

SCIENTIFIC INVESTIGATIONS

## Longitudinal associations between high school sleep characteristics and young adult health outcomes

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**Study Objectives:** Short sleep duration and evening chronotype are independently associated with negative health outcomes. However, it is unclear how adolescent sleep duration and chronotype are longitudinally associated with health outcomes during early adulthood.

**Methods:** Participants from the NEXT Generation Health Study (n = 2,783; 54.5% female) completed measures of sleep duration (scheduled day and unscheduled day) and chronotype in high school. Sleep duration, chronotype, general health, depressive symptoms, and psychosomatic symptoms were also assessed 4 years after high school. Latent variables estimated high school scheduled-day sleep duration, unscheduled-day sleep duration, and chronotype using the during high school measures. Two path analyses tested the prospective associations between high school sleep duration (separate models for scheduled and unscheduled days) and chronotype with 4 years after high school health outcomes as mediated by concurrent sleep duration and chronotype.

**Results:** In the scheduled-day model, longer high school sleep duration and later chronotype were associated with longer duration and later chronotype in early adulthood. Longer high school sleep duration was directly associated with fewer psychosomatic symptoms and indirectly associated with fewer depressive and psychosomatic symptoms through longer sleep duration in early adulthood. Later chronotype in high school was indirectly associated with poorer general health, greater depressive symptoms, and greater psychosomatic symptoms in early adulthood through later chronotype.

**Conclusions:** Findings highlight the roles of scheduled-day sleep duration and evening chronotype in shaping health outcomes and suggest the importance of chronotype and optimal sleep habits among adolescents.

**Keywords:** adolescence, sleep duration, sleep timing, chronotype, longitudinal mediation models

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### BRIEF SUMMARY

**Current Knowledge/Study Rationale:** Short sleep duration and evening chronotype both contribute to adverse physical and mental health outcomes, but research has yet to examine the independent longitudinal effects of sleep duration and chronotype at the transition from adolescence to adulthood. This study sought to examine longitudinal health outcomes associated with sleep duration and chronotype from adolescence to early adulthood using a nationally representative sample.

**Study Impact:** Findings highlight short scheduled-day sleep duration and evening chronotype in adolescence as contributing to increased depressive and psychosomatic symptoms and poorer general health in early adulthood. Furthermore, findings suggest that sleep timing and duration habits developed in adolescence persist into early adulthood, raising important questions about the types and timing of intervention to address high value modifiable health behaviors.

### INTRODUCTION

The majority of adolescents experience deficiencies in sleep duration (< 8 h/night) and less optimal timing due to conflicts between their intrinsic evening chronotype, early school and work start times, and other social and environmental demands.<sup>1,2</sup> At the onset of puberty, circadian clocks slow, resulting in a longer biological day and a drive to go to bed later and wake later.<sup>3</sup> Thus, relative to young children and adults, adolescents typically do not go to bed earlier to accommodate early rise times necessitated by school or other morning commitments because of their biological circadian phase delay.<sup>4</sup> While in general, early adulthood is a period of relatively good health,<sup>5</sup> a notable proportion of this age group report experiences of depressive and psychosomatic symptoms.<sup>6,7</sup> Data

from the National Survey on Drug Use and Health (NSDUH) indicate that almost 10% of individuals aged 18–25 report 12-month prevalence of a major depressive episode.<sup>6</sup> Young people also report mild but frequent psychosomatic symptoms, including headache and back ache.<sup>7</sup> Using a prospective design, we examine how both deficient sleep duration and timing in adolescence contribute to early adult indicators of depressive symptoms, psychosomatic symptoms, and general health.

Much literature demonstrates the adverse health consequences of short sleep duration among adolescents. For example, a study of cross-sectional data from the Youth Risk Behavior Survey found that high school students who reported < 8 hours of sleep on school nights had higher odds of reporting substance use, risk behavior, poor dietary habits, and feelings of depression than

students reporting sufficient school night sleep duration.<sup>8</sup> Short sleep duration is also cross-sectionally associated with poorer self-rated health, increased odds of being overweight, frequent or severe headaches, and atopic conditions.<sup>9,10</sup> Using a longitudinal design, Roberts and Duong<sup>11</sup> found that sleep deprivation ( $\leq 6$  h/night) predicted depressive symptoms 1 year later when accounting for baseline symptoms. Additionally, short sleep duration is associated with longitudinal risk of low self-esteem, low life satisfaction, and increased physical health risk among youth.<sup>12,13</sup>

Chronotype refers to an individual's biologically preferred timing of sleep during the 24-hour day and is an important component of sleep health.<sup>3,4</sup> Adolescence is marked by a shift to later chronotype, peaking around age 20.<sup>4</sup> Later chronotype (ie, a preference for later bed and wake times) is cross-sectionally associated with increased mental health symptoms, poor emotion regulation, and adverse behavioral outcomes.<sup>14–16</sup> Longitudinal studies evaluating consequences of poor sleep timing in adolescence largely focus on substance use.<sup>17,18</sup> There is only 1 longitudinal study among youth that examines chronotype and mental health, which focuses on depressive symptoms, and it found that later chronotype predicts greater depressive symptoms.<sup>19</sup> Similar findings have been found in longitudinal samples of adults.<sup>20,21</sup>

As evening chronotype and short sleep duration are both common among adolescents and have well-established associations with poorer health outcomes, studies have proposed a broader conceptualization of deficient sleep in adolescents that incorporates both duration and timing.<sup>16</sup> Accordingly, various studies have examined these factors together,<sup>14,16,22</sup> but research regarding the joint effects among high school students is mixed. Some studies suggest a more prominent contribution of chronotype on psychological health and other outcomes, including academic performance and self-regulation,<sup>14,16,22</sup> although there is also evidence indicating independent roles of both sleep duration and chronotype.<sup>23</sup> Notably, this work is cross-sectional,<sup>14,16,22,23</sup> highlighting the importance of investigating these potential independent associations with a longitudinal study. Moreover, despite being health concerns among adolescents, independent contributions of chronotype and sleep duration on psychosomatic symptoms and self-rated health have not been explored.

Additionally, it remains unclear if longitudinal sequelae of short sleep duration and evening chronotype are due to the unique effects of poor sleep health during adolescence or because poor sleep health becomes habitual and persists throughout early adulthood. Research indicates that year-to-year sleep duration is stable among adolescents<sup>24</sup> even in times of transition.<sup>25</sup> Similar research has not been conducted examining stability of chronotype across adolescence and into early adulthood, although research suggests stability in chronotype among adults.<sup>20</sup> Extant cross-sectional research indicates that the overall distribution of chronotype shifts later in adolescence and the distribution of individual chronotypes remains normal within each age group.<sup>4,20,26</sup>

Because adolescence is marked by change and growing independence from caregivers,<sup>27</sup> it is a critical period for youth to develop healthful lifestyle habits, including adequate sleep duration and sleep/wake times. Sleep habits developed in adolescence can persist into adulthood and influence subsequent

health behaviors, as is seen with dietary habits<sup>28</sup> and substance use.<sup>29</sup> To address the dearth of research on longer term stability of sleep and circadian characteristics and impacts on subsequent wellbeing, this study investigated potential pathways to longitudinal sleep-related and circadian-related health outcomes from high school through early adulthood.

We examined associations of high school sleep duration and high school chronotype with general health, depressive symptoms, and psychosomatic symptoms 4 years after high school. First, we hypothesized that adolescents with shorter sleep duration and later chronotype during high school would experience greater depressive symptoms, greater psychosomatic symptoms, and poorer physical health 4 years after high school. Additionally, we examined if young adult sleep duration and chronotype accounted for indirect pathways from high school sleep duration and chronotype to young adult health outcomes. We hypothesized that sleep duration and chronotype in early adulthood would mediate the relations between high school sleep duration and chronotype and health outcomes in early adulthood.

## METHODS

All data came from the NEXT Generation Health Study, a 7-year cohort study of multiple health indicators and behaviors in a nationally representative sample of US adolescents. School districts were randomly selected from each of the 9 US census divisions, and schools were randomly selected within participating school districts; the probability of selection at each level was proportional to enrollment. Out of 137 schools selected, 81 (64%) agreed to participate and all students within 1 to 5 randomly selected 10th grade classrooms within schools were eligible for inclusion. Baseline data were collected during the 2009–2010 school year for all but 1 school; due to timing of school approval for participation, baseline assessments for that school (261 participants) occurred during the second wave (2010–2011, 11th grade). Parents provided informed consent; participant consent was obtained when they turned 18 years old. In total, 2,783 participants from 22 states were surveyed annually until early adulthood. In the first year (T1) participants completed surveys during in their classroom. From T2 onward, participants were contacted by email, provided a unique password to access their survey, which was completed online. Multiple outreach efforts were employed (eg, Facebook and text messages) to encourage participants to complete their surveys. The present study focused on 10th, 11th, and 12th grades (T1–T3) and the fourth year after high school (T7). The study protocol was approved by the institutional review board at the Eunice Kennedy Shriver National Institute of Child Health and Human Development.

## Measures

### Sleep variables (T1–T3, T7)

**Sleep duration.** Participants reported what time they “usually wake up” and “usually go to sleep the night or day before” (hour, minute, AM/PM designation) on scheduled (ie, go to

school, work, or have similar activities) and unscheduled (ie, do not have to get up at a certain time) days using items from the National Longitudinal Study of Adolescent Health.<sup>30</sup> To address questionable AM vs PM designations, we followed the methodology utilized in analyzing sleep duration data in the NEXT study: wake time hours of 5–11 were designated as “AM” and wake times of 12, 1, and 2 were designated as “PM,” whereas sleep time hours of 8–11 were designated as “PM” and 12 and 1–4 were designated as “AM.”<sup>31</sup> This resulted in changing AM/PM designations for 0.06–2.50% of wake times and 2.70–8.21% of sleep times at each wave. Sleep duration for scheduled and unscheduled days was the length of time between reported sleep and wake times.

**Chronotype.** Chronotype was derived from self-reported free-day sleep period. The midpoint between the wake time and bedtime was corrected for oversleeping due to sleep debt to calculate chronotype for each participant [chronotype = free-day sleep midpoint – 0.5 \* (scheduled-day sleep duration – weekly sleep duration)].<sup>4</sup> Higher values indicate later chronotype or more eveningness (ie, worse sleep timing). This method of assessment yields a validated quantitative measure of sleep phase<sup>32</sup> and derivation of chronotype for adolescents.<sup>4</sup>

### Young adult mental health and wellbeing (T7)

**General health.** Participants answered the single item question, “Would you say your health is ... ?” (1 = poor to 4 = excellent). A single-item global assessment of self-perception is a consistent predictor of mortality, independent of other more specific health indicators.<sup>33</sup> This assessment method has been used previously with adolescent samples in the Health Behavior in School-Aged Children (HBSC) study.<sup>34</sup>

**Depressive symptoms.** Participants completed the 8-item Patient-Reported Outcomes Measurement Information System (PROMIS) pediatric depressive symptoms scale.<sup>35</sup> Participants indicated how often each item (eg, I felt lonely) was true over the past 7 days from 1 (*never*) to 5 (*almost always*). Scores were converted to *t*-scores normed to distributions of scores in the national pediatric population (mean = 50, standard deviation = 10) with higher scores indicating higher depressive symptoms ( $\alpha = .96$ ).

**Psychosomatic symptoms.** Participants indicated how often they experienced 8 symptoms: headache, stomach ache, back ache, feeling low, irritability or bad temper, feeling nervous, difficulties in getting to sleep, and feeling dizzy (1 = rarely/never to 5 = about every day) using a validated measure with prior use in the HBSC study.<sup>36</sup> A mean score was calculated, with higher scores indicating more psychosomatic symptoms ( $\alpha = .84$ ).

### Covariates (T1, T7)

T1 measures of depressive symptoms, general health, and psychosomatic symptoms were included as covariates to account for baseline health in adolescence. At T1, the NEXT Generation Health Study assessed depressive symptoms with the Modified Depression Scale.<sup>37</sup> Participants reported how often they felt 6 symptoms (eg, grouchy or irritable or in a bad mood) in the past 30 days on a scale of 1 (never) to 5 (always). Since PROMIS

scores were used to assess depressive at T7, scores were standardized (mean = 50, standard deviation = 10) to be consistent with the PROMIS scores, with higher scores indicating higher depressive symptoms.<sup>38</sup> The T1 measures of general health and psychosomatic symptoms were the same as those used at T7.

Models also included T7 college status (not enrolled or enrolled in higher education), T7 employment status (not full-time employed, full-time employed), and baseline demographic variables, including sex, race/ethnicity (White, African American, Hispanic, other), and perceived family affluence (high, medium, and low) using the Family Affluence scale, which inquired about family car and computer ownership, child having their own bedroom, and holiday travel.<sup>39</sup>

### Analysis plan

First, bivariate associations among scheduled-day and unscheduled-day sleep duration, chronotype, and health outcome variables in adolescence and early adulthood were investigated. Next, measurement models estimated separate latent structures for high school scheduled-day sleep duration, unscheduled-day sleep duration, and chronotype using the T1, T2, and T3 measures. Then 2 path models were estimated. The first model estimated the direct effects of high school scheduled-day sleep duration and chronotype on each T7 health outcome and the indirect effects of high school scheduled-day sleep duration and chronotype through T7 scheduled-day sleep duration and chronotype, respectively. The second model paralleled the first but replaced the scheduled-day sleep duration with unscheduled-day sleep duration. The residual variances between all outcome variables were correlated. Survey design variables, sex (referent = female), race/ethnicity (referent = White), family affluence (referent = high), employment status (referent = not full-time employed), and college enrollment (referent = not enrolled) were included as controls. In addition, measures of depressive symptoms, general health, and psychosomatic symptoms in adolescence were covaried in each path model to account for health symptoms at baseline. Descriptive statistics were conducted in SAS 9.4 (Cary, NC); the latent structures and path model were estimated in Mplus 8.<sup>40</sup> The path model used bootstrapping resampling methods to estimate the bias-corrected confidence intervals of each indirect effect, which maximizes power and does not assume normal distributions in the data.<sup>41</sup> To make use of all available data and account for missing data, all models were estimated using full information maximum likelihood. We used 3 goodness-of-fit indexes to determine model fit adequacy: comparative fit index (CFI), Tucker-Lewis index (TLI), and root mean square error of approximation (RMSEA). CFI and TLI > .95 and RMSEA ≤ .06 indicate acceptable fit.<sup>42</sup>

## RESULTS

Sample characteristics are reported in **Table 1**, and descriptive statistics and correlations of model variables are reported in **Table 2**. Average scheduled-day sleep duration ranged from 7 hours, 20 minutes to 7 hours, 50 minutes; average unscheduled-day sleep duration ranged from 8 hours, 53 minutes to 9 hours, 17 minutes across time points. Average chronotype, or midsleep time, ranged

**Table 1**—Sample characteristics (n = 2,783).

		n	Weighted %
Sex	Male	1,254	45.49%
	Female	1,524	54.51%
Race/Ethnicity	Latinx	835	19.27%
	African American	687	20.19%
	White	1,106	55.72%
	Other (eg, Asian, Hawaiian/Pacific Islander, and American Indian/Alaskan Native)	142	4.82%
Family Affluence	Low	920	24.92%
	Moderate	1,285	48.53%
	High	578	26.55%
T7 Employment Status	Employed Full Time	1,063	49.29%
	Not Employed Full Time	1,251	50.71%
T7 College Enrollment Status	Enrolled in Higher Education	990	38.13%
	Not Enrolled in Higher Education	1,326	61.87%

Fluctuating n values are due to missing data on demographic variables.

from 4:27 AM (4.45) to 4:38 AM (4.63) across time points, where greater chronotype reflects more eveningness or later (ie, worse) sleep timing.

The bivariate relations of high school sleep duration and chronotype with health outcomes in early adulthood indicated overall patterns in the longitudinal relations (see **Table 2**): (1) longer scheduled-day sleep duration in high school (T1–T3) was associated with better general health, fewer depressive symptoms, and fewer psychosomatic symptoms in early adulthood (T7); (2) unscheduled sleep duration in high school (T1–T3) was not associated with general health, depressive symptoms, or psychosomatic symptoms in early adulthood (T7); and (3) high school chronotype (T1–T3) was overall not related to general health or depressive symptoms, but a later high school chronotype was associated with more psychosomatic symptoms in early adulthood (T7). Additionally, longer scheduled-day sleep duration in high school (T1–T3) was associated with longer scheduled-day sleep duration in early adulthood (T7), longer unscheduled-day sleep duration in high school (T1–T3) was associated with longer unscheduled-day sleep duration in early adulthood (T7), and later high school chronotype (T1–T3) was associated with later young adult chronotype (T7). When examining the cross-sectional bivariate results of chronotype and scheduled and unscheduled sleep duration in early adulthood (T7) with health outcomes in early adulthood (T7; for correlation plots, see **Figure S1**, **Figure S2**, **Figure S3** in the supplemental material), longer scheduled-day and unscheduled-day sleep duration were each significantly associated with more depressive symptoms, and later chronotype was associated with poorer general health and more depressive and psychosomatic symptoms.

Three measurement models were estimated to create the latent structures for high school sleep duration and high school chronotype. Because all 3 models were just-identified (ie, models with no available degrees of freedom), the process provided no meaningful

global fit statistics (Chi square, CFI, TLI, RMSEA). Instead, we examined the component fit of each latent structure to evaluate the standardized factor loadings of each observed measure. In the measurement models for high school sleep, the T1, T2, and T3 standardized factor loadings for the latent structures were .61, .68, and .45 for scheduled-day sleep duration; .60, .63, and .43 for unscheduled sleep duration; and .72, .76, and .65 for chronotype. Thus, all 3 time points for high school sleep duration and chronotype loaded adequately onto their respective latent structures.

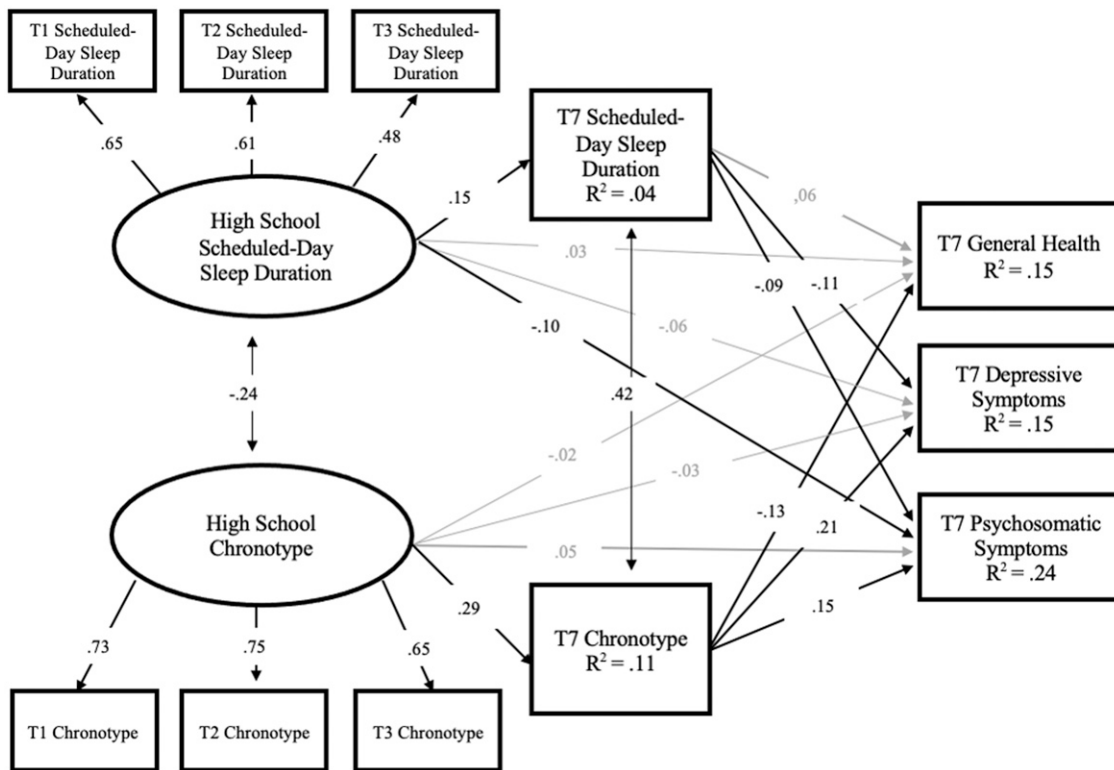
Results of the path model predicting health outcomes from high school scheduled-day sleep duration and high school chronotype while accounting for baseline health symptoms are found in **Figure 1**. The final model fit was adequate (CFI = 0.98; TLI = .95; RMSEA = 0.01). Longer high school scheduled-day sleep duration was associated with longer T7 sleep duration and with fewer T7 psychosomatic symptoms. Longer T7 scheduled-day duration was related to fewer depressive and psychosomatic symptoms. Indirect pathways were present for high school scheduled-day sleep duration through T7 sleep duration to depressive and psychosomatic symptoms (**Table 3**), such that longer high school duration was associated with fewer depressive symptoms and psychosomatic symptoms through longer T7 sleep duration. For high school chronotype, there was a positive association with T7 chronotype, such that later high school chronotype predicted later T7 chronotype, but no significant direct paths to the T7 health outcomes. Later T7 chronotype was associated with poorer T7 general health and increased T7 depressive and psychosomatic symptoms. All 3 indirect paths of high school chronotype through T7 chronotype to T7 health outcomes were significant (**Table 3**), such that later high school chronotype was associated with worse outcomes through later T7 chronotype. The model accounted for 15%, 15%, and 24% of the variance in T7 general health, depressive symptoms, and psychosomatic symptoms, respectively.

**Table 2**—Descriptive statistics and correlations of model variables.

	M	(SE)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
<b>Scheduled-Day Sleep Duration</b>																				
1.	T1	7.46	(1.29)	—																
2.	T2	7.44	(1.40)	.42*	—															
3.	T3	7.33	(1.35)	.34*	.39*	—														
4.	T7	7.83	(2.02)	.09*	.10*	.14*	—													
<b>Unscheduled-Day Sleep Duration</b>																				
5.	T1	9.28	(1.83)	.16*	.10*	.12*	—													
6.	T2	9.29	(1.92)	.12*	.23*	.10*	.35*	—												
7.	T3	9.04	(1.71)	.16*	.12*	.28*	.34*	.39*	—											
8.	T7	8.89	(1.97)	.02	.05	.07*	.14*	.18*	.21*	—										
<b>Chronotype</b>																				
9.	T1	4.47	(1.39)	-.11*	-.10*	-.07*	-.03	-.25*	-.06*	-.04	.02	—								
10.	T2	4.45	(1.40)	-.12*	-.06*	-.11*	-.02	-.06*	-.23*	-.05	.00	.52*	—							
11.	T3	4.47	(1.37)	-.11*	-.11*	-.04	-.06*	-.06*	-.10*	-.03	.47*	.49*	—							
12.	T7	4.63	(1.67)	-.11*	-.10*	-.14*	.21*	.01	.02	-.01	.19*	.21*	.22*	—						
<b>General Health</b>																				
13.	T1	2.17	(.83)	-.06	-.05	-.02	-.01	-.02	.01	.01	.01	.01	-.01	.04	—					
14.	T7	2.78	(.76)	.05	.04	.09*	.02	.02	.02	.03	.01	-.02	-.01	-.12*	.29*	—				
<b>Depressive Symptoms</b>																				
15.	T1	51.12	(9.97)	-.10*	-.07	-.07	.03	.03	-.01	-.06	-.01	.07	.04	.04	.07	.31*	.20*	—		
16.	T7	49.76	(11.96)	-.10*	-.04	-.06*	-.04	-.03	.03	-.02	-.08*	.04	.05	.02	.15*	.14*	-.32*	.30*	—	
<b>Psychosomatic Symptoms</b>																				
17.	T1	2.22	(.83)	-.07	-.04	-.05	-.02	.01	-.01	-.03	-.06	.06	.05	.05	.01	.25*	.14*	.63*	.27	—
18.	T7	1.88	(.79)	-.12*	-.05	-.09*	-.02	-.04	-.01	-.03	-.04	.08*	.05	.08*	.19*	-.33*	.34*	.61*	.42*	—

\*P < .001. T1 = assessment during the 10th grade, T2 = assessment during 11th grade, T3 = assessment during 12th grade, T7 = assessment during 4 years after the last year of high school.

**Figure 1**—Path model predicting health outcomes from high school scheduled-day sleep duration and high school chronotype.



Standardized estimates are reported. Sex, race/ethnicity, family affluence, T1 general health, depressive symptoms, and psychosomatic symptoms and T7 college status and employment status are included as covariates. T1 = assessment during the 10th grade, T2 = assessment during 11th grade, T3 = assessment during 12th grade, T7 = assessment 4 years after the last year of high school.

Results of the path model predicting health outcomes from high school unscheduled-day sleep duration and high school chronotype while accounting for baseline health symptoms are found in **Figure 2**. The final model fit was marginal (CFI = 0.88; TLI = .71; RMSEA = 0.035). Longer high school unscheduled-

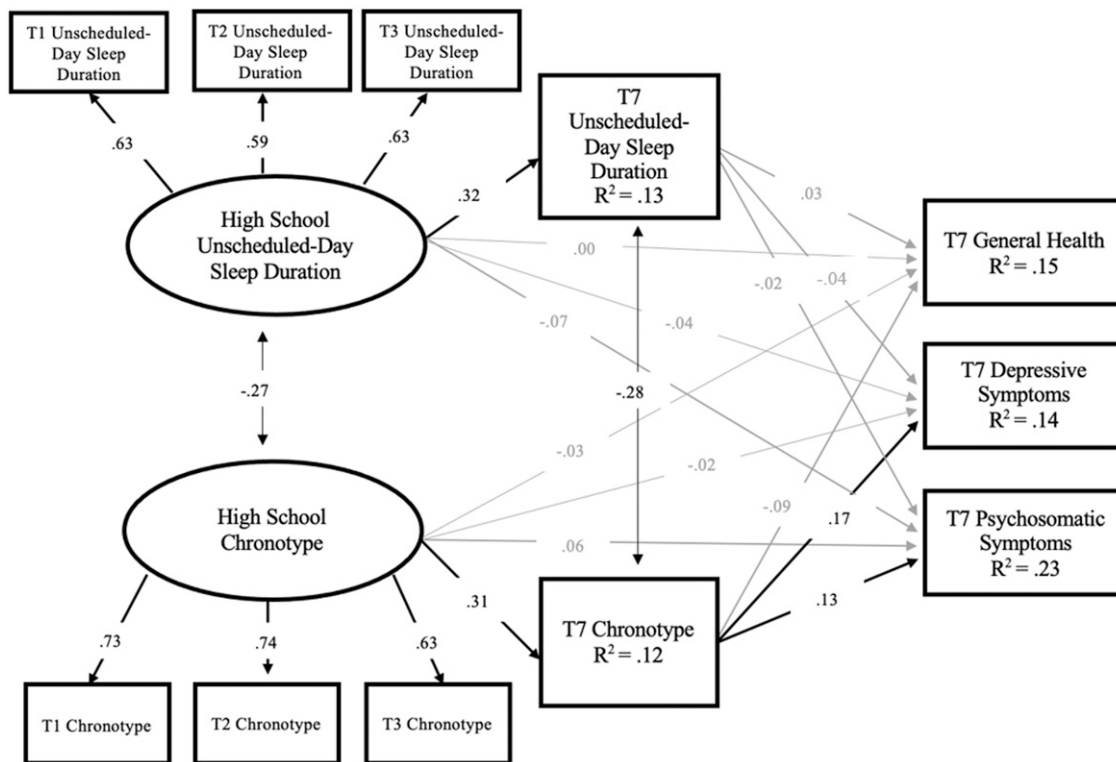
day sleep duration was related to longer T7 sleep duration. T7 sleep duration was not associated with T7 health outcomes, and there were no indirect effects present (**Table 4**). There was a positive association between later high school chronotype and later T7 chronotype, but there were no direct paths from high school

**Table 3**—Indirect effects from **Figure 1**.

Predictors (latent variables)		Mediators		Health Outcomes	95% CI		
					Lower	β	Upper
High School Scheduled-Day Sleep Duration	→	T7 Scheduled-Day Sleep Duration	→	General Health	.000	.008	.032
High School Scheduled-Day Sleep Duration	→	T7 Scheduled-Day Sleep Duration	→	Psychosomatic Symptoms	<b>-.039</b>	<b>-.014</b>	<b>-.005</b>
High School Scheduled-Day Sleep Duration	→	T7 Scheduled-Day Sleep Duration	→	Depressive Symptoms	<b>-.046</b>	<b>-.016</b>	<b>-.003</b>
High School Chronotype	→	T7 Chronotype	→	General Health	<b>-.078</b>	<b>-.036</b>	<b>-.009</b>
High School Chronotype	→	T7 Chronotype	→	Psychosomatic Symptoms	<b>.019</b>	<b>.043</b>	<b>.076</b>
High School Chronotype	→	T7 Chronotype	→	Depressive Symptoms	<b>.039</b>	<b>.062</b>	<b>.095</b>

Bold values indicate a significant indirect effect. T1 = assessment during the 10th grade, T2 = assessment during 11th grade, T3 = assessment during 12th grade, T7 = assessment 4 years after the last year of high school.

**Figure 2**—Path model predicting health outcomes from high school unscheduled-day sleep duration and high school chronotype.



Standardized estimates are reported. Sex, race/ethnicity, family affluence, T1 general health, depressive symptoms, and psychosomatic symptoms and T7 college status and employment status are included as covariates. T1 = assessment during the 10th grade, T2 = assessment during 11th grade, T3 = assessment during 12th grade, T7 = assessment 4 years after the last year of high school.

chronotype to the T7 health outcomes. Later T7 chronotype was significantly associated with increased depressive symptoms and increased psychosomatic symptoms. Significant indirect pathways were found for high school chronotype through T7 chronotype to depressive and psychosomatic symptoms (Table 4), such

that later high school chronotype was associated with greater depressive symptoms and psychosomatic symptoms through later T7 chronotype. The model accounted for 15%, 14%, and 23% of the variance in general health, depressive symptoms, and psychosomatic symptoms, respectively.

**Table 4**—Indirect effects from Figure 2.

Predictors (latent variables)		Mediators		Health Outcomes	95% CI		
					Lower	$\beta$	Upper
High School Unscheduled-Day Sleep Duration	→	T7 Unscheduled-Day Sleep Duration	→	General Health	-.015	.008	.033
High School Unscheduled-Day Sleep Duration	→	T7 Unscheduled-Day Sleep Duration	→	Psychosomatic Symptoms	-.033	-.005	.016
High School Unscheduled-Day Sleep Duration	→	T7 Unscheduled-Day Sleep Duration	→	Depressive Symptoms	-.041	-.013	.005
High School Chronotype	→	T7 Chronotype	→	General Health	-.067	-.028	.002
High School Chronotype	→	T7 Chronotype	→	Psychosomatic Symptoms	<b>.014</b>	<b>.039</b>	<b>.074</b>
High School Chronotype	→	T7 Chronotype	→	Depressive Symptoms	<b>.032</b>	<b>.053</b>	<b>.081</b>

Bold values indicate a significant indirect effect. T1 = assessment during the 10th grade, T2 = assessment during 11th grade, T3 = assessment during 12th grade, T7 = assessment 4 years after the last year of high school.

## DISCUSSION

This study extended previous research by investigating longitudinal associations between high school scheduled-day and unscheduled-day sleep duration and chronotype with subsequent sleep duration, chronotype, and wellbeing outcomes 4 years after high school while accounting for baseline health outcomes in high school. Consistent with other adolescent samples,<sup>2</sup> our sample reported insufficient average sleep duration on scheduled days (ie, when they go to school or work). However, on days in which they do not have to get up at a certain time (ie, unscheduled days), our sample reported adequate sleep duration. Scheduled-day sleep duration and chronotype uniquely contributed to measures of young adult health, highlighting the important roles of these behaviors in relation to physical and psychological health outcomes.

Findings build upon previous longitudinal research evidencing adverse health impacts of evening chronotype<sup>19</sup> and short sleep duration<sup>11,13</sup> in adolescence and indicate that both scheduled-day duration and chronotype demonstrate independent relations with general health, depressive symptoms, and psychosomatic symptoms 4 years after high school. Interestingly, findings build upon mixed cross-sectional literature about this definition of deficient sleep that incorporates both duration and timing<sup>14,16,23</sup> by using longitudinal evidence to evaluate independent associations. The present longitudinal findings suggest that though a focus on sleep timing is important, sleep duration also remains a critical component of developing sleep health.

Findings also indicate that sleep duration and chronotype measured at the same time point are related to one another. In high school, shorter scheduled-day and unscheduled-day sleep duration were modestly associated with later chronotype. Prior research has attributed this to social/contextual factors in high school such as early school start times, increasingly demanding school curricula, and other demands.<sup>1,26</sup> Four years after high school this relation changed, such that longer scheduled-day sleep duration was related to later chronotype, which may reflect the way young adults use the greater flexibility in their scheduled-day habits to match their preferred sleep period.

The longitudinal findings in this study corroborate those from previous studies indicating that sleep duration is generally stable.<sup>24–26</sup> Further, these findings also build upon results from Druiven et al,<sup>20</sup> which indicate longitudinal stability in chronotype among adults, and suggest that chronotype remains stable during the transition from adolescence to early adulthood. The significant indirect pathways from high school weekday sleep duration and chronotype to later health outcomes through concurrent sleep characteristics may reflect consistent sleep habits that persist across development and shape young adult health outcomes. Specifically, our findings that consistency in sleep duration and chronotype are associated with greater depressive symptoms, psychosomatic symptoms, and general health are supported by cross-sectional empirical evidence that concurrent sleep habits are associated with adverse health outcomes.<sup>8,15,22</sup> However, our findings indicate that not all sleep characteristics follow this pattern; neither high school nor young adult unscheduled-day sleep duration was associated with health outcomes. Discrepancies in outcomes associated with scheduled-

day and unscheduled-day duration may be due to differences in reported sleep duration. As is well-documented in the literature,<sup>1,2,8</sup> high school students reported sleeping an insufficient duration on scheduled days. However, they reported sufficient duration (ie, 8 hours a night) on unscheduled days. Indeed, on unscheduled days, adolescents are not bound to early rise times due to school or other morning commitments and therefore may be better able to meet their sleep need. Notably, this pattern remained throughout young adulthood and highlights the clinical utility of examining scheduled-day and unscheduled-day sleep duration separately.

Prior research shows associations between deficient sleep and decrements in mood,<sup>14</sup> emotion regulation,<sup>16</sup> headache severity,<sup>9</sup> and general health.<sup>10</sup> Long-term deficits in scheduled-day sleep duration and chronotype may exacerbate such effects, which may contribute to greater depressive symptoms, psychosomatic symptoms, and poorer general health. The biological nature of chronotype may make it a difficult intervention target outside of clinical settings,<sup>4</sup> but our independent findings suggest that a focus on improving sleep duration through sleep hygiene and consistency in sleep schedules<sup>43,44</sup> may have the potential to mitigate adverse long-term outcomes, including emotional and physical health.

Adolescence is a sensitive period for the development of healthful behavioral habits. Importantly, prior research has identified adolescence as an important time to develop healthy eating behavior<sup>28</sup> and substance use<sup>29</sup> patterns, and this study provides similar evidence for sleep. Adolescents who report short scheduled-day sleep duration and evening chronotype are at heightened risk for worse longitudinal health outcomes in early adulthood, highlighting that cultivating adequate scheduled-day sleep schedules and maintaining optimal sleep timing in adolescence is foundational to long-term positive health development. An identified barrier to motivating adolescents to prioritize healthful lifestyles<sup>45</sup> is a common perception that consequences from unhealthy lifestyles are too far in the future to impact their current behavior.<sup>46</sup> This study provides evidence that there are long-term consequences rooted in adolescence (or earlier). This message should be incorporated into community educational efforts and policy considerations, such as setting of later school start times.

The present study utilized a large, nationally representative longitudinal sample of US students to examine sleep characteristics over multiple years, accounted for temporal precedence in sleep measures, and included important baseline control variables. However, there are notable limitations. All measures were self-reported, which are prone to social desirability and overestimation of sleep duration from conflating bed and sleep times.<sup>47</sup> Sleep duration and timing were the only sleep variables included and were derived from single-item questions. We also measured general health with one item, without domain specific (ie mental, physical) assessments. More comprehensive assessments of mental and physical health could have provided a broader scope of health outcomes. Further, although this study accounts for health outcomes at baseline in the longitudinal relations of high school sleep and chronotype with young adult health outcomes, we cannot conclude a causal link in these relations from observational data due to the possibility of other unmeasured influences.

Future research should include additional sleep parameters, such as daytime sleepiness, sleep quality, insomnia symptoms,<sup>15,48,49</sup>



and more comprehensive measures of general health. The associations found here could be tested using actigraphic data, an objective measure of sleep, which may be a more reliable estimate than self-reports. Given present findings regarding the importance of adolescence as a period to develop healthful sleep habits, it is the authors' opinions that future research could explore educational efforts or motivational interviewing as a mechanism to encourage youth, families, and policy makers to prioritize youth sleep. Other avenues of interest include longitudinal examinations of bedtime procrastination to disentangle biological vs behavioral reasons for delaying sleep timing<sup>50,51</sup> and night time use of social networking sites and other digital media in association with both sleep parameters and psychological health.<sup>52</sup> In addition, specific evaluation of the efficacy of sleep health interventions and investigation of durable changes in sleep and long-term physical and mental health outcomes may be justified investment given the findings of this study.

## CONCLUSIONS

This study identified adolescence as a critical time to establish healthful sleep timing and duration habits given the association between late chronotype and scheduled sleep (resulting in sleep insufficiency) in high school and these sleep characteristics 4 years later, which, in turn, were associated with health outcomes. Moreover, sleep duration during high school was directly associated with psychosomatic symptoms 4 years later, when accounting for high school chronotype, baseline symptoms, and later sleep characteristics. The independent effects of duration and chronotype on health outcomes warrant more attention in longitudinal studies to best target intervention efforts.

## ABBREVIATIONS

CFI, comparative fit index  
 HBSC, Health Behaviour in School-Aged Children  
 PROMIS, Patient-Reported Outcomes Measurement Information  
 RMSEA, root mean square error of approximation  
 T1, assessment during the 10th grade  
 T2, assessment during 11th grade  
 T3, assessment during 12th grade  
 T7, assessment four years after the last year of high school  
 TLI, Tucker-Lewis index

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