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Impact of Experimentally Manipulated Sleep on Adolescent Simulated Driving

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Abstract

Objective/Background—Sleep restriction (SR) impairs adolescents' attention, which could contribute to high rates of driving crashes. Here, we examine the impact of experimental SR on adolescent drivers, considering whether that impact is moderated by the nature of the drive (urban/suburban vs. rural) or how vulnerable each adolescent is to attentional decline after SR.

Participants/Methods—17 healthy 16-18-year-old licensed drivers completed two, five-night sleep conditions: SR (6.5 hours in bed) vs. Extended Sleep (ES; 10 hours in bed) in counterbalanced order. After each, participants completed rural and urban/suburban courses in a driving simulator, and parents rated participants' attention in day-to-day settings. Vulnerability to SR was computed as cross-condition change in parent ratings. Dependent variables included standard deviation of lateral lane position (SDLP), mean speed, SD of speed, and crashes. Multivariate models examined the main and interaction effects of sleep condition, driving environment, and vulnerability to SR, covarying for years licensed.

Results—Although effects for the other outcomes were non-significant, there were three-way interactions (sleep-by-drive-by-vulnerability) for mean speed and SDLP ($p < .02$). During the rural drive, adolescents had less consistent lateral vehicle control in SR than ES, despite slower driving among those reported to be vulnerable to SR. During the urban/suburban drive, SR worsened SDLP only among adolescents reported to be vulnerable to SR.

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Conclusions—These preliminary findings suggest that even a moderate degree of SR may be a modifiable contributor to adolescent driving problems for some. This impact is widely present during monotonous rural drives and in a subgroup during interesting urban/suburban drives.

Keywords

sleep restriction; trait-like differences; vulnerability; adolescence; rural driving; urban driving; attention

1. Introduction

Automobile crashes are a leading cause of death among adolescent drivers,¹ and a major cause of non-fatal injuries and property damage.² Sleep restriction (SR), which is common among adolescents on school nights,³ may contribute. In correlational studies, adolescents who sleep less have higher crash rates,⁴ and quasi-experimental findings link later school start times to fewer crashes.⁵ However, these non-experimental studies cannot fully establish causation.

Experimental studies demonstrate driving impairments in adults following sleep deprivation.^{6, 7} For example, compared to a typical night's rest, one night of sleep deprivation diminishes adult drivers' lateral vehicle control, as evidenced in lane crossings towards opposing traffic.⁶ Unfortunately, these findings may not generalize to adolescents. Adult studies often rely on full-night sleep deprivation⁶ or brief partial sleep paradigms⁷ which differ from the chronic-partial SR typical of adolescence.⁸ Most adolescent crashes also occur during brief drives in populous areas,⁹ rather than during the long, boring drives known to be sensitive to sleep deprivation in adults. Finally, adolescents use more attentional resources while driving, which could increase vulnerability to SR.¹⁰

Even so, adult findings point to key considerations for adolescent studies. First, the nature of the task is important; tasks that require sustained vigilance are more sensitive to SR than short, stimulating tasks.¹¹ Second, individuals differ in response to sleep loss.¹² Given inter-individual differences in adult driving during sleep deprivation,¹² trait-like differences in how SR affects attention outside of a driving setting might identify those whose driving skills are most vulnerable.

This exploratory study examines the impact of experimental SR on adolescent drivers, using a five-night SR protocol that mimics the experience of 20-25% of adolescents on school nights.³ Further, it examines whether the impact of SR is moderated by the nature of the driving task (urban/suburban vs. rural) or individual differences in vulnerability to the effect of SR on day-to-day attentional functioning.

2. Method

Healthy adolescents aged 16-18.9 years with a valid driver's license were recruited from advertisements within a regional pediatric hospital. Exclusion criteria included a reported psychiatric or neurologic history, use of a medication affecting sleep/alertness, body mass index >30, or symptoms consistent with obstructive sleep apnea or nocturnal restlessness.

Adolescent participants provided informed assent and their parents provided informed consent. All study procedures were approved and overseen by the local institutional review board.

Adolescent sleep was manipulated over the course of three weeks in the summer using the sleep manipulation protocol detailed by Beebe et al.^{3,13,14} Rise time was held constant all three weeks, set at the time needed to prepare for an 08:30 am appointment. During the baseline week, participants were asked to rise on time in the morning, but could self-select bedtimes. During subsequent weeks, participants changed bedtimes to create two, five-night sleep conditions in a randomized cross-over design. The two sleep conditions were SR and Extended Sleep (ES), consisting of 6.5 and 10 hours of sleep opportunity, respectively. There was a two-night washout between sleep conditions, during which adolescents self-selected their bedtimes. Participants slept at home, monitored via objective actigraphy, as detailed in prior publications.¹⁵

At the end of each condition, participants attended afternoon evaluations, consistent with the afternoon peak in adolescent driving crashes.⁵ Visits started at either 02:00 or 04:00 pm, with the time held constant for each participant. At the baseline visit, teens were acclimated to the driving simulator by participating in a 7-minute practice drive. The simulator (STISIM M300; www.stisimdrive.com) is equipped with three driving displays to provide a 135-degree field-of-view, full-size steering and braking/acceleration controls, and an adjustable car seat. STISIM systems have been found to be sensitive to driving impairments related to obstructive sleep apnea¹⁶ and adult sleep deprivation.¹⁷

During the ES and SR visits, adolescents completed two simulated drives: 1) a 20-minute drive reflecting the suburban and light urban driving conditions that confer the highest risk for adolescent crashes (multiple turns, low speed, moderate traffic, frequent stops) and 2) a 30-minute rural drive (some curves, light traffic, higher speed, few stops) reflecting the conditions most sensitive to sleep deprivation in adults.⁵ Although the order of the drives was counterbalanced across participants, any given adolescent completed them in the same order during both SR and ES, with cosmetic modifications (e.g., building appearance, look and timing of challenges) to minimize the effect of recall.

Driving speed and lateral lane position were sampled at 3 Hz. Dependent measures included (1) standard deviation (SD) of lateral position (SDLP) relative to the center line, which indexes consistency of steering within the lane, (2) mean speed, (3) SD of speed, and (4) whether a crash occurred (0=no, 1=crash) for each drive.

While each adolescent was in the simulator, a parent completed a questionnaire assessing the adolescent's attention, which has been shown to be sensitive to changes in sleep in previous work.³ The 9 items, rated from 0 ("never") to 3 ("often"), made no reference to driving, instead focusing on core inattention symptoms of attention-deficit/hyperactivity disorder. Vulnerability to the effects of SR was defined as the raw-score change in attention ratings between SR and ES.

3. Analytic Plan

Repeated measures analyses of covariance were conducted to test the effects of sleep condition (SR vs ES) and drive type (urban/suburban vs. rural), as within-subject factors, on SDLP, mean speed and SD speed. A 2 (sleep) X 2 (drive type) mixed-model logistic regression was conducted to examine the effect of sleep and drive type on crash rates. Years licensed was a covariate for all analyses. Vulnerability to SR was entered as a between subjects factor. Order effects were considered in preliminary analyses, but were nonsignificant and trimmed from subsequent models.

4. Results

Of 19 initial participants, one failed to rise on time during the baseline and was dropped prior to randomization, and one was nonadherent to the sleep instructions during the experimental weeks. The final 17 participants (8M/9F) were 17.4 ± 0.9 years old and had been licensed for 0.90 ± 0.73 years (47% licensed <6 months).

Consistent with previous findings utilizing this sleep manipulation,¹⁸ compared to HS, participants in SR experienced much less nightly sleep ($p=.001$) and more attention problems ($p=.015$) (Table 1). During the urban/suburban drive, adolescents drove more slowly, but with greater lane variability and higher crash rates ($p<.01$) than during the rural drive. This was likely a function of the lower speed limits, increased turns and abrupt driving challenges in the urban/suburban drive.

Sleep condition did not affect crash rates or variability in speed, but was part of three-way interactions (sleep X drive X vulnerability) affecting mean speed and SDLP ($p<.02$). Following up on these interactions, we repeated analyses within each drive type (Figure 1).

In the urban/suburban drive, neither sleep condition nor attentional vulnerability affected average speed, but they interacted to affect SDLP ($p=.050$). Adolescents whose attention was reported to worsen during SR in comparison to ES showed the greatest effect of SR on SDLP.

In the rural drive, the driving speed of adolescents whose parents reported that they were less vulnerable to SR did not differ across sleep conditions. However, those with greater attentional vulnerability tended to drive slower during SR than ES (interaction $p=.027$). The whole sample had more variable lane position during SR than ES ($p=.047$), regardless of attentional vulnerability.

5. Discussion

A realistic dose of experimental sleep restriction may be a significant, modifiable contributor to driving problems for some adolescent drivers. Findings suggest that preventative efforts to improve sleep might be targeted towards adolescents who are most vulnerable to negative attentional effects of SR and those who drive in rural environments.

Consistent with adult work,¹² adolescents differed in their response to sleep restriction. In a simulated urban/suburban environment, adolescents that had trouble maintaining a consistent lane position after sleep restriction were those whose parents reported sleep-related changes in attention outside the simulator. These adolescents also slowed their speed in rural driving environments, potentially negatively impacting traffic flow and safety¹⁹; however, this effect was not significant when using the first 20 minutes of the rural drive indicating that vulnerability to sleep restriction is especially risky in long drives. These findings suggest that adolescents most at-risk for day-to-day driving problems could be identified and targeted for interventions (e.g., teaching sleep hygiene, parental involvement in sleep or driving decisions).

The negative effect of sleep restriction on lane variability was more widely present across adolescents during rural drives. This effect remained when we reanalyzed using only the first 20 minutes of the rural drive, suggesting that its monotonous content was a key factor in the effect of sleep restriction. This is consistent with previous work with adults suggesting that monotony likely contributes to high crash risks in rural driving environments.²⁰

Study limitations should be acknowledged. Our sample was small and our dependent measures were based not based on real-world driving. Future research is needed to replicate these findings using larger samples. Still, these preliminary findings suggest that alleviating the common phenomenon of sleep restriction on school nights for adolescents could be an important avenue for addressing adolescent driving problems that warrants further investigation.

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References

1. National Highway Traffic Safety Administration [NHTSA]. Transportation Do. Washington, D.C.: 2011. Traffic Safety Facts Early Estimate of Motor Vehicle Traffic Fatalities in 2010..
2. Naumann RB, Dellinger AM, Zaloshnja E, Lawrence BA, Miller TR. Incidence and total lifetime costs of motor vehicle-related fatal and nonfatal injury by road user type, United States, 2005. *Traffic Injury Prevention*. 2010; 11(4):353–360. [PubMed: 20730682]
3. Beebe DW, Fallone G, Godiwala N, Flanigan M, Martin d, Schaffner L, Amin R. Feasibility and behavioral effects of an at-home multi-night sleep restriction protocol for adolescents. *Journal of Child Psychology and Psychiatry*. 2008; 49(9):915–923. [PubMed: 18564072]
4. Martiniuk AL, Senserrick T, Lo S, Williamson A, Du W, Grunstein RR, Woodward M, Glozier N, Stevenson M, Norton R. Sleep-deprived young drivers and the risk for crash: the DRIVE prospective cohort study. *JAMA Pediatrics*. 2013; 167(7):647–655. [PubMed: 23689363]
5. Vorona RD, Szklo-Coxe M, Wu A, Dubik M, Zhao Y, Ware JC. Dissimilar teen crash rates in two neighboring southeastern Virginia cities with different high school start times. *Journal of Clinical Sleep Medicine*. 2011; 7(2):145. [PubMed: 21509328]

6. Philip P, Sagaspe P, Moore N, Taillard J, Charles A, Guilleminault C, Bioulac B. Fatigue, sleep restriction and driving performance. *Accident Analysis & Prevention*. 2005; 37(3):473–478. [PubMed: 15784201]
7. Åkerstedt T, Ingre M, Kecklund G, Anund A, Sandberg D, Wahde M, Philip P, Kronberg P. Reaction of sleepiness indicators to partial sleep deprivation, time of day and time on task in a driving simulator—the DROWSI project. *Journal of Sleep Research*. 2010; 19(2):298–309. [PubMed: 20050992]
8. Owens J, Au R, Carskadon M, Millman R, Wolfson A, Braverman PK, Adelman WP, Breuner CC, Levine DA, Marcell AV. Insufficient sleep in adolescents and young adults: an update on causes and consequences. *Pediatrics*. 2014; 134(3):e921–e932. [PubMed: 25157012]
9. Hellinga LA, McCartt AT, Mandavilli S. Temporal Patterns of Crashes of 16-to 17-Year-Old Drivers in Fairfax County, Virginia. *Traffic Injury Prevention*. 2007; 8(4):377–381. [PubMed: 17994491]
10. Dahl RE. Biological, developmental, and neurobehavioral factors relevant to adolescent driving risks. *American Journal of Preventive Medicine*. 2008; 35(3):S278–S284. [PubMed: 18702982]
11. Lim J, Dinges DF. A meta-analysis of the impact of short-term sleep deprivation on cognitive variables. *Psychological Bulletin*. 2010; 136(3):375. [PubMed: 20438143]
12. Van Dongen H, Baynard MD, Maislin G, Dinges DF. Systematic interindividual differences in neurobehavioral impairment from sleep loss: evidence of trait-like differential vulnerability. *Sleep*. 2004; 27(3):423–433. [PubMed: 15164894]
13. Beebe DW, Simon S, Summer S, Hemmer S, Strotman D, Dolan LM. Dietary intake following experimentally restricted sleep in adolescents. *Sleep*. 2013; 36(6):827. [PubMed: 23729925]
14. Baum KT, Desai A, Field J, Miller LE, Rausch J, Beebe DW. Sleep restriction worsens mood and emotion regulation in adolescents. *Journal of Child Psychology and Psychiatry*. 2014; 55(2):180–190. [PubMed: 24889207]
15. Beebe DW. Cognitive, behavioral, and functional consequences of inadequate sleep in children and adolescents. *Pediatric Clinics of North America*. 2011; 58(3):649–665. [PubMed: 21600347]
16. Pizza F, Contardi S, Mondini S, Trentin L, Cirignotta F. Daytime sleepiness and driving performance in patients with obstructive sleep apnea: comparison of the MSLT, the MWT, and a simulated driving task. *Sleep*. 2009; 32(3):382. [PubMed: 19294958]
17. Gurtman CG, Broadbear JH, Redman JR. Effects of modafinil on simulator driving and self-assessment of driving following sleep deprivation. *Human Psychopharmacology: Clinical and Experimental*. 2008; 23(8):681–692. [PubMed: 19039821]
18. Beebe DW, Rose D, Amin R. Attention, learning, and arousal of experimentally sleep-restricted adolescents in a simulated classroom. *Journal of Adolescent Health*. 2010; 47(5):523–525. [PubMed: 20970088]
19. Stavrinou D, Jones JL, Garner AA, Griffin R, Franklin CA, Ball D, Welburn SC, Ball KK, Sisiopiku VP, Fine PR. Impact of distracted driving on safety and traffic flow. *Accident Analysis & Prevention*. 2013; 61:63–70. [PubMed: 23465745]
20. Thiffault P, Bergeron J. Monotony of road environment and driver fatigue: a simulator study. *Accident Analysis & Prevention*. 2003; 35(3):381–391. [PubMed: 12643955]

Highlights

- Adolescent drivers are at risk both for crashes and for sleep restriction (SR).
- Prior studies linking adolescent crashes to SR cannot fully establish causation.
- Adult experiments show causation, but findings may not generalize to adolescents.
- This study provides preliminary evidence that SR can worsen some adolescents' lateral vehicle control.
- The effect differed across driving settings and reflected individual vulnerability.

Figure 1.

Results of follow-up tests on the sleep condition X drive type X vulnerability interactions. Although presented dichotomously for illustration purposes (divided at the median), the vulnerability variable was analyzed continuously. † Follow-up analyses were conducted using the first 20 minutes of the rural drive in order to determine whether the effects are driven by the length of the rural drive. Results of follow-up analyses on SDLP remain unchanged but the interaction for the effect on average speed was no longer significant when using first 20 minutes of the rural drive.

Table 1

Primary Findings from Sleep Manipulation and Driving Simulator

	Mean $\pm$ SD or percent		Partial η^2 (p-value) for Main and Interaction Effects				
	Sleep Restriction (SR)	Extended Sleep (ES)	Sleep Condition	Drive Type	Sleep X Drive	Sleep X Vulnerability	Sleep X Drive X Vulnerability
Sleep Onset	00:54 $\pm$ 0:26	22:39 $\pm$ 0:45	.70 ($<.001$)	n/a	n/a	.08 (.295)	n/a
Sleep Offset	07:42 $\pm$ 0:24	07:24 $\pm$ 0:31	.06 (.367)	n/a	n/a	.00 (.838)	n/a
Sleep Duration	6:48 $\pm$ 0:27	08:45 $\pm$ 0:35	.59 (.001)	n/a	n/a	.08 (.287)	n/a
Attention Problems	13.1 $\pm$ 3.4	10.5 $\pm$ 2.7	.34 (.015)	n/a	n/a	n/a	n/a
At least 1 crash	Urban 58.8%	64.7%	1.02 (.864) ^a	1.65 (.005) ^a	.87 (.565) ^a	1.03 (.302) ^a	1.02 (.505) ^a
	Rural 17.6%	17.6%					
Speed Mean (mph)	Urban 27.0 $\pm$ 3.0	27.3 $\pm$ 3.2	.02 (.615)	.94 ($<.001$)	.06 (.361)	.13 (.166)	.36 (.015)
	Rural 47.0 $\pm$ 2.9	48.1 $\pm$ 5.4					
Speed SD	Urban 15.3 $\pm$ 0.8	15.2 $\pm$ 0.7	.04 (.437)	.12 (.181)	.01 (.661)	.01 (.661)	.09 (.269)
	Rural 14.7 $\pm$ 1.9	15.44 $\pm$ 3.0					
SD of Lane Position	Urban 9.59 $\pm$ 0.7	9.39 $\pm$ 1.0	.03 (.525)	.98 ($<.001$)	.03 (.530)	.15 (.145)	.33 (.019)
	Rural 1.03 $\pm$ 0.3	0.94 $\pm$ 0.4					

SD = Standard deviation; mph = Miles per hour

^a For crash rate analyses, effects are expressed as an odds ratio; all others reflect partial η^2 . Degrees of freedom (df) = 1, 14 for driving analyses, df = 1, 15 for sleep analyses, and df = 1, 16 for attention problem analyses. Sleep and drive type were analyzed within subjects. Time since licensure was a covariate. Vulnerability (defined as the difference in parent-reported attention problems between SR and ES) was entered as a between-subjects variable.