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Brief Communication

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: A total of 17 healthy 16–18-year-old licensed drivers completed two five-night sleep conditions: SR (6.5 h in bed) versus extended sleep (ES; 10 h 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 (SD) 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 the effects for the other outcomes were nonsignificant, there were three-way interactions (sleep × drive × vulnerability) for mean speed and SDLP ($p < 0.02$). 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.

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.

1. Introduction

Automobile crashes are a leading cause of death among adolescent drivers [1], and a major cause of nonfatal injuries and property damage [2]. Sleep restriction (SR), which is common among adolescents on school nights [3], may contribute to these incidents. 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 be generalized in adolescents. Adult studies often rely on full-night sleep deprivation [6] or brief partial sleep paradigms [7], 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 interindividual differences in adult driving during sleep deprivation [12], trait-like differences in how SR affects adolescent's attention outside of a driving setting might identify adolescents whose driving skills are most vulnerable.

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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. The 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 crossover design. The two sleep conditions were SR and extended sleep (ES), consisting of 6.5 and 10 h 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-min practice drive. The simulator (STISIM M300; http://www.stisimdrive.com) is equipped with three driving displays to provide a 135° 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 apnea [16] and adult sleep deprivation [17].

During the ES and SR visits, adolescents completed two simulated drives: (1) a 20-min drive reflecting the suburban and light urban driving conditions that confer the highest risk for adolescent crashes (multiple turns, low speed, moderate traffic, and frequent stops) and (2) a 30-min rural drive (some curves, light traffic, higher speed, and 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 (eg, building appearance, and 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 the following: (1) standard deviation (SD) of lateral position (SDLP) relative to the center line, which indexes the consistency of steering within the lane, (2) mean speed, (3) SD of speed, and (4) whether a crash occurred (0 = no and 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 nine 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) × 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-subject factor. Order effects were considered in preliminary analyses, but they 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. In addition, one was nonadherent to the sleep instructions during the experimental weeks. The final 17 participants (eight males and 9 females) were 17.4 ± 0.9 years old and had been licensed for 0.90 ± 0.73 years (47% licensed < 6 months).

Table 1
Primary findings from sleep manipulation and driving simulator.

		Mean ± SD or percent		Partial η^2 (p-value) for main and interaction effects				
		Sleep restriction (SR)	Extended sleep (ES)	Sleep condition	Drive type	Sleep × drive	Sleep × vulnerability	Sleep X Drive × vulnerability
Sleep onset		00:54 ± 0:26	22:39 ± 0:45	**0.70** (**<0.001**)	n/a	n/a	0.08 (0.295)	n/a
Sleep offset		07:42 ± 0:24	07:24 ± 0:31	0.06 (0.367)	n/a	n/a	0.00 (0.838)	n/a
Sleep duration		6:48 ± 0:27	08:45 ± 0:35	**0.59 (0.001)**	n/a	n/a	0.08 (0.287)	n/a
Attention problems		13.1 ± 3.4	10.5 ± 2.7	**0.34 (0.015)**	n/a	n/a	n/a	n/a
At least 1 crash	Urban	58.8%	64.7%	1.02 (0.864)[a]	**1.65 (0.005)**[a]	0.87 (0.565)[a]	1.03 (0.302)[a]	1.02 (0.505)[a]
	Rural	17.6%	17.6%					
Speed mean (mph)	Urban	27.0 ± 3.0	27.3 ± 3.2	0.02 (0.615)	**0.94** (**<0.001**)	0.06 (0.361)	0.13 (0.166)	**0.36 (0.015)**
	Rural	47.0 ± 2.9	48.1 ± 5.4					
Speed SD	Urban	15.3 ± 0.8	15.2 ± 0.7	0.04 (0.437)	0.12 (0.181)	0.01 (0.661)	0.01 (0.661)	0.09 (0.269)
	Rural	14.7 ± 1.9	15.44 ± 3.0					
SD of lane position	Urban	9.59 ± 0.7	9.39 ± 1.0	0.03 (0.525)	**0.98** (**<0.001**)	0.03 (0.530)	0.15 (0.145)	**0.33 (0.019)**
	Rural	1.03 ± 0.3	0.94 ± 0.4					

[a] for crash rate analyses, the 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-subject variable.
SD = Standard deviation; mph = miles per hour.