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Circadian Timing, Drowsy Driving, and Health Risk Behavior in Adolescent Drivers

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Circadian Timing, Drowsy Driving, and Health Risk Behavior in Adolescent Drivers

Report: ATLAS-2016-16

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16. Abstract

Both worldwide and in the UnitedStates, major contributors to adolescent and early adult mortality and morbidity arise from health risks characterized as behavioral misadventure. The large majority of deaths among 10-to 24-year-olds are due to risk-related events, and morbidity statistics for nonfatal events show a similar pattern. Motor-vehicle crashes account for over one-third of adolescent deaths. The reason for this elevated risk is likely multifactorial, implicating developmental, environmental, and biological mechanisms. One leading theory suggests a developmental maturity mismatch (DMM) between an earlier and faster-developing limbic-based "bottom-up" neural system characterized by heightened reactivity to motivational stimuli and rewards, while the prefrontally organized "top-down" system that enables more effective cognitive control and judgment matures more slowly. This DMM is hypothesized to contribute to elevated risk. Circadian timing may independently contribute to and interact with this DMM, increased risk for behavioral misadventure, and driver error. Both an evening chronotype and circadian misalignment are associated with decrements in sleep duration and sleep continuity, along with increased risk-taking and cognitive impairment. Thus, circadian mechanisms may affect neurocognitive pathways regulating reward-related behavior and decision making. Drowsy driving is common in adolescents and is a health-risk behavior that lends itself to exploring how the interaction of DMM and the regulation of the sleep-wake cycle may predispose novice, adolescent drivers to a set of developmentally unique vulnerabilities. There is thus a critical need to understand the mechanisms contributing to drowsy driving among novice, adolescent drivers, in order to improve preventive interventions, develop novel ones, and address potential changes in social and educational policies that can mitigate this major population health burden. The proposed research aims to characterize the role of chronotype and circadian misalignment in drowsy-driving and risky-driving behaviors, and the potentially mediating neurocognitive factors of impaired executive function and risk-reward processing.

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Introduction

Both worldwide and in the United States, major contributors to mortality and morbidity during adolescence and early adulthood arise from health risks that can be characterized as behavioral misadventure [1]. In the United States, the large majority of deaths among 10- to 24-year-olds are due to risk-related events, and morbidity statistics for nonfatal events show a similar pattern [2]. Motor-vehicle crashes (MVCs) represent the largest cause of death among teens, accounting for over one-third of all deaths [3]. Driver error (e.g. inattention, distraction) is the single most important cause for teen-involved crashes, yet the principal mechanisms associated with driver error are unknown. One possible cause of elevated error rates is a developmental maturity mismatch (DMM) between an earlier and faster-developing limbic-based "bottom-up" neural system characterized by heightened reactivity to motivational stimuli and rewards, while the prefrontally organized "top-down" system that enables more effective cognitive control and judgment matures more slowly [4]. Circadian rhythms may independently contribute to and interact with this DMM, conferring increased risk for behavioral misadventure and driver error.

Circadian timing interacts with the homeostatic sleep drive [5] to influence sleep propensity, and it modulates mood, neurobehavioral performance, and reward motivation [6, 7], all processes that potentially influence relevant human factors associated with safety issues, including alertness, fatigue and operator capability, and readiness in novice drivers. Circadian timing is influenced by individual preferences in the timing of sleep and wake patterns (i.e., chronotype) [8, 9] and circadian misalignment, which occurs when work/school schedules are mismatched with an individual's endogenous circadian rhythm [10]. Both an evening chronotype and circadian misalignment are associated with decrements in sleep duration and sleep continuity, along with increased risk taking and cognitive impairments [11-14]. Thus, circadian mechanisms may affect neurocognitive pathways regulating reward-related behavior and decision making. Drowsy driving is a health-risk behavior that lends itself to exploring how the interaction of a developmental maturity mismatch with the regulation of the sleep-wake cycle may predispose novice, adolescent drivers to a set of developmentally unique vulnerabilities.

Drowsy driving is common among adolescents, with 40% of teens reporting drowsy-driving episodes and only 19% of these teens reporting that they would stop driving when drowsy [15]. Pack and colleagues' (1995) seminal drowsy study [16] estimated that 55% of all sleep-related crashes occurred in predominantly young (≤ 25 years of age; peak age of 20) and male drivers (74.5%). In addition, the temporal distribution of all drowsy-driving crashes occurred during the two known periods of circadian variation in sleepiness, at night and midafternoon (i.e., "siesta time"; ~ 3:00 p.m.). Younger drivers in this study had an increased risk of accidents occurring at night with a peak in the morning hours (between 5 a.m. and 7 a.m.). Although several studies indicate the occurrence of MVCs follows a circadian pattern [17-19] and that the time of day may mediate the impact of sleep loss on driving performance [18, 19], the role of circadian factors (e.g., chronotype and circadian misalignment) remains poorly characterized, especially among novice drivers [20]. The few simulated-driving studies exploring the role of circadian factors indicate that evening chronotypes performed worse than morning types when tested in the morning hours [21, 22] when evening types would theoretically experience a higher homeostatic sleep load, which when linked to circadian misalignment, might contribute to a deterioration in performance [23].

There is thus a ***critical need to understand the mechanisms*** contributing to drowsy driving among novice, adolescent drivers, in order to ***improve preventive interventions***, and develop novel ones, and to address ***potential changes in social and educational policies*** that can ***mitigate this major population health burden***.

Study Approach

Data was collected within the context of an ongoing NICHD funded study, Neurodevelopmental Pathways in Adolescent Health Risk Behavior (R01HD075806; UM IRB: HUM00084650; PI: Keating). For presentation purposes, we have labeled this cohort as the study of Adolescent Health Risk Behavior (AHRB). That study is designed to evaluate the developmental maturity mismatch (DMM) hypothesis, a leading hypothesis for elevated rates of adolescent behavioral misadventure. The DMM hypothesis posits that adolescent risk behavior is a consequence of asynchrony between an earlier and faster- developing limbic-based “bottom-up” neural system characterized by heightened reactivity to motivational stimuli and rewards, in comparison to the prefrontallyorganized “top-down” system that enables more effective cognitive control and judgment, but matures later and more slowly [4]. This study aims to characterize the behavioral, psychosocial, and neurocognitive pathways of adolescent and early-adulthood risk-taking in a large (N = 2000), diverse sample of youth using a longitudinal accelerated cohort design. The parent study assesses behavioral misadventure broadly, including risky-driving behaviors. Although the specific association between circadian and sleep factors with risky-driving-related behaviors is not a central question of the parent study, it is the focus of the current work. In order to identify the influence of circadian and sleep factors on risky-driving behavior, specifically drowsy driving, among novice, adolescent drivers, an assessment of chronotype, circadian misalignment, and sleep must be coupled with a comprehensive assessment of health-risk behaviors and associated psychosocial risk factors (i.e., impulsivity, sensation seeking). The proposed research incorporates such an integrated investigation into a large-scale, cross-sectional design of adolescent drivers.

Specific Aims

1. The first aim of the proposed research is to characterize the association of circadian and sleep-related factors with drowsy driving in a cohort of relatively novice drivers.

2. The second aim of the proposed research is to characterize the association of circadian and sleep-related factors with other risky driving behaviors in this cohort (distracted driving, driving and drinking, being a passenger in a car with a driver who has been drinking).

Methods

Participants

A total of 2,017 10th and 12th grade high-school students were recruited from 11 public high schools across nine southeastern Michigan school districts (Figure 1). The target recruitment goal of 2,000 was met yielding a diverse sample of youth (Table 1). Compared with U.S. data for elementary and secondary school enrollment combined in 2014 (from the National Center for Education Statistics [NCES]), the ascertained sample has broadly comparable diversity: White – 57% (AHRB) vs. 51% (NCES); African American – 23% (AHRB) vs. 16% (NCES); Hispanic – 8% (AHRB) vs. 24% (NCES); and more than one race – 13% (AHBR) vs. 3% (NCES). It is not possible to know how this last category would alter the distribution if students had selected only one race or ethnicity.

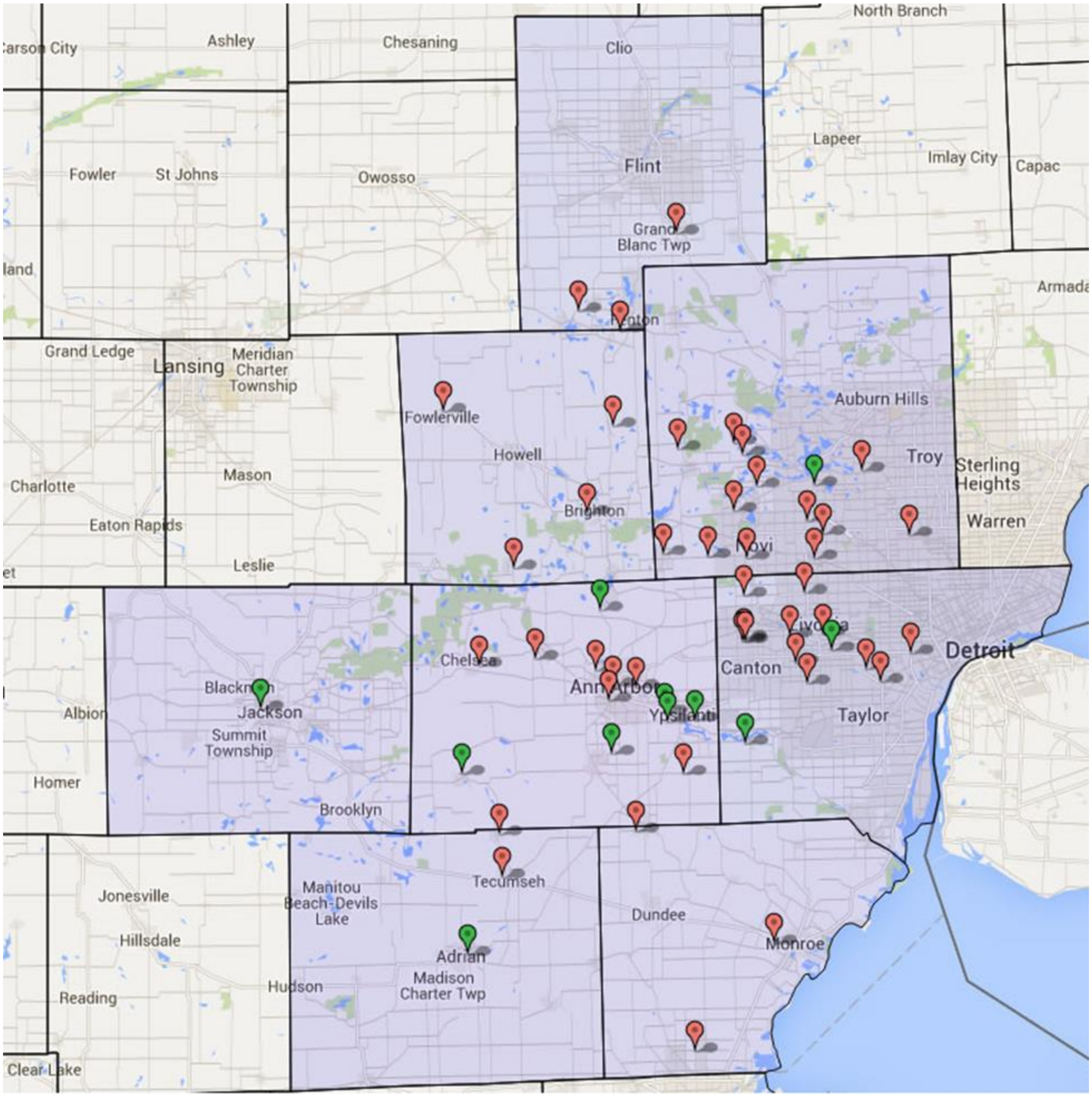

Figure 1. Map of participant recruitment. High-school students from grades 10 and 12 were recruited from nine public school districts across eight southeastern Michigan counties. Green markers indicate schools participating in AHRB Phase I Wave 1 and red markers indicate schools that declined participation.

Table 1

Demographic characteristics of participants

	10th grade *n* = 985		12th grade *n* = 1032		Total *N* = 2017	
Characteristic	*n*	%	*n*	%	*n*	%
Female	553	56.1	557	44.7	1110	55.0
Race						
American Indian or Alaskan Native	4	0.4	7	0.7	11	0.5
Asian	21	2.1	35	3.4	56	2.8
Black or African American	243	24.7	222	21.5	465	23.1
Native Hawaiian or other Pacific Islander	2	0.2	1	0.1	3	0.1
White	535	54.3	615	59.6	1150	57.0
More than one race	136	13.8	117	11.3	253	12.5
Unknown or not reported	44	4.5	30	2.9	74	3.7
Ethnicity, Hispanic or Latino	96	9.7	65	6.3	161	8.0
Age, M(SD)	15.77 (0.46)		17.78 (0.47)		16.8 (1.1)	

Procedures

Study participants completed two, 50-minute, computer-administered surveys on two consecutive days. Day one included self-report questionnaires assessing psychosocial constructs associated with behavioral misadventure (e.g., impulsivity, sensation seeking). Participants indicated frequency of engagement in a range of health risk behaviors (e.g., drowsy driving, substance exposure), which used to quantify behavioral misadventure. Day two consisted of a battery of cognitive tasks (data not shown).

Measures

Behavioral misadventure was quantified by assessing self-reported exposure to a range of health-risk behaviors (e.g., substance use, risky driving, interpersonal aggression, unprotected sex) in the past 12 months. The self-report of risk behaviors was adapted from two large national surveys that included high-school students, to allow for comparisons between the study sample and nationally representative populations. Specifically, we merged and adapted a risk-behavior questionnaire from the well-established Monitoring the Future (MTF) survey, conducted over several decades by SRC [24, 25] and the Youth Risk Behavior Surveillance System (YRBSS), conducted since 1991 by the Centers for Disease Control and Prevention (CDC). We assess a full range of risk behaviors with health consequences. From our prior research, we also include items to gather supplementary information on the degree of planfulness [26]; judgments of costs and benefits [27]; motivations for engaging in the behavior [28, 29]; and experienced consequences [28, 30]. Each of these has been shown to affect risk-behavior prevalence and judgments about them. Correlations between the health-risk behavior domains ranged from .49 to .75 (ps $< .001$).

The Barratt Impulsiveness Scale-Brief (BIS-Brief; [31]) is an eight-item, unidimensional measure of impulsiveness based on a reduced item set derived from the Barratt Impulsiveness Scale [32] and 11th revision [33]. Items are rated on a four-point Likert-type scale; response options include *rarely/never* (1), *occasionally* (2), *often* (3), and *almost always/always* (4). A total score is calculated by first reverse scoring nonimpulsive items (1, 4, 5, and 6) and then summing all eight BIS-Brief items. Scores range from 8 to 32 with higher scores indicating greater impulsiveness. Reliability and validity of the BIS-Brief have been documented in adolescent and adult clinical samples and an adult control sample [31] with $\alpha = .83$ and .73 for the clinical and healthy samples, respectively (clinical [adult]: *M* = 21.8, *SD* = 4.2; healthy [adult]: *M* = 13.5, *SD* = 8.9).

The Brief Sensation Seeking Scale (BSSS-8; [34]) is an eight-item self-report measure of sensation seeking derived from the 40-item Sensation Seeking Scale (SSS-V; [35]). Items are tailored for adolescents and young adults with each of the four primary dimensions of sensation seeking represented by two items including experience seeking (ES), boredom susceptibility (BS), thrill and adventure seeking (TAS), and disinhibition (Dis). Response options include *strongly disagree* (1), *disagree* (2), *neither disagree nor agree* (3), *agree* (4), and *strongly agree* (5). A mean score is computed with scores ranging from 1 – 5 with higher scores indicating greater sensation-eeking tendencies. Reliability and validity of the BSSS have been documented in adolescent, young adult, and clinical samples with α = .70 - .74 [34, 36-39].

The Munich ChronoType Questionnaire (MCTQ; [40]), is a 14-item self-report instrument used to estimate individual differences in phase preference of entrainment, i.e., chronotype. The MCTQ estimates chronotype by a single phase reference point, the midpoint between sleep onset and waking on free days (mid-sleep on free days, MSF) corrected for "oversleep" due to sleep debt accrued over the work/school week (midpoint of sleep on work-free days, sleep-corrected, MSFsc; [8]). The dimension of MSFsc is a continuous, not categorical variable and considered a representation of local time. The degree to which one can be considered "early" or "late" is contingent on the reference population, therefore to compare different chronotypes within a sample, a median split, quartiles or decile can be used (e.g., earliest 25% vs. the latest 25% of a given sample; [41]). The MCTQ can be used to quantify the discrepancy between biological and social timing, i.e., *social jetlag*, [10] difference by the absolute difference between mid-sleep on workdays (MSW) and midsleep on free days (MSF):

ΔMSF = | MSF – MSW |.The MCTQ has demonstrated convergent validity with the Morningness-Eveningness Questionnaire [42] and dim-light melatonin onset, [43, 44] the most reliable measure of circadian phase position in humans [45].

Results

In the past 12 months 30.5% (*n* = 616) of the youth sampled reported at least one occasion of drowsy driving. Demographic characteristics of the drowsy-driving sample are summarized below (Table 2).

Table 2

Drowsy Driving Characteristics

	10th grade *n* = 162 (26.3%)		12th grade *n* = 454 (73.7%)		Total *n* = 616	
Characteristic	*n*	%	*n*	%	*n*	%
Female	98	60.5	243	53.5	341	55.4
Race						
American Indian or Alaskan Native	1	0.6	3	0.7	4	0.6
Asian	3	1.9	16	3.5	19	3.1
Black or African American	24	14.8	52	11.5	76	17.9
Native Hawaiian or other Pacific Islander	2	1.2	0	0	2	0.3
White	108	66.7	338	74.4	446	72.4
More than one race	21	13	37	8.1	58	9.4
Unknown or not reported	3	1.3	8	1.8	11	1.8
Ethnicity, Hispanic or Latino	8	4.9			29	4.7
Age, *M*(*SD*)	15.8 (0.4)		17.8 (0.4)		17.3 (1.0)	

Among youth reporting drowsy driving histories in the past year, 13.5% indicated the decision to drive while drowsy was planned and 87.9% reported that the risks outweighed the benefits. There were no sex or grade differences between these groups.

Drowsy driving was positively correlated with additional risky-driving behaviors including distracted driving and driving under the influence, as well as risk factors associated with elevated health-risk behaviors including impulsivity and sensation seeking (Table 3).

Table 3

Correlations between risky driving and psychosocial risk variables

	1	2	3	4
1. Drowsy driving	-			
2. Driving under the influence	.215***	-		
3. Distracted driving	.399***	.237***	-	
4. Barratt Impulsiveness Scale- Brief	.145***	.129***	0.065	-
5. Brief Sensation Seeking Scale	.191***	.192***	.232***	.356***

Relatively small effects were observed for the frequency of insufficient sleep and the amount of circadian misalignment with 10th grade students reporting fewer days of insufficient sleep and less circadian misalignment than 12th graders (Table 4; *p*'s < .001 and $r = .07$ and .10, respectively).

Table 4

Circadian and Sleep characteristics

Characteristic	10th grade *M*	*SD*	12th grade *M*	*SD*	Total *M*	*SD*
Frequency of insufficient sleep (past 30 days)	14.0	9.5	15.3	9.5	14.6	9.5
Total sleep time school nights (hrs.)	6.5	1.5	6.4	1.4	6.5	1.5
Total sleep time weekend (hrs.)	9.1	1.9	8.9	1.9	9.0	1.9
Chronotype	4.8	1.6	4.9	1.5	4.9	1.5
Circadian misalignment (hrs.)	3.0	1.4	2.8	1.3	2.9	1.3

Among the circadian and sleep variables, only the frequency of insufficient sleep was associated with drowsy-driving frequency in the past year (Table 5). This variable was combined with demographic characteristics and the psychosocial risk factors impulsivity and sensation seeking in an ordinal regression model to evaluate their relative contributions.

Table 5

Correlations between risky driving behaviors and circadian and sleep parameters

	1	2	3	4	5	6	7	8
1. Drowsy driving	-							
2. Driving under the influence	.22***	-						
3. Distracted driving	.40***	.24***	-					
4. Frequency of insufficient sleep (past 30 days)	.15**	-.03	.03	-				
5. Total sleep time school nights (hrs.)	-.04	-.05	.05	-.22***	-			
6. Total sleep time weekend (hrs.)	-.04	-.08	0	.07	.17***	-		
7. Chronotype	-.01	-.03	-.01	.08	-.03	-.01	-	
8. Circadian misalignment (hrs.)	-.04	0	0	.01	-.15***	.17***	.06	-

Based on the parameter estimates obtained from an ordinal regression model (Table 6) three significant predictors of drowsy driving were identified: sensation seeking, insufficient sleep, and grade level. As illustrated in figures 2–4 an increase in these parameters yields an increase in drowsy-driving frequency. Impulsivity was not a significant predictor of drowsy-driving frequency in this model.

Table 6

Drowsy driving parameter estimates

		Estimate	SE	95% Confidence Interval	*p*
Drowsy Driving	Threshold 1	4.6	0.6	3.4 - 5.7	.000
(Threshold)	Threshold 2	5.2	0.6	4.0 - 6.4	.000
	Threshold 3	6.2	0.6	5.1 - 7.4	.000
	Threshold 4	6.8	0.6	5.6 - 8.0	.000
Independent Variable	Impulsivity	0.0	0.0	0.0 - 0.0	.913
	Sensation Seeking	0.6	0.1	0.4 - 0.8	.000
	Insufficient Sleep	0.0	0.0	0.0 - 0.0	.000
	Grade	1.5	0.1	1.3 - 1.8	.000
Race	Unknown or Not Reported	-0.2	0.7	-1.5 - 1.1	.739
	Black or African American	-0.3	0.3	-1.0 - 0.3	.360
	White	0.4	0.3	-0.2 - 1.0	.232
	More than one race	-0.3	0.4	-1.0 - 0.4	.430
	Other	—			
Ethnicity	Not Hispanic or Latino	0.7	0.4	0.0 - 1.4	.053
	Hispanic or Latino	—			

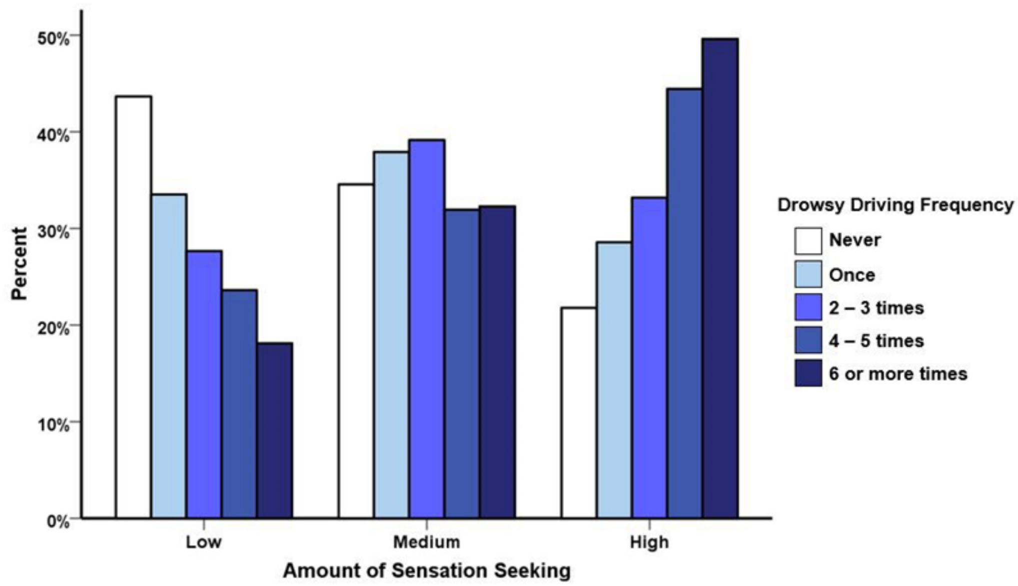

Figure 2. Associations between drowsy-driving frequency and sensation seeking

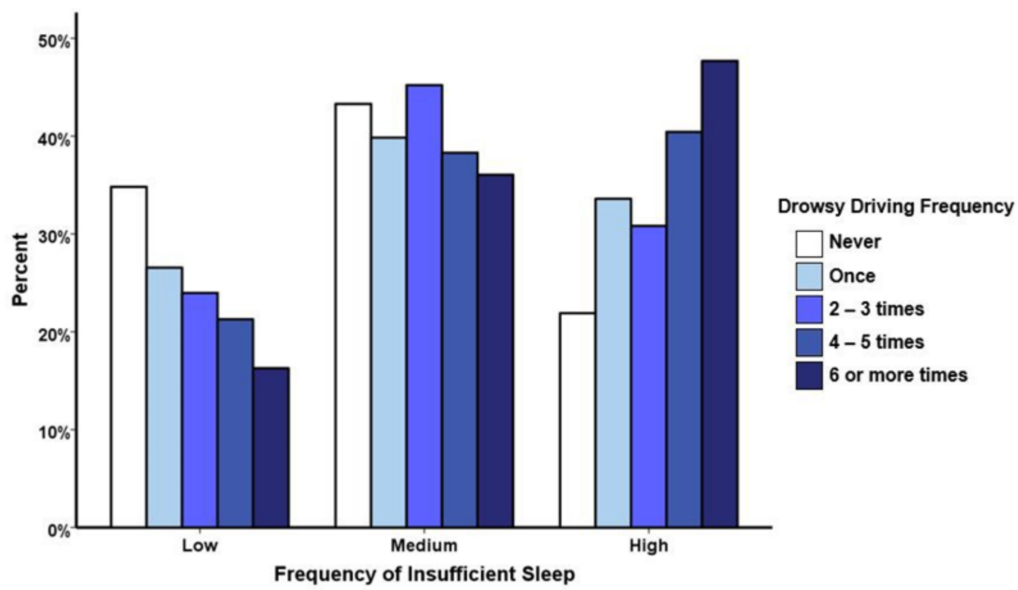

Figure 3. Associations between drowsy-driving frequency and insufficient sleep

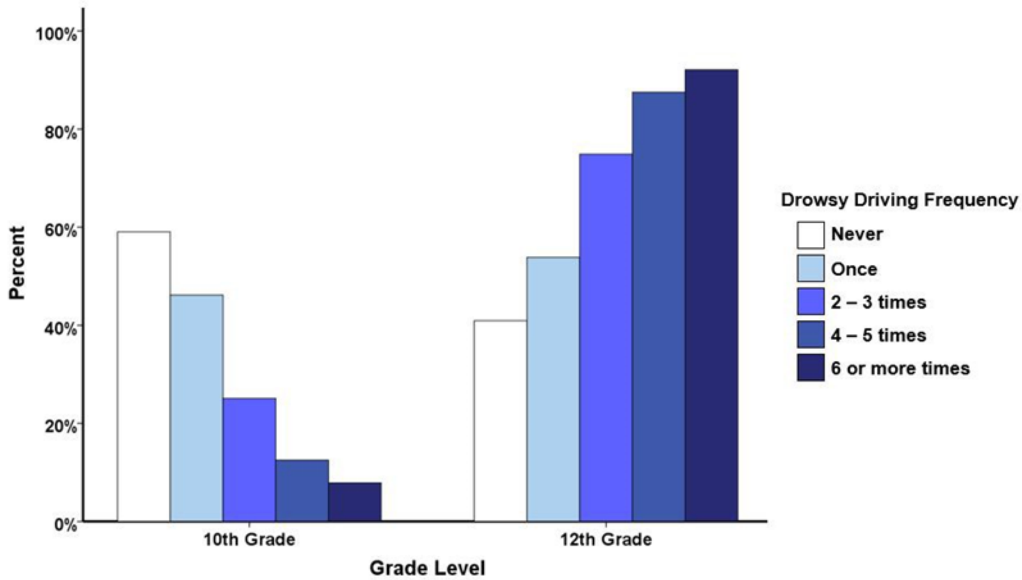

Figure 4. Associations between drowsy-driving frequency and grade

Discussion

The risky driving behaviors were all positively correlated however, the expected associations between circadian factors and risky driving were not observed. The data support a correlation between higher sensation seeking and a higher instance of drowsy driving, as well as a relationship between more self-reported insufficient sleep and a higher likelihood of drowsy driving. These results indicate that adolescents seem to be more vulnerable to act upon sensation-seeking tendencies, which could lead to behavioral misadventure in general and drowsy driving specifically.

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