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Longitudinal relationships of sleep and inhibitory control deficits to early adolescent cigarette and alcohol use

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INTRODUCTION

Substance use initiation during early adolescence has been associated with numerous long-term health risks, including elevated risk of dependence or abuse later in life (Dawson et al. 2008; Lopez-Quintero et al. 2011). Approximately 7.7% of US middle school students have tried a tobacco product (Arrazola et al., 2015) and 27% have tried alcohol (Johnston, 2015). Despite substantial reductions in adolescent cigarette smoking and alcohol use over recent decades, both substances remain leading causes of preventable death in the US and worldwide (Yoon, 2014).

Recent research with high school youth suggests that insufficient sleep may constitute an important predictor of both cigarette and alcohol use (Pasch et al., 2010). Sleep has multiple parameters, the most studied of which include average nightly duration and differences in wake and bed-times between weekdays and weekends. For example, a study by Pasch and colleagues identified prospective relationships between weekday, but not weekend sleep hours and both cigarette and alcohol use in a middle and high school-aged cohort (Pasch et al., 2012). This study extended two previous cross-sectional studies by prospectively linking self-reported sleep duration (Pasch et al., 2010; Fischer et al., 2008), sleep problems (Patten et al. 2000), and shifting of weekend bedtime relative to weekday bedtime (O'Brien & Mindell, 2005), to increased rates of substance use among middle and high school students. Proposed were two mechanisms through which these effects may occur: sleep-related deficits in emotional regulation, and sleep-related deficits in other executive functions (EFs), most notably inhibitory control.

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EFs are associated with both sleep behavior (Durmer & Dinges, 2005; Killgore, 2010) and youth substance use (Pentz & Riggs, 2013; Riggs et al., 2012) and have been shown to support emotional regulation, inhibition of impulsive behaviors and promotion of adaptive self-regulatory and goal-directed behaviors, which may facilitate choosing alternatives to substance use (Pentz & Riggs, 2013). Furthermore work by Wong et al demonstrated prospective associations between parent-reported childhood (age 3–8) sleep problems and illicit substance use outcomes in young adulthood (age 18–20), mediated by performance on a computerized inhibitory control task in late adolescence (age 15–17) (Wong et al., 2010). Taken together, these findings suggest that EFs—particularly the subdomain of inhibitory control—may also mediate effects of reduced sleep duration or greater sleep dysregulation on substance use initiation risk in early adolescence—a critical developmental period associated with substance use experimentation. However, this hypothesis has not yet been formally tested.

A recent review by Hasler et al proposes a framework through which weekend shifts in sleep-wake patterns may influence adolescent substance use behaviors through impaired self-regulation (Hasler, Soehner, & Clark, 2015). In their view, early school start times and children's chronobiological tendency toward later bed and wake times across adolescence (Crowley et al., 2007) lead to misalignment of children's natural circadian rhythms. Since the circadian rhythms governing sleep during childhood adapt more readily to delayed bedtimes than advanced wake-times (Dahl & Lewin, 2002), children who delay their bed-times on weekends relative to weeknights, typically experience greater difficulty falling asleep and sleep loss on weeknights (Hasler et al., 2015). Converging neuroscientific evidence suggests that such sleep disruptions selectively impair reward processing, leading to increased sensitivity to rewards and devaluation of potential losses (Holm et al., 2009). Such a shift would thus predispose children toward novel, risk-taking behaviors, such as the alcohol and cigarette initiation outcomes observed in the present study. Within this paradigm, a child's ability to inhibit a prepotent behavioral response which is biased toward risk-taking as a result of sleep loss may serve a key mediational role within the substance use initiation pathway.

As such, the aims of the present study were: **1)** To determine whether the prospective relationships between reduced sleep duration and increased substance use risk identified by Pasch et al operate similarly in late-elementary age youth who are first initiating substance use compared to the middle or high school youth previously studied, and **2)** To test whether sleep-related changes in inhibitory control or other EF subdomains mediate these prospective relationships between sleep patterns and substance use initiation risk.

METHODS

Background

Study data were gleaned from the fourth (baseline), fifth, and sixth grade waves of assessment in *Pathways to Health*, a cluster randomized control trial for the prevention of multiple obesity-related behaviors (Sakuma et al., 2012).

Participants

Participants were 1005 4th grade assented students with full active parental consent to participate in the study. Of these, 709 participants had complete data for all three years and constituted the analysis sample for the present study. Of the 296 participants who did not have complete data, 249 (85%) were lost due to families moving out of the study area, 18 (6%) were lost due to student, parent, or administrator decline at a follow-up assessment, and 29 (10%) were lost due to student absence on days of assessment. When compared to the 709 study participants the 296 participants lost to follow-up were more likely to be Hispanic (33% vs. 26%; $p<.05$) and low SES (35% vs. 21%; $p<.001$). The two groups did not differ significantly on any other study variables. The final analytic sample was 50% female, 26% Hispanic and 21% low-SES with a mean age of 9.27 ($SE=.47$; range 8–11 years) at fourth grade. These students represent 75 classrooms and 24 Southern California schools. All human subjects procedures were approved by the appropriate Institutional Review Board.

Measure

Data for the study were drawn from a 145-item self-report survey administered to children during an in-school assessment period. The survey included the following variables:

Sleep—A continuous variable representing participants' average nightly sleep hours was calculated using four survey items which asked participants: "On an average school day what time do you go to bed/wake up?" and "On an average weekend day what time do you go to bed/wake up?". These items were taken from the Sleep Habits Survey, a self-report measure developed and validated for use in adolescents (Wolfson et al., 2003). A continuous variable estimating participants' average nightly sleep hours across the week was created by calculating and multiplying students' reported school day sleep duration by five, calculating and multiplying students' reported weekend day sleep duration by two and dividing the sum by seven. Continuous estimates of participants' average weekly and weekend sleep hours were calculated by subtracting self-reported wake-times from bedtimes during the week and weekend, respectively. To estimate the degree to which participants shifted their wake times on weekends relative to school nights, weekend wake times were subtracted from weekday wake times, creating a continuous variable indicating the number of hours children "slept in" on weekends. Finally, to estimate the degree to which participants shifted their bedtimes on weekends relative to school nights, weekend bed times were subtracted from weekday bed times, creating a continuous variable indicating the number of additional hours that children delayed bed-times on weekend nights relative to weekday nights.

Executive Function—Items from four of eight clinical sub-scales of the Behavioral Rating Inventory of Executive Function-Self-Report (BRIEF-SR) were used to assess EF (Guy, 2004). The BRIEF was designed to be an appropriate and ecologically valid measure of EF skills associated with goals and actions in everyday problem solving situations encountered by school-age children, rather than an indicator of laboratory or structured task performance. Our decision to abbreviate the BRIEF-SR measure was motivated by time-constraints imposed by partner schools for in-class survey administration. However, previous work has found the abbreviated BRIEF-SR scales demonstrate predictive validity when

compared to full BRIEF-SR scales (Riggs et al., 2010). The four selected sub-scales represented inhibitory control (e.g., *I do things without thinking first*), emotional control (e.g., *I yell, scream, or cry for no reason*), working memory (e.g., *I forget what I'm doing in the middle of things*), and organization of materials (e.g., *My desk is a mess*). The 23-item abbreviated questionnaire was prompted by the following text: *"In the past month, how often has each of the following behaviors been a problem?"* Item response choices ranged from 1=Never, 2=Sometimes, 3=Often. For the present study, abbreviated scales were constructed using the highest loading index items from a pilot study and demonstrated acceptable internal consistency ($\alpha=0.63\text{--}0.74$) (Riggs et al., 2010).

Lifetime Cigarette and Alcohol Use—Self-reported lifetime cigarette and alcohol use items were drawn from a national drug use survey and previous prevention research (Pentz et al., 1989) computed from two items that asked youth about their lifetime cigarette and alcohol use: *"Have you ever smoked a cigarette in your whole life?"* and *"Have you ever tried alcohol (beer, wine, liquor that is not for religious purposes?)"*. Response options for the lifetime cigarette use item were as follows: 0= No, not even a puff; 1= Yes, just a puff; 2= Yes, more than just a puff (part or all of a cigarette); 3= Yes, one cigarette or more. Response choices for the alcohol use item ranged from 0=No, not even a sip; 1= Yes, just a sip; 2= Yes, more than a sip (part or all of a glass or can). For the present analyses, self-report of one or more puffs indicated lifetime cigarette use, whereas self-report of more than one sip of alcohol was used to indicate lifetime alcohol use.

Covariates—Participant gender (Kuhn, 2015), ethnicity (Johnston, 2015), age at 4th grade, and socioeconomic status (Keyes et al., 2015) (using federal free lunch program eligibility as a proxy) were included as covariates based on previous research, which identified relationships between each factor, sleep and adolescent substance use. Participant ethnicity was entered as a dichotomous covariate using two dummy variables (Hispanic vs. non-Hispanic and White vs. non-White). Final models only adjusted for White vs. non-White as the inclusion of Hispanic vs. non-Hispanic ethnicity did not significantly impact parameter estimates or overall model fit. Perceived psychosocial stress was assessed via an adapted 6-item Cohen Perceived Stress Scale (Cohen et al., 1983) and was included as a continuous covariate due to previous work linking it to both adolescent sleep and substance use outcomes (*Paying With Our Health*, 2015). Mean scores from a 4-item anhedonia scale were also calculated for each participant and tested as a covariate in all models since past work has identified associations between depressive symptoms and both increased substance use risk (Hallfors et al., 2005) and reduced sleep duration (Pasch et al., 2010). However, anhedonia was not included in final models as it neither significantly impacted parameter estimates nor contributed to the model. Participation in the intervention condition was also tested, but not included in final models for the same reason. Finally, since it is plausible that the presence of parental rules or other monitoring behaviors governing children's health behavior would be associated with both sleep and substance use behaviors, we fit each of our final models including the following dichotomous indicators separately and in aggregate: *Does your parent (or other important adult) have rules about how much time each day you can watch TV, listen to music, or be on a computer?* and *Does your parent (or other important adult) have rules about what you can eat after you get home from school?*

However, these indicators were not included in the final models as they neither significantly impacted parameter estimates nor contributed to the model.

Analysis Plan

A multivariate path modeling approach was employed for the present analyses using the cluster robust maximum likelihood estimator in MPLUS 7.4. Dichotomous items representing lifetime substance use at 6th grade were used as the primary outcome variable for both cigarette and alcohol use analyses. Prospective associations between sleep and substance use variables were then evaluated via specification of direct paths from each sleep variable to both substance use outcomes. To begin, separate models were fit for each of the following sleep parameters: average weeknight sleep duration, average weekend sleep duration, average weekend wake-time delay, and average weekend-sleep time delay. Covariate paths were then specified for each model, first adding each covariate separately to test independent relationships and then adding all paths simultaneously to examine unique associations after adjusting for covariance among all included variables. Interaction terms were also fit individually for all covariate patterns. No significant interactions ($p < .10$) were identified. Covariates remained in each model if they contributed significantly to the model ($p < .10$) or if their removal led to substantial differences ($>10\%$) in parameter estimates between key study variables. After specifying these models, weeknight and weekend sleep duration were combined into a single “average nightly sleep duration” model for parsimony since models examining effects of weeknight and weekend sleep duration had equivalent fit and very similar patterns of parameter estimates. Indirect effects were tested from sleep parameters to cigarette and alcohol use through each of the four EF subdomains. Estimates of indirect effects and their corresponding standard errors were calculated by Mplus using the delta method.

Analyses were first conducted on the full panel sample ($N=709$) adjusting for baseline cigarette and alcohol use and then on a subsample ($N=684$) of participants who did not report baseline cigarette or alcohol use at 4th grade. Results from hypothesis testing were very similar for both the full panel sample and after excluding the 25 baseline substance users. However, below we report parameter estimates from the $N=684$ subsample in order to strengthen causal inference and clarify timing of the observed effects. Cluster robust options by 6th grade classroom ($N=75$) were utilized for all analyses due to students’ shared classroom environment, a potential violation of statistical independence assumptions. Correlated residual covariance paths were specified between 6th grade substance use behaviors as well as between each of the four EF subdomains assessed at 5th grade. Due to *a priori* hypotheses regarding the directionality of the observed relationships, one-sided p -values are utilized for path model parameter estimates. Results are reported as standardized beta coefficients and statistical significance was set at $p < .05$.

RESULTS

Sleep

Participants slept an average of 9.77 hours per night, sleeping significantly less on weekdays (9.66 hours) relative to weekends (10.08 hours) ($t=4.53$; $p < .001$). Significant Pearson

correlations were observed between nightly sleep duration and weekend bedtime delay are ($r = -.13$, $p < .001$), between nightly sleep duration and weekend wake-time delay ($r = .10$, $p < .001$) and between weekend bedtime delay and weekend wake-time delay ($r = .20$, $p < .001$). At baseline, males slept significantly less than females overall ($p < .05$) [Table 1]. Children from low-SES families slept in significantly more on weekends than children from higher SES families ($p < .05$). On average, White children slept significantly longer ($p < .01$) and delayed both bed-times ($p < .001$) and wake-times ($p < .05$) to a lesser degree than non-White children.

Cigarette Use

In adjusted path models, older ($p < .05$) and lower SES ($p < .05$) students were more likely to report lifetime cigarette use at 6th grade. Students reporting greater inhibitory control were less likely than their counterparts to report lifetime cigarette ($p < .001$) and alcohol ($p < .01$) use at 6th grade. Cigarette and alcohol use outcomes at 6th grade were strongly associated ($p < .001$). Average nightly sleep duration at 4th grade was also directly associated with lifetime cigarette use at 6th grade ($p < .1$) [Table 2]. However, differences in weekend bed- and wake-time delay [Tables 3 and 4] were not directly associated with lifetime cigarette use.

Alcohol Use

Male ($p < .01$), low SES ($p < .1$), and non-White ($p < .001$) students were more likely than their counterparts to report lifetime alcohol use at 6th grade. Students reporting greater inhibitory control were less likely than their counterparts to report lifetime alcohol use at 6th grade ($p < .05$). Weekend bed-time delay was directly associated with lifetime alcohol use ($p < .1$), whereas weekend wake-time delay and average nightly sleep duration were not [Tables 3 and 4].

Mediational relationships

In models testing the impact of sleep duration [Figure 1], weekend bed-time delay [Figure 2] and weekend wake-time delay [Figure 3] on substance use initiation, indirect effects were tested through each of the four EF subdomains. Indirect effects were identified from sleep duration to both cigarette ($p < .1$) and alcohol use ($p < .05$) through inhibitory control. Indirect effects from sleep duration to each substance use outcome through working memory, organization, and emotional control were non-significant. Significant mediation was also found when weekend bed-time delay was examined, with significant indirect effects identified through inhibitory control from weekend bed-time delay to both cigarette use ($p < .01$) and alcohol use ($p < .05$). Similarly, significant indirect effects were also found through inhibitory control from weekend wake-time delay to both cigarette ($p < .01$) and alcohol use ($p < .1$) outcomes.

DISCUSSION

This study tested the prospective impact of both sleep duration and weekend shifting of sleep-wake patterns on cigarette and alcohol use initiation among late-elementary schoolchildren. While prospective relationships were identified between average nightly sleep duration and cigarette use initiation, direct effects were not significant for alcohol use.

These data support work identifying significant prospective associations between weekday sleep and cigarette use, but not alcohol use in an older cohort (Pasch et al., 2012). In Pasch et al.'s study, the only prospective association identified between sleep variables and alcohol use was for weekend bedtime delay. The authors propose that this increased variability in children's bedtimes may reflect a lack of household structure with less parental monitoring. In the present study, direct associations between weekend bedtime and wake-time delay and substance use were non-significant, suggesting that such relationships may operate differently in younger children. For instance, elementary school students may not have as ready access to cigarettes or alcohol, and are likely subject to greater parental monitoring compared to the older children studied by Pasch et al (Pasch et al., 2012). While much attention has been paid to the role of parental monitoring in substance use prevention efforts, improving understanding of the role parental monitoring can play with regard to childhood sleep promotion across childhood and adolescence is also likely to be of considerable public health significance.

Although direct effects of weekend bed-time and wake-time delay on subsequent substance use behaviors were only significant for weekend bed-time delay and alcohol use in the present study, significant indirect effects through inhibitory control were identified from each sleep parameter to both cigarette and alcohol use behaviors. This suggests that inhibitory control deficits induced by circadian dysregulation may be operating within the causal chain leading to substance use initiation in these youth. Though it has been suggested that disrupted sleep may confer increased substance use risk through changes in self-regulation or inhibitory control, only a single study has empirically investigated such relationships (Wong et al., 2010). The present study builds upon findings of Wong et al. (2010) by extending their work to a larger and more diverse sample with respect to participant gender, ethnicity and socioeconomic status as well as by assessing cigarette and alcohol use initiation outcomes in late elementary school, rather than use outcomes and self-reported "drug/alcohol-related problems" in early adulthood. Furthermore, the sleep parameters assessed in the present study are more comprehensive and generalizable to the broader pediatric population than the "childhood sleep problems" items utilized by Wong et al, since such sleep problems are relatively rare among adolescents (Johnson & Breslau, 2001).

While inhibitory control is an important component of a cluster of self-regulatory processes known as EF, other key subdomains include working memory and emotional control. In light of past work linking sleep restriction with impaired emotional regulation (Baum et al., 2014) and another body of work linking problems with emotional regulation to substance use, researchers have hypothesized that emotional control may mediate relationships between sleep and substance use outcomes. While we found that inhibitory control mediated relationships between multiple sleep variables (weekday sleep duration, weekend wake-time delay, weekend bed-time delay) and both cigarette and alcohol use outcomes, emotional control did not play a similar mediational role.

When hypothesizing causal mechanisms linking sleep deprivation to subsequent substance use outcomes, recent work (Hasler et al., 2015) has raised concern regarding reverse causation due to the fact that both alcohol and nicotine have been shown to interfere with

sleep. By excluding baseline substance users from our analytic sample we are able to demonstrate that the effect of early childhood sleep on subsequent alcohol and cigarette use is not a result of alcohol or nicotine-induced sleep problems. As such, the present findings lend support to the hypothesis that childhood sleep patterns may represent an important early indicator of neuropsychological difficulties with self-regulation, which may subsequently impact a wide range of future behavior, including but not limited to increased substance use risk (Clark et al., 2012).

A small, but growing body of evidence suggests that early childhood sleep patterns may be especially important predictors of multiple risk behaviors later in adolescence. For example, in the aforementioned study by Wong et al. (2010), self-reported sleep problems in mid-late adolescence were no more predictive of future substance use than parent-report of sleep problems in early childhood. This led the authors to suggest that childhood sleep patterns may constitute a key intervention target for multiple substance use prevention programs. Prior work has found childhood sleep to be amenable to a variety of school-based (Moseley & Gradisar, 2009) and clinical intervention (Gradisar et al., 2011) modalities. Since the present study and others (Wong et al., 2010) have demonstrated that sleep dysregulation may increase future substance use risk through inhibitory control pathways, interventions which target both sleep and inhibitory control may be particularly promising. Mindfulness meditation, which has been linked to improvements in adolescent sleep (Bei et al. 2013) and inhibitory control (Greenberg et al., 2012) may provide a promising therapeutic avenue. One such intervention was recently found to improve sleep, and reduce adolescent substance use risk in a small pilot study (Britton et al., 2010), though further evaluation is needed.

Limitations and Future Directions

There are several methodological limitations to the present study. First, this study measured sleep duration and sleep patterns, and did not take into account other important aspects of sleep, including sleep quality and latency (Roeser et al., 2012) —the amount of time it takes to fall asleep. Such parameters can be captured through use of sleep actigraphy, which future work should consider employing in order to minimize concerns about possible bias stemming from self-report. Due to time and human subjects restrictions imposed by partner school districts regarding data collection, all data in the present study were self-report. Furthermore, we were unable to assess participants' pubertal development, which may affect the phase-shifting of circadian rhythms (Colrain & Baker, 2011). Finally, whereas cigarette smoking among US youth has declined in recent years, use of e-cigarettes and hookahs is currently on the rise (Arrazola et al., 2015). Recent school-based work in a 7th grade population identified similar pathways through executive function for both e-cigarette and cigarette use (Pentz et al., 2015). Future work should explore whether sleep patterns prospectively impact e-cigarette and hookah use in a similar manner as identified in the present manuscript and in particular whether such effects are also mediated by inhibitory control deficits.

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FIGURE 1.

Longitudinal associations between nightly sleep duration and substance use, demonstrating significant mediational effects through inhibitory control

Model goodness of fit: χ^2 Test (12 df): 10.12 $p=.61$; TLI=1.016 RMSEA=.000; 90% CI (.000-.036)

Indirect effects from Nightly Sleep Duration to Cigarette Use through Inhibitory Control $B=-.031$; $SE=.016$; $p<.05$

Indirect effects from Nightly Sleep Duration to Alcohol Use through Inhibitory Control $B=-.014$; $SE=.009$; $p<.1$

Only paths with significance $p<.1$ shown.

Standardized covariances between EF subdomains ranged from (.42–.52) and were omitted from this figure for clarity.

Errors for endogenous variables were also omitted from this figure to improve clarity.

Exogenous variables allowed to correlate freely.

* $p < .05$ ** $p < .01$ *** $p < .001$

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FIGURE 2.

Longitudinal associations between weekend bed-time delay and substance use, demonstrating significant mediational effects through inhibitory control

Model goodness of fit: χ^2 Test (16 df): 16.96 $p=.39$; TLI=.993; RMSEA=.01; 90%CI (.000–.039)

Indirect effects from Weekend Bed-time delay to Cigarette Use through Inhibitory Control $B=.049$; $SE=.019$; $p<.01$

Indirect effects from Weekend Bed-time delay to Alcohol Use through Inhibitory Control $B=.021$; $SE=.012$; $p<.05$

Only paths with significance $p<.1$ shown.

Standardized covariances between EF subdomains ranged from (.42–.52) and were omitted from this figure for clarity.

Errors for endogenous variables were also omitted from this figure to improve clarity.

Exogenous variables allowed to correlate freely.

* $p<.05$ ** $p<.01$ *** $p<.001$

FIGURE 3.

Longitudinal associations between weekend wake-time delay and substance use, demonstrating significant mediational effects through inhibitory control

Model goodness of fit: χ^2 Test (16 df): 26.29 $p=.05$; TLI=.981; RMSEA=.032; 90%CI (.000-.054)

Indirect effects from Weekend Wake-time delay to Cigarette Use through Inhibitory Control
 $B=.047$; $SE=.018$; $p<.01$

Indirect effects from Weekend Wake-time delay to Alcohol Use through Inhibitory Control
 $B=.019$; $SE=.013$; $p<.1$

Only paths with significance $p<.1$ shown.

Standardized covariances between EF subdomains ranged from (.43-.51) and were omitted from this figure for clarity.

Errors for endogenous variables were also omitted from this figure to improve clarity.

Exogenous variables allowed to correlate freely.

* $p<.05$ ** $p<.01$ *** $p<.001$

TABLE 1

Demographic characteristics of study participants

	N (%)	4 th grade Mean Nightly Sleep Hours (SD)	4 th grade average weekend- wake-time delay (SD)	4 th grade average weekend- bed- time delay (SD)	5 th Grade Mean Inhibitory Control (SD)	5 th Grade Mean Emotional Control (SD)	5 th Grade Mean Working Memory (SD)	5 th Grade Mean Organ- ization (SD)	6 th Grade N (%) of students reporting lifetime cigarette use	6 th Grade N (%) of students reporting lifetime alcohol use
All Subjects	709 (100)	9.77 (1.07)	1.80 (2.06)	1.39 (1.46)	2.25 (.41)	2.43 (.38)	2.32 (.44)	2.37 (.43)	46 (6.49)	52 (7.33)
Males vs. Females										
Males	354 (49.9)	9.69 (1.16) *	1.66 (2.39)	1.43 (1.57)	2.20 (.43) **	2.49 (.37) ***	2.31 (.43)	2.32 (.43) **	32 (9.04) **	37 (10.45) **
Females	355 (50.07)	9.85 (.97) *	1.94 (1.77)	1.36 (1.35)	2.29 (.39) **	2.37 (.38) ***	2.34 (.45)	2.41 (.42) **	14 (3.94) **	15 (4.23) **
Free Lunch vs. No										
Free Lunch	148 (20.87)	9.67 (1.17)	2.16 (2.16) *	1.59 (1.83)	2.24 (.44)	2.44 (.41)	2.28 (.50)	2.29 (.46) *	17 (11.49) **	18 (12.16) *
No Free Lunch	561 (79.13)	9.80 (1.05)	1.71 (2.03) *	1.34 (1.35)	2.25 (.41)	2.43 (.37)	2.34 (.43)	2.39 (.42) *	29 (5.17) **	34 (6.06) *
Ethnicity										
White	233 (33)	9.90 (1.10) *	1.56 (2.26) *	1.08 (1.05) ***	2.23 (.44)	2.45 (.35)	2.36 (.43)	2.39 (.41)	7 (3) **	8 (3.43) **
Non- White	476 (67)	9.71 (1.06) *	1.92 (1.95) *	1.55 (1.61) ***	2.26 (.40)	2.42 (.39)	2.31 (.45)	2.36 (.44)	39 (8.19) **	44 (9.24) **

Pairwise comparisons are bold if t test significant at p<.05

* p<.05

** p<.01

*** p<.001

TABLE 2

Standardized path coefficients and standard errors for prospective associations between 4th grade sleep duration and 6th grade substance use shown in Figure 1 (N=684)

Direct effects from 6th Grade Cigarette Use	β (SE)
--> 4th Grade Nightly Sleep Duration	-.14 (.10) ⁺
--> 5th Grade Inhibitory Control	-.35 (.09) ^{***}
--> 5th Grade Emotional Control	-.09 (.08)
--> 5th Grade Working Memory	.05 (.07)
--> 5th Grade Organization	.08 (.08)
--> Age	.18 (.08) [*]
--> Low SES	.14 (.09) [*]
--> Male Gender	.15 (.10) ⁺
--> White Ethnicity	-.25 (.11) [*]
Direct effects from 6th Grade Alcohol Use	
--> 4th Grade Nightly Sleep Duration	-.04 (.09)
--> 5th Grade Inhibitory Control	-.16 (.08) [*]
--> 5th Grade Emotional Control	-.08 (.09)
--> 5th Grade Working Memory	-.07 (.08)
--> 5th Grade Organization	.06 (.07)
--> Age	.05 (.07)
--> Low SES	.10 (.06) ⁺
--> Male Gender	.20 (.09) ^{**}
--> White Ethnicity	-.21 (.08) ^{***}
Direct effects from 5th Grade Inhibitory Control	
--> 4th Grade Nightly Sleep Duration	.09 (.04) ^{**}
--> 5th Grade Perceived Stress	-.15 (.04) ^{***}
--> 4th Grade Age	.06 (.03) [*]
Direct effects from 5th Grade Emotional Control	
--> 4th Grade Nightly Sleep Duration	.05 (.04)
--> 5th Grade Perceived Stress	-.20 (.04) ^{***}
--> Male Gender	.15 (.05) ^{***}
Direct effects from 5th Grade Working Memory	
--> 4th Grade Nightly Sleep Duration	.03 (.03)
--> 5th Grade Perceived Stress	-.11 (.04) ^{**}
--> Age	-.06 (.04) ⁺
Direct effects from 5th Grade Organization	
--> 4th Grade Nightly Sleep Duration	.07 (.03) [*]

Direct effects from 6th Grade Cigarette Use		β (SE)
--> 5th Grade Perceived Stress		-.05 (.04) ⁺
--> Male Gender		-.09 (.04)*
--> Low SES		-.09 (.04)*
INDIRECT EFFECTS FROM 4TH GRADE NIGHTLY SLEEP DURATION TO 6TH GRADE CIGARETTE USE		
--> Via 5th Grade Inhibitory Control		-.031 (.016)*
--> Via 5th Grade Emotional Control		-.004 (.005)
--> Via 5th Grade Working Memory		.001 (.003)
--> Via 5th Grade Organization		.006 (.006)
INDIRECT EFFECTS FROM 4TH GRADE NIGHTLY SLEEP DURATION TO 6TH GRADE ALCOHOL USE		
--> Via 5th Grade Inhibitory Control		-.014 (.009) ⁺
--> Via 5th Grade Emotional Control		-.004 (.006)
--> Via 5th Grade Working Memory		-.002 (.003)
--> Via 5th Grade Organization		.004 (.006)
+p<.1 *p<.05 **p<.01 ***p<.001		
X ² = 10.12(12df) p=.61; TLI=1.016; RMSEA= .000 (90% CI .000-.036)		
Model R ² for 6 th grade Cigarette Use = .293		
Model R ² for 6 th grade Alcohol Use = .149		

TABLE 3

Standardized path coefficients and standard errors for prospective associations between 4th grade weekend bed-time delay and 6th grade substance use shown in Figure 2 (N=684)

6th Grade Cigarette Use	β (SE)
--> 4th Grade Weekend Bed-time Delay	-.02 (.11)
--> 4th Grade Nightly Sleep Duration	-.17 (.11) ⁺
--> 5th Grade Inhibitory Control	-.35 (.09) ^{***}
--> 5th Grade Emotional Control	-.09 (.08)
--> 5th Grade Working Memory	.05 (.07)
--> 5th Grade Organization	.08 (.08)
--> Age	.18 (.08) [*]
--> Low SES	.15 (.09) [*]
--> Male Gender	.15 (.10) ⁺
--> White Ethnicity	-.24 (.11) [*]
6th Grade Alcohol Use	
--> 4th Grade Weekend Bed-time Delay	.11 (.08) ⁺
--> 4th Grade Nightly Sleep Duration	-.03 (.09)
--> 5th Grade Inhibitory Control	-.15 (.09) [*]
--> 5th Grade Emotional Control	-.10 (.09)
--> 5th Grade Working Memory	-.05 (.08)
--> 5th Grade Organization	.07 (.08)
--> Age	.04 (.08)
--> Low SES	.09 (.06) ⁺
--> Male Gender	.20 (.09) [*]
--> White Ethnicity	-.18 (.08) ^{**}
5th Grade Inhibitory Control	
--> 4th Grade Weekend Bed-time Delay	-.14 (.05) ^{**}
--> 5th Grade Perceived Stress	-.16 (.03) ^{***}
--> Age	.06 (.03) [*]
--> Male Gender	-.10 (.04) [*]
5th Grade Emotional Control	
--> 4th Grade Weekend Bed-time Delay	-.04 (.04)
--> 5th Grade Perceived Stress	-.21 (.04) ^{***}
--> Male Gender	.15 (.05) ^{***}
5th Grade Working Memory	
--> 4th Grade Weekend Bed-time Delay	-.10 (.04) ^{**}
--> 5th Grade Perceived Stress	-.11 (.04) ^{**}
--> Age	-.06 (.04) ⁺

6th Grade Cigarette Use		β (SE)
5th Grade Organization		
--> 4th Grade Weekend Bed-time Delay		-.11 (.04)**
--> 5th Grade Perceived Stress		-.06 (.04) ⁺
--> Male Gender		-.09 (.04)*
--> Low SES		-.08 (.04)*
INDIRECT EFFECTS FROM 4TH GRADE WEEKEND BED-TIME DELAY TO 6TH GRADE CIGARETTE USE		
--> Via 5th Grade Inhibitory Control		.049 (.019)**
--> Via 5th Grade Emotional Control		.003 (.005)
--> Via 5th Grade Working Memory		-.004 (.006)
--> Via 5th Grade Organization		-.009 (.010)
INDIRECT EFFECTS FROM 4TH GRADE WEEKEND BED-TIME DELAY TO 6TH GRADE ALCOHOL USE		
--> Via 5th Grade Inhibitory Control		.021 (.012)*
--> Via 5th Grade Emotional Control		.004 (.006)
--> Via 5th Grade Working Memory		.005 (.008)
--> Via 5th Grade Organization		-.007 (.010)
MODEL FIT STATISTICS:		
$\chi^2 = 16.96$ (16df) $p = .39$; TLI = .993; RMSEA = .01 (90% CI .000-.039)		
Model R^2 for 6 th grade Cigarette Use = .293		
Model R^2 for 6 th grade Alcohol Use = .157		

TABLE 4

Standardized path coefficients and standard errors for prospective associations between 4th grade weekend wake-time delay and 6th grade substance use shown in Figure 3 (N=684)

6th Grade Cigarette Use	β (SE)
--> 4th Grade Weekend Wake-time Delay	.04 (.08)
--> 4th Grade Nightly Sleep Duration	-.18 (.12) ⁺
--> 5th Grade Inhibitory Control	-.35 (.09) ^{***}
--> 5th Grade Emotional Control	-.09 (.08)
--> 5th Grade Working Memory	.05 (.07)
--> 5th Grade Organization	.09 (.09)
--> Age	.18 (.08) [*]
--> Low SES	.15 (.08) [*]
--> Male Gender	.15 (.10)
--> White Ethnicity	-.25 (.11) [*]
6th Grade Alcohol Use	
--> 4th Grade Weekend Wake-time Delay	.17 (.08) [*]
--> 4th Grade Nightly Sleep Duration	-.08 (.09)
--> 5th Grade Inhibitory Control	-.14 (.09) [*]
--> 5th Grade Emotional Control	-.10 (.09)
--> 5th Grade Working Memory	-.04 (.08)
--> 5th Grade Organization	.07 (.07)
--> Age	.04 (.08)
--> Low SES	.08 (.06) ⁺
--> Male Gender	.22 (.09) ^{**}
--> White Ethnicity	-.20 (.08) ^{**}
5th Grade Inhibitory Control	
--> 4th Grade Weekend Wake-time Delay	-.13 (.04) ^{***}
--> 5th Grade Perceived Stress	-.15 (.03) ^{***}
--> Age	.05 (.03) [*]
--> Male Gender	-.11 (.04) ^{**}
5th Grade Emotional Control	
--> 4th Grade Weekend Wake-time Delay	-.03 (.04)
--> 5th Grade Perceived Stress	-.20 (.04) ^{***}
--> Male Gender	.14 (.05) ^{**}
5th Grade Working Memory	
--> 4th Grade Weekend Wake-time Delay	-.15 (.04) ^{***}
--> 5th Grade Perceived Stress	-.10 (.04) ^{**}
--> Age	-.07(.04) ⁺

6th Grade Cigarette Use	β (SE)
5th Grade Organization	
--> 4th Grade Weekend Wake-time Delay	-.12 (.03)***
--> 5th Grade Perceived Stress	-.05 (.04) ⁺
--> Male Gender	-.10 (.04)**
--> Low SES	-.08 (.04)*
INDIRECT EFFECTS FROM 4TH GRADE WEEKEND WAKE- TIME DELAY TO 6TH GRADE CIGARETTE USE	
--> Via 5th Grade Inhibitory Control	.047 (.018)**
--> Via 5th Grade Emotional Control	.003 (.004)
--> Via 5th Grade Working Memory	-.008 (.012)
--> Via 5th Grade Organization	-.011 (.011)
INDIRECT EFFECTS FROM 4TH GRADE WEEKEND WAKE-TIME DELAY TO 6TH GRADE ALCOHOL USE	
--> Via 5th Grade Inhibitory Control	.019 (.013) ⁺
--> Via 5th Grade Emotional Control	.003 (.005)
--> Via 5th Grade Working Memory	.006 (.012)
--> Via 5th Grade Organization	-.008 (.009)
MODEL FIT STATISTICS:	
$X^2 = 26.29(16df)$ $p = .05$; TLI = .981; RMSEA = .032 (90%CI .000-.054)	
Model R^2 for 6 th grade Cigarette Use = .296	
Model R^2 for 6 th grade Alcohol Use = .172	