamic construct, and the way in which sleep loss deficits are expressed may vary across individuals, and across risky behaviours (Rossa, Sawhney, Allan & Smith, 2015). Further analyses testing day-to-day associations between sleepiness and driving behaviours are needed.

Finally, this study consisted of a convenience sample of young adults predominantly from university environments. The majority of participants were highly educated, and their beliefs and behaviours may not reflect the driving styles or sleepiness habits of the broader youth population.

Strengths

The present study was the first prospective study to investigate the sleepiness and driving habits of young adults. The use of in-vehicle and on-person 24-hour monitoring allowed for a multidimensional but objective understanding of young adult behaviour. One strength of this study was the objective assessment of the 'everyday' sleep-wake habits of young adults using actigraphy. The actigraph has been well validated against standard polysomnography in detecting sleep-wake parameters in both healthy and sleep disordered populations (Ancoli-Israel et al., 2003).The American Academy of Sleep Medicine (AASM) champions the use of actigraphy as the most empirically reliable and robust method for long-term continuous measurement of sleep-wake behaviours in situations where standard polysomnography is neither practical nor cost-effective (AASM, 1995).

Continuous monitoring of 'real-life' risky driving performance using accelerometers was another significant strength of this study. The assessment of elevated kinematic forces during driving has demonstrable power in predicting crash and near-crash rates in young drivers (Simons-Morton et al., 2013; Simons-Morton et al., 2011; Simons-Morton et al., 2012). This study is the first to use actigraphy *in combination* with vehicle accelerometry for safety monitoring of young drivers.

Finally, prospective sampling of a large number of participants over a representative period, across sites, and at different times of the year ensured a broad snapshot of young adult driving behaviours.

Conclusion

Sleepiness measurably impacts on young driver performance. Current interventions rely upon subjective identification of sleepiness, an evaluation of sleepiness as a risk, and identification of an effective countermeasure. This study identified a discrepancy between subjective and objective impacts of sleep duration and other sleep characteristics on safety-related driving behaviours. Key messages that could be incorporated into future interventions include:

- Road crash remains a major cause of death for young adults.

- Sleepiness impairs cognitive functions essential for safe driving.
- Better sleep is associated with safer driving.
- Sleep duration, quality and regularity should be promoted to reduce driving risk.
- Young drivers may not be good judges of their sleepiness.
- Self-regulation strategies may help individuals to reduce their risk.

The data and results from this study have improved our understanding of the relationships between sleep, stress, other risk factors and driving behaviours in young adult drivers. Well-controlled trials addressing sleepiness-related driving risks are needed to improve the level of evidence for current interventions, to broaden the range of available interventions, and to span the spectrum from individual-level to public health- level interventions.

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