Original Investigation

Sleep-Deprived Young Drivers and the Risk for Crash
The DRIVE Prospective Cohort Study

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IMPORTANCE Short sleep duration is common in adolescents and young adults, and short sleep duration is a risk factor for motor vehicle crash.

OBJECTIVE To assess the association between hours of sleep and the risk for motor vehicle crash, including the time of day of crash and types of crash (single, multiple vehicle, run off road, and intersection).

DESIGN Prospective cohort study.

SETTING New South Wales, Australia.

PARTICIPANTS Questionnaire responses were obtained from 20 822 newly licensed drivers aged 17 to 24 years. Participants held a first-stage provisional license between June 2003 and December 2004 prospectively linked to licensing and police-reported crash data, with an average of 2 years of follow-up. Analyses were conducted on a subsample of 19 327 participants for which there was full information.

EXPOSURE Sleeping 6 or fewer hours per night.

MAIN OUTCOMES AND MEASURES The main outcome variable was police-reported crash. Multivariable Poisson regression models were used to investigate the role of sleep duration on the risk for crash.

RESULTS On average, those who reported sleeping 6 or fewer hours per night had an increased risk for crash compared with those who reported sleeping more than 6 hours (relative risk [RR], 1.21; 95% CI, 1.04-1.41). Less weekend sleep was significantly associated with an increased risk for run-off-road crashes (RR, 1.55; 95% CI, 1.21-2.00). Crashes for individuals who had less sleep per night (on average and on weekends) were significantly more likely to occur between 8 PM and 6 AM (RR, 1.86; 95% CI, 1.11-3.13, for midnight to 5:59 AM and RR, 1.66; 95% CI, 1.15-2.39, for 8:00 PM to 11:59 PM).

CONCLUSIONS AND RELEVANCE Less sleep per night significantly increased the risk for crash for young drivers. Less sleep on weekend nights increased the risk for run-off-road crashes and crashes occurring in the late-night hours. This provides rationale for governments and health care providers to address sleep-related crashes among young drivers.

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Every day, more than 3000 people die in motor vehicle crashes around the world, amounting to more than 1.3 million motor vehicle–related deaths worldwide each year—and between 20 million and 50 million more are injured and often left disabled for life.[1] Motor vehicle crashes also have a huge economic impact worldwide, responsible for up to 3% of a country's gross national product costs per year.[1] In the United States, it is estimated that drowsy driving is responsible for 20% of all motor vehicle crashes, meaning that in the United States alone, drowsy driving may cause 1 million crashes, 50 000 injuries, and 8000 deaths each year.[2] Young drivers are involved in a disproportionate number of these crashes.[3] Adolescents and young adults are at particular risk for sleep deprivation. There are many lifestyle factors that lead to reduced sleep hours in adolescents and young adults, including biological development, academic responsibilities, socialization, and employment, as well as increased use of electronic communication devices.[4-6] Population-based data indicate young adults sleep less than older adults.[7] Moreover, identical periods of experimental sleep deprivation result in greater sleepiness and impaired attention in younger adults compared with healthy elderly people.[8] This higher biological sleep need reflects developmental changes in sleep, arousal, and circadian regulation.[4,9]

Worldwide, adolescents frequently say they get inadequate sleep and experience daytime sleepiness,[10] including 60% of US youth aged 17 to 24 years.[11] Complaints of sleepiness are associated with lapses in attention, slowed reaction time, impairments in judgment, difficulty regulating emotions including increased aggression, and risky behavior; these effects are magnified when alcohol is also involved.[4,5,9,10,12-22] Young drivers (aged <25 years) are at the highest risk for sleep-related motor vehicle crashes.[4,13,23-25] Australian data show that although only 20% of their driving occurs at night,[24] 60% of young driver deaths happen at night,[26] with a US study showing 37% of such deaths occur on weekend nights.[25] While all drivers have a greater risk for crashing at night, existing data suggest young drivers are at even greater risk, potentially with lack of sleep a contributing factor. For drivers of all ages, estimates in the United States, United Kingdom, and Australia report that between 5% and 30% of crashes are attributed to fatigue.[3,24,27-31] Young drivers report driving while tired, with 51% of US young drivers reporting driving while drowsy and 9% reporting nodding off while driving in the past year.[32] Not only are they more likely to have sleep-related crashes, these crashes are more likely to be fatal compared with other crash causes.[33] In one study, young driver crashes classified as fatigue related tended to be single-vehicle crashes if they occurred during the night, but they were more often head-on crashes during the day.[24]

Importantly, to our knowledge, previous studies of crash risk due to sleepiness have not focused on young drivers and have mainly had descriptive,[34] case-control, or retrospective cohort designs.[27,35,36] While these studies have provided valuable information, retrospective designs risk biased exposure information. For example, information on sleep collected after a crash could be affected by social desirability response bias. Also, data on fatigue-related crashes are often subjectively reported by police at the crash scene. Another important limitation of many previous studies is the inability to control for important confounders such as driving exposure, psychological disturbances, urban/rural status, alcohol use, and risk taking. A prospective study allows the opportunity to collect information on chronic sleepiness and other possible confounders, such as alcohol use and mental health, before the crash occurs. Therefore, we used a large prospective cohort study to determine the role of sleep on the risk for future motor vehicle crashes. Specifically, we aimed to determine crash risk in young drivers according to the number of sleep hours per night, the relationship between weekday and weekend sleep hours and crash risk, and relationships for different types and times of crashes among those who crashed.

Methods

The Drive Study

Data were derived from the DRIVE Study, a prospective cohort of 20 822 drivers aged 17 to 24 years in New South Wales (NSW), Australia. Detailed information on participant heterogeneity and study methods have been reported elsewhere.[37] In brief, all drivers resident in NSW aged 17 to 24 years holding a first-stage provisional license between June 2003 and December 2004 were invited to participate. Follow-up data were collected until the a priori selected completion date of December 31, 2005. An online baseline survey queried sleep hours (weekends and weekdays), as well as demographics, driving exposure, driver training, drug and alcohol use, risky driving, and sensation seeking. All respondents gave consent for their survey data to be linked prospectively to data held by the state jurisdictional authority, the Roads and Traffic Authority, including information about police-reported crashes. Average follow-up time was 2 years. Ethics committees of the University of Sydney and NSW Health approved the study.

Study Sample

Of 131 000 eligible new drivers, 20 822 (16%) participated in the DRIVE Study. Analyses were conducted on a subsample of 19 327 participants for which there was full information on sleep duration (1087 participants had missing data), risky driving behaviors (318 missing), and average weekly driving hours (90 missing). In this sample, there were 1383 crashes (of which 280 were single vehicle and 305 run off road).

Study Outcome: Crash

The outcome variable was police-recorded crash as a driver. In NSW, a crash is recorded by police when a person is killed or injured; when the crash is a hit and run; when damage to property is more than A$500; when 1 or more of the drivers was reported to be driving under the influence of alcohol; or if a vehicle involved in the crash was towed away. We classified this primary outcome as binary (ie, none vs 1 or more crashes), as well as the secondary outcomes of crash times and crash types (eg, a type of crash vs all other crashes). Thus, the secondary analyses had a reduced sample size, including only those who crashed, to determine the unique role sleep duration may have played.

Study Exposure: Sleep

Total sleep hours were assessed at the time of the baseline survey by asking: "During the past month, about how long have you slept for each night (weekday hours) and (weekend hours)?"—a standard assessment used in large epidemiological studies reporting on the consequences of sleep duration (eg, National Health and Nutrition Examination Survey).[38] Values provided were rounded to the nearest integer value. The weighted average of weekday and weekend sleep hours was used to determine average sleep duration. Sleep was categorized according to 3 classifications: average sleep hours per week, average weekday sleep hours, and average weekend (Saturday and Sunday) sleep hours. We contrasted sleep hours within each classification as 6 or fewer hours vs more than 6 hours. Previous research has focused on a 5-hour cutoff[13,27] when exploring crash risk, but a 6-hour cutoff for other health risks.[11,14,15] Because sleeping 6 or fewer hours is expected to affect more of the population, this cutoff was chosen owing to its anticipated public health impact.[11,14,15]

Confounders

Confounding variables were collected at the time of the baseline survey, including age group (17, 18-19, or 20-24 years), sex, average weekly driving hours (≤2, 3-4, 5-9, or ≥10 hours), remoteness of residence (urban, inner region, or rural),[39] drinking behavior (Alcohol Use Disorders Identification Test score <7 or ≥7),[40] and risky driving behaviors (adapted from Donovan and Jessor[41] and the University of Otago Young Driver Pilot Study[42]), such as speeding (categorized as low, medium, and high frequency), self-harm (yes/no),[43,44] crash history (yes/no), drug-use habit (never, ≤1/month, 2-4 times/month, 2-3 times/week, and ≥4 times a week),[45] sensation seeking (low, medium, and high),[46] and Kessler Psychological Distress Scale score (low, moderate, high, and very high).[47,48] The information collected on confounders refers to the 1 month preceding the baseline survey, except for the question about self-harm, which refers to the 12 months preceding the baseline survey.

Statistical Analyses

Relative risks (RRs) for the association between sleep duration (hours) and crash involvement were calculated using Poisson regression. Poisson regression models were used, which allows for an offset that takes into account time in the study since subject entry and exit from the study, and thus time at risk for crash varied. All models controlled for prior crashes. To examine the association between sleep hours and crashes, we forced all confounders into the model, while for sleep hours and crash types we forced only age group, sex, average weekly driving hours, remoteness of residence, and drinking behavior owing to smaller sample sizes. Interaction terms involving sleep hours were added individually to regression models, and a likelihood ratio test was used to compare model with interaction terms vs model without interaction terms. We intended to retain these interactions for P values less than .05; however, no interaction was significant. SAS version 9.1 was used for all analyses.[49]

Results

Young drivers' sleep hours by crash risk factors are presented in the **Table** for weekday and weekend nights. Older drivers (aged 18-19 and 20-24 years) were more likely to sleep 6 or fewer hours per night than younger drivers (aged 17 years); 10% of 17-year-old subjects, 15% of 18- to 19-year-old subjects, and 17% of 20- to 24-year old subjects slept 6 or fewer hours a night. There was no difference in sleep hours by remoteness of residence. Men and women reported sleeping approximately an equal numbers of hours, except women slept less than men on weekends. Drivers who slept fewer hours per night drove more hours than those who slept more. Risky driving, sensation seeking, self-harm, higher Kessler Psychological Distress Scale score, and greater drug and alcohol intake were reported more often by individuals who obtained less sleep.

Figure 1 presents the RRs for crash by average hours of sleep per day. In unadjusted models, shorter sleep duration was significantly associated with increased crash risk for 6 or fewer hours vs more than 6 hours of sleep a night (RR, 1.36; 95% CI, 1.17-1.57). Adjusted models demonstrated a slightly attenuated risk for crash (RR, 1.21; 95% CI, 1.04-1.41). Shorter sleep duration per night was significantly related to multiple vehicle crashes (≤6 hours vs >6 hours of sleep a night; RR, 1.30; 95% CI, 1.11-1.53). Run-off-road-type crashes neared significance in the relationship with shorter sleep duration (≤6 hours vs >6 hours of sleep a night; RR, 1.37; 95% CI, 1.00-1.89). Less sleep per night (≤6 hours vs >6 hours) was significantly associated with crashes occurring in 2 periods: midnight to 5:59 AM (RR, 1.86; 95% CI, 1.11-3.13) and 8:00 PM to 11:59 PM (RR, 1.66; 95% CI, 1.15-2.39).

Figure 2 presents the RRs for crash by average hours of sleep per weekday night. In unadjusted models, shorter sleep duration was significantly associated with increased crash risk (RR, 1.20; 95% CI, 1.05-1.38). Adjusted models demonstrated a slightly attenuated risk for crash (RR, 1.12; 95% CI, 0.97-1.29). Shorter sleep duration per night was significantly related to multiple-vehicle crashes (≤6 hours vs >6 hours of sleep a night; RR, 1.19; 95% CI, 1.02-1.38). Less sleep per night (≤6 hours vs >6 hours) was not significantly associated with crashes occurring in any particular period.

Figure 3 presents the RRs for crash by average hours of sleep per weekend night. In unadjusted models, shorter sleep duration was significantly associated with increased crash risk (RR, 1.24; 95% CI, 1.10-1.39). Adjusted models demonstrated risk for crash, but they were nonsignificant for 6 or fewer hours vs more than 6 hours of sleep per night (RR, 1.08; 95% CI, 0.95-1.23). Shorter sleep duration per weekend night was significantly related with run-off-road-type crashes (≤6 hours vs >6 hours of sleep a night; RR, 1.55; 95% CI, 1.21-2.00). Less sleep per night (≤6 hours vs >6 hours) was significantly associated with crashes occurring in 2 periods: midnight to 5:59 AM (RR, 1.78; 95% CI, 1.13-2.80) and 8:00 PM to 11:59 PM (RR, 1.42; 95% CI, 1.03-1.94). Results for sleeping 5 or fewer hours a night were similar to the findings for those sleeping 6 or fewer hours per night.

Discussion

This study demonstrated that sleeping 6 or fewer hours per night, similar to 5 or fewer hours, is associated with an increased risk for motor vehicle crashes among young drivers. This increased risk remained even after controlling for confounders including exposure to driving.[12-18] Reduced average sleep hours per night

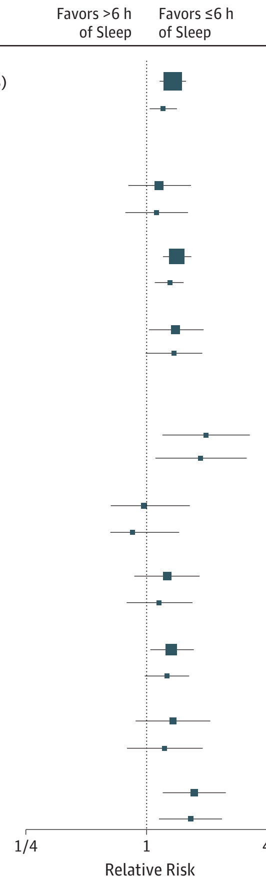
Table. Description of Factors by Average Hours of Sleep Per Night[a]

	Average Sleep Hours/Night, No. (%)				
	Weekdays		Weekends		
	≤6 (n = 2759)	>6 (n = 16 568)	≤6 (n = 3963)	>6 (n = 15 364)	Total (N = 19 327)
Age group, y					
17	1083 (39.3)	8336 (50.3)	1785 (45.0)	7634 (49.7)	9419 (48.7)
18-19	1138 (41.3)	6057 (36.6)	1667 (42.1)	5528 (36.0)	7195 (37.2)
20-24	538 (19.5)	2175 (13.1)	511 (12.9)	2202 (14.3)	2713 (14.0)
Sex					
Male	1300 (47.1)	7525 (45.4)	1596 (40.3)	7229 (47.1)	8825 (45.7)
Female	1459 (52.9)	9043 (54.6)	2367 (59.7)	8135 (52.9)	10 502 (54.3)
Average driving, h					
<2	519 (18.8)	3306 (20.0)	484 (12.2)	3341 (21.8)	3825 (19.8)
3-4	423 (15.3)	3187 (19.2)	583 (14.7)	3027 (19.7)	3610 (18.7)
5-9	719 (26.1)	5006 (30.2)	1241 (31.3)	4484 (29.2)	5725 (29.6)
≥10	1098 (39.8)	5069 (30.6)	1655 (41.8)	4512 (29.4)	6167 (31.9)
Risk-taking level					
Low	789 (28.6)	5921 (35.7)	825 (20.8)	5885 (38.3)	6710 (34.7)
Medium	900 (32.6)	5422 (32.7)	1300 (32.8)	5022 (32.7)	6322 (32.7)
High	1070 (38.8)	5225 (31.5)	1838 (46.4)	4457 (29.0)	6295 (32.6)
Residential remoteness					
Urban	2234 (81.0)	12 161 (73.4)	2886 (72.8)	11 509 (74.9)	14 395 (74.5)
Inner region	444 (16.1)	3629 (21.9)	898 (22.7)	3175 (20.7)	4073 (21.2)
Rural	81 (2.9)	778 (4.7)	179 (4.5)	680 (4.4)	859 (4.4)
Self-harm					
Yes	351 (12.7)	1148 (6.9)	469 (11.8)	1030 (6.7)	1499 (7.8)
No	2329 (84.4)	15 187 (91.7)	3430 (86.6)	14 086 (91.7)	17 516 (90.6)
Unknown	11 (0.4)	233 (1.4)	64 (1.6)	248 (1.6)	312 (1.6)
Crash history					
Yes	909 (33.0)	4804 (29.0)	1453 (36.7)	4260 (27.7)	5713 (29.6)
No	1839 (66.7)	11 713 (70.7)	2495 (63.0)	11 057 (72.0)	13 552 (70.1)
Unknown	11 (0.4)	51 (0.3)	15 (0.4)	47 (0.3)	62 (0.3)
Kessler score					
Low	486 (17.6)	5096 (30.8)	898 (22.7)	4684 (30.5)	5582 (28.9)
Moderate	924 (33.5)	6480 (39.1)	1455 (36.7)	5949 (38.7)	7404 (38.3)
High	898 (32.6)	3909 (23.6)	1153 (29.1)	3654 (23.8)	4807 (24.9)
Very high	442 (16.0)	1023 (6.2)	445 (11.2)	1020 (6.6)	1467 (7.6)
Unclassified	9 (0.3)	60 (0.4)	12 (0.3)	57 (0.4)	69 (0.4)
Sensation score					
Low	705 (25.6)	5400 (32.6)	814 (20.5)	5291 (34.4)	6105 (31.6)
Medium	821 (29.8)	5417 (32.7)	1110 (28.0)	5128 (33.4)	6238 (32.3)
High	1209 (43.8)	5582 (33.7)	1991 (50.2)	4800 (31.2)	6791 (35.1)
Unclassified	24 (0.9)	169 (1.0)	48 (1.2)	145 (0.9)	193 (1.0)
Drinks/wk					
<7	2340 (84.8)	14 422 (87.1)	2969 (74.9)	13 793 (89.8)	16 762 (86.7)
>7	419 (15.2)	2141 (12.9)	994 (25.1)	1566 (10.2)	2560 (13.3)
Unknown	0 (0)	5 (0)	0 (0)	5 (0)	5 (0)
Drug-use habit, times/mo					
Never	2491 (90.3)	15 452 (93.3)	3444 (86.9)	14 499 (94.4)	17 943 (92.8)
1	182 (6.6)	823 (5.0)	360 (9.1)	645 (4.2)	1005 (5.2)
2-4	52 (1.9)	172 (1.0)	110 (2.8)	114 (0.7)	224 (1.2)
2-3	17 (0.6)	32 (0.2)	26 (0.7)	23 (0.2)	49 (0.3)
≥4 times/wk or more	14 (0.5)	27 (0.2)	16 (0.4)	25 (0.2)	41 (0.2)
Unknown	3 (0.1)	62 (0.4)	7 (0.2)	58 (0.4)	65 (0.3)

[a] All adjusted models included age, sex, exposure to driving, remoteness of residence, and alcohol; for crashes, we added the supplementary variables of previous crash, self-harm, Kessler Psychological Distress Scale score, sensation-seeking scale, and drug use.

Figure 1. Relative Risk for Crash by Average Sleep Hours per Day (>6 Hours vs ≤6 Hours)

	≤6 h of Sleep No. of Crashes/ Total No. of Participants (%)	>6 h of Sleep No. of Crashes/ Total No. of Participants (%)	Relative Risk (95% CI)
Driver had a crash			
Unadjusted	202/2156 (9.37)	1181/17 171 (6.88)	1.36 (1.17-1.57)
Adjusted*			1.21 (1.04-1.41)
Crash type			
Single vehicle			
Unadjusted	35/1989 (1.76)	245/16 235 (1.51)	1.16 (0.82-1.65)
Adjusted*			1.13 (0.79-1.61)
Multiple vehicles			
Unadjusted	167/2121 (7.87)	936/16 926 (5.53)	1.42 (1.21-1.67)
Adjusted*			1.30 (1.11-1.53)
Run off road			
Unadjusted	45/1999 (2.25)	260/16 250 (1.60)	1.40 (1.02-1.92)
Adjusted*			1.37 (1.00-1.89)
Crash time			
12:00 AM-5:59 AM			
Unadjusted	19/1973 (0.96)	78/16 068 (0.49)	1.98 (1.20-3.25)
Adjusted*			1.86 (1.11-3.13)
6:00 AM-8:59 AM			
Unadjusted	16/1970 (0.81)	133/16 123 (0.82)	0.98 (0.58-1.64)
Adjusted*			0.86 (0.51-1.45)
9:00 AM-12:59 PM			
Unadjusted	32/1986 (1.61)	205/16 195 (1.27)	1.27 (0.88-1.84)
Adjusted*			1.16 (0.80-1.69)
1:00 PM-5:59 PM			
Unadjusted	73/2027 (3.60)	442/16 432 (2.69)	1.33 (1.04-1.71)
Adjusted*			1.26 (0.98-1.62)
6:00 PM-7:59 PM			
Unadjusted	25/1979 (1.26)	150/16 140 (0.93)	1.35 (0.88-2.07)
Adjusted*			1.23 (0.80-1.90)
8:00 PM-11:59 PM			
Unadjusted	37/1991 (1.86)	173/16 163 (1.07)	1.73 (1.21-2.48)
Adjusted*			1.66 (1.15-2.39)

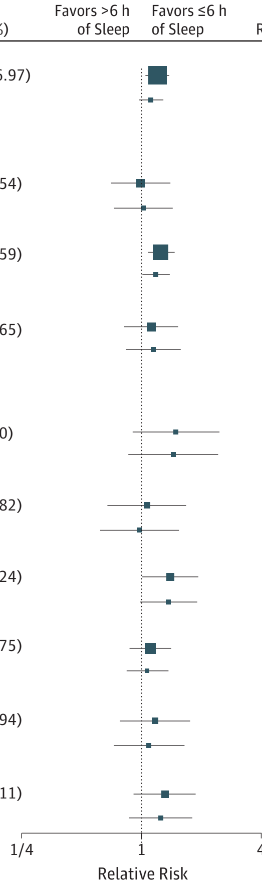


*Adjusted analyses of all crashes by sleep hours controlled for time in the study, prior crashes, age group, sex, average weekly driving hours, remoteness of residence, drinking behavior (Alcohol Use Disorders Identification Test score), risky driving behaviors, self-harm, drug use, sensation seeking, and psychological distress. Adjusted analyses of crash types by sleep hours controlled for time in the study, prior crashes, age group, sex, average weekly driving hours, remoteness of residence, and driving behavior owing to smaller sample sizes.

was also significantly associated with crashes occurring between 8 PM and 6 AM. Importantly, this study also found that reduced sleep hours on the weekends was significantly associated with an increased risk for run-off-road crashes and crashes occurring between 8 PM and 6 AM. Our findings offer a potential improvement over past research of sleep and crash that have focused on a 5-hour cutoff, which is a less common level of reduced sleep hours, and have been retrospective or case-control studies and thus more likely to have had important biases.[24,27,50,51] Previous studies have observed greater magnitudes of crash risk for those who are sleepy (RR, 8.2; 95% CI, 3.4-19.7), have had fewer than 5 hours of sleep (RR, 2.7; 95% CI, 1.4-5.4), drive between 2 AM and 5 AM (RR, 5.6; 95% CI, 1.4-22.7),[27] and those reporting they were falling asleep (RR, 14.2; 95% CI, 1.4-14.7).[36] These relatively large RRs from earlier studies are bounded by wide confidence intervals indicating smaller sample sizes compared with the current data. The lower RRs observed in the current study compared with previous literature may be owing to weaknesses in prior study design. Alternatively, it may be owing to the concept of drowsiness, which differs from reported hours of sleep, and may have more to do with changes in factors such as sleep pattern or length of driving. Differences may also be owing to the inclusion of all crashes not just injury crashes in the current study. In the DRIVE Study sample, about 13% of the cohort reported sleeping 6 or fewer hours per night, consistent with previous estimates of 15%.[14,52,53] In the DRIVE Study, drivers who slept fewer hours per night were more likely to be older, report a high number of weekly driving hours, engage in risky driving, be high-sensation seekers, engage in self-harm, and have higher Kessler Psychological Distress Scale scores, and greater drug and alcohol use. It is possible that those who slept less drove more because of work or school commuting, although sleep hours did not differ by remoteness of residence. Previous authors have suggested that the nighttime driving restrictions within graduated driver licensing may deal indirectly with some portion of this excess risk, but it has been argued that these restrictions do not resolve morning risks when driving to school or work or afternoon hours returning home, when adolescents can be similarly fatigued.[54] However, our study only observed an increased risk from 8 PM to 6 AM. This highlights a need to further investigate nighttime driving

Figure 2. Relative Risk for Crash by Average Sleep Hours per Weekday (>6 Hours vs ≤6 Hours)

	≤6 h of Sleep No. of Crashes/ Total No. of Participants (%)	>6 h of Sleep No. of Crashes/ Total No. of Participants (%)	Relative Risk (95% CI)
Driver had a crash			
Unadjusted	229/2759 (8.30)	1154/16 568 (6.97)	1.20 (1.05-1.38)
Adjusted*			1.12 (0.97-1.29)
Crash type			
Single vehicle			
Unadjusted	39/2569 (1.52)	241/15 655 (1.54)	1.00 (0.71-1.40)
Adjusted*			1.03 (0.73-1.44)
Multiple vehicles			
Unadjusted	190/2720 (6.99)	913/16 327 (5.59)	1.26 (1.08-1.47)
Adjusted*			1.19 (1.02-1.38)
Run off road			
Unadjusted	47/2577 (1.82)	258/15 672 (1.65)	1.12 (0.82-1.52)
Adjusted*			1.15 (0.84-1.57)
Crash time			
12:00 AM-5:59 AM			
Unadjusted	19/2549 (0.75)	78/15 492 (0.50)	1.49 (0.91-2.46)
Adjusted*			1.45 (0.86-2.43)
6:00 AM-8:59 AM			
Unadjusted	22/2552 (0.86)	127/15 541 (0.82)	1.07 (0.68-1.67)
Adjusted*			0.98 (0.62-1.54)
9:00 AM-12:59 PM			
Unadjusted	44/2574 (1.71)	193/15 607 (1.24)	1.40 (1.01-1.93)
Adjusted*			1.37 (0.98-1.90)
1:00 PM-5:59 PM			
Unadjusted	79/2609 (3.03)	436/15 850 (2.75)	1.11 (0.88-1.41)
Adjusted*			1.07 (0.84-1.37)
6:00 PM-7:59 PM			
Unadjusted	28/2558 (1.09)	147/15 561 (0.94)	1.17 (0.78-1.75)
Adjusted*			1.09 (0.73-1.65)
8:00 PM-11:59 PM			
Unadjusted	37/2567 (1.44)	173/15 587 (1.11)	1.31 (0.92-1.88)
Adjusted*			1.26 (0.88-1.80)



*Adjusted analyses of all crashes by sleep hours controlled for time in the study, prior crashes, age group, sex, average weekly driving hours, remoteness of residence, drinking behavior (Alcohol Use Disorders Identification Test score), risky driving behaviors, self-harm, drug use, sensation seeking, and psychological distress. Adjusted analyses of crash types by sleep hours controlled for time in the study, prior crashes, age group, sex, average weekly driving hours, remoteness of residence, and driving behavior owing to smaller sample sizes.

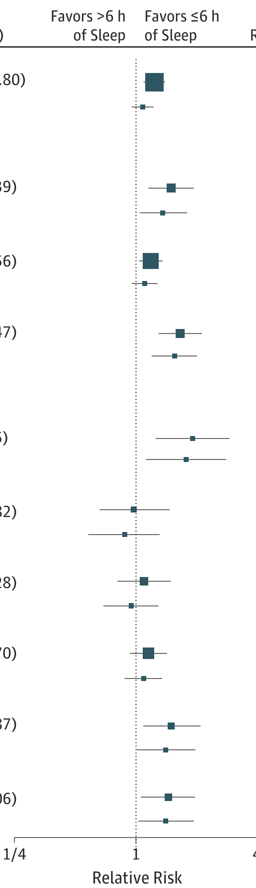
restrictions.[55,56] In our study data, the hypothesized increased risk for early-morning driving crashes (eg, driving to school/work, which we would expect after 6 AM) was not observed.

This study has significant strengths. First, to our knowledge, no prospective study has investigated the relationship between sleep and motor vehicle crash. Second, this study used police-recorded crashes, providing an objective outcome measure with little loss to follow-up. Third, this study enrolled a large number of participants, controlled for several potential confounders, and investigated sleep hours by weekdays and weekends, as well as more specific crash types and times. These findings may help increase awareness of the impact of reduced sleep hours on crash risk and highlight subgroups of young drivers and times of day for targeted intervention. Owing to feasibility in this large, prospective cohort study, average measures of sleep per night on weekdays and weekends and Alcohol Use Disorders Identification Test scores for alcohol use were taken at baseline; however, we recognize these are not as ideal as measures of sleep deprivation and alcohol intoxication at the time of the crash. For instance, asking about usual or average sleep may not reflect variability of sleep, and we cannot determine whether crashes occurred on days of little sleep. However, previous research indicates that crashes can be affected both by proximal sleep deprivation (eg, the day of the crash) and more distal effects of chronic sleep loss (eg, months preceding the crash), as well as the effects of sleep loss on the acquisition of a new skill such as driving.[25] More objective methods to measure sleep (eg, actigraphy) were unavailable for this study, having an unknown effect on the results. Also, some analyses, such as single-vehicle crash analyses, were limited by small numbers even though the study enrolled more than 20 000 young drivers; thus, we observed less precision around the magnitude of risk for these analyses. Additionally, previous research has demonstrated that single-vehicle crashes are less likely to be reported to police, which may have occurred in this study. Lastly, this study enrolled participants via an online, voluntary questionnaire and was not designed to be generalizable. However, a heterogeneous population of young drivers was represented in this study.

A range of measures may prevent crashes due to sleepiness or reduce their seriousness. Changes to road design (eg,

Figure 3. Relative Risk for Crash by Average Sleep Hours per Weekend (>6 Hours vs ≤6 Hours)

	≤6 h of Sleep No. of Crashes/ Total No. of Participants (%)	>6 h of Sleep No. of Crashes/ Total No. of Participants (%)	Relative Risk (95% CI)
Driver had a crash			
Unadjusted	338/3963 (8.53)	1045/15 364 (6.80)	1.24 (1.10-1.39)
Adjusted*			1.08 (0.95-1.23)
Crash type			
Single vehicle			
Unadjusted	78/3703 (2.11)	202/14 521 (1.39)	1.49 (1.15-1.94)
Adjusted*			1.36 (1.04-1.78)
Multiple vehicles			
Unadjusted	260/3885 (6.69)	843/15 162 (5.56)	1.19 (1.04-1.36)
Adjusted*			1.11 (0.96-1.28)
Run off road			
Unadjusted	92/3717 (2.48)	213/14 532 (1.47)	1.67 (1.31-2.13)
Adjusted*			1.55 (1.21-2.00)
Crash time			
12:00 AM-5:59 AM			
Unadjusted	32/3657 (0.88)	65/14 384 (0.45)	1.91 (1.26-2.91)
Adjusted*			1.78 (1.13-2.80)
6:00 AM-8:59 AM			
Unadjusted	30/3655 (0.82)	119/14 438 (0.82)	0.98 (0.66-1.46)
Adjusted*			0.88 (0.58-1.32)
9:00 AM-12:59 PM			
Unadjusted	52/3677 (1.41)	185/14 504 (1.28)	1.09 (0.81-1.49)
Adjusted*			0.95 (0.69-1.30)
1:00 PM-5:59 PM			
Unadjusted	118/3743 (3.15)	397/14 716 (2.70)	1.15 (0.94-1.41)
Adjusted*			1.09 (0.89-1.35)
6:00 PM-7:59 PM			
Unadjusted	49/3674 (1.33)	126/14 445 (0.87)	1.51 (1.08-2.10)
Adjusted*			1.41 (1.00-1.98)
8:00 PM-11:59 PM			
Unadjusted	57/3682 (1.55)	153/14 472 (1.06)	1.44 (1.06-1.96)
Adjusted*			1.42 (1.03-1.94)



*Adjusted analyses of all crashes by sleep hours controlled for time in the study, prior crashes, age group, sex, average weekly driving hours, remoteness of residence, drinking behavior (Alcohol Use Disorders Identification Test score), risky driving behaviors, self-harm, drug use, sensation seeking, and psychological distress. Adjusted analyses of crash types by sleep hours controlled for time in the study, prior crashes, age group, sex, average weekly driving hours, remoteness of residence, and driving behavior owing to smaller sample sizes.

tactile road edges and divided highways), as well as education campaigns, may help reduce crash risk.[57,58] Using a rest stop (RR, 0.5), drinking coffee (RR, 0.5), and playing the radio while driving (RR, 0.6) have been shown to be significantly protective against crashes, at least in the short term.[36] In Australia, New Zealand, the United States, and several other countries, extended campaigns on the short 30-minute powernap are run by road authorities.[32,59,60]

Although residual confounding may remain, in particular by acute alcohol intoxication, reduced sleep hours is a risk factor for crashes independent of other covariates.[61,62] Young drivers sleeping a few hours per night also had other risk factors for crashes, thus interventions may be well placed to address multiple risk factors simultaneously. Future research could also evaluate the effects of harm-minimization strategies at parties and other youth entertainment events, such as alcohol sales restrictions, and legal and peer dynamics education along with education to reduce drowsy driving.[63] Young drivers should be a key focus because this group experiences more impairment in alertness, mood, and physical performance compared with older age groups with similar sleep deprivation.[8]

Our current paper addresses several of the research needs highlighted during the recent Hopkinton Conference on Future Directions in Fatigue and Safety Research including time of day effects, fatigue, and risk taking,[64] as well as the use of prospective study designs.[65] This study provides rationale for addressing sleep deprivation among young drivers[66]—in particular highlighting increased risks for crash with 6 or fewer hours of sleep per night, weekend run-off-road crashes, and crashes between 8 PM and 6 AM.

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