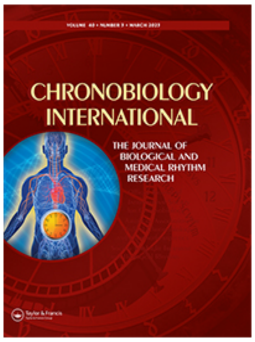

Taylor & Francis
Taylor & Francis Group

Chronobiology International
The Journal of Biological and Medical Rhythm Research

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/icbi20

Is the association of chronotype with adolescent behavior problems mediated through social jetlag?

Mia Q. Zhu, Henry Oliveros, Constanza Marín, Mercedes Mora-Plazas & Eduardo Villamor

To cite this article: Mia Q. Zhu, Henry Oliveros, Constanza Marín, Mercedes Mora-Plazas & Eduardo Villamor (2023): Is the association of chronotype with adolescent behavior problems mediated through social jetlag?, Chronobiology International, DOI: 10.1080/07420528.2023.2216790

To link to this article: https://doi.org/10.1080/07420528.2023.2216790

CHRONOBIOLOGY INTERNATIONAL
https://doi.org/10.1080/07420528.2023.2216790

ORIGINAL ARTICLE

Is the association of chronotype with adolescent behavior problems mediated through social jetlag?

Mia Q. Zhu[a], Henry Oliveros[b], Constanza Marín[b], Mercedes Mora-Plazas[c], and Eduardo Villamor[a]

[a]Department of Epidemiology, University of Michigan School of Public Health, Ann Arbor, Michigan, USA; [b]Facultad de Medicina, Universidad de La Sabana, Chía, Colombia; [c]FINUSAD, Foundation for Research in Nutrition and Health, Bogotá, Colombia

ABSTRACT

We examined the associations of chronotype with behavior problems in a cross-sectional study of 957 Colombian adolescents (mean age, 14.6 years; 56% female), in addition to the mediating role of social jetlag. The midpoint of bedtime and waketime on free days, corrected for sleep debt accumulated during school week (MSF_{sc}), was estimated from parent reports and used to assess chronotype. Behavior problems were evaluated through the Youth Self-Report (YSR) and the parent-completed Child Behavior Checklist (CBCL) questionnaires. We estimated adjusted mean differences with 95% CI in externalizing, internalizing, attention, social, and thought problem scores per one hour difference in chronotype using linear regression. Later chronotype was related to internalizing and externalizing behavior problems. Eveningness was associated with higher adjusted mean YSR scores (unit difference per hour) in externalizing behavior (1.0; 95% CI: 0.6, 1.5), internalizing behavior (0.6; 95% CI: 0.2, 1.1), attention problems (0.2; 95% CI: 0.0, 0.3), social problems (0.4; 95% CI: 0.1, 0.8), and thought problems (0.3; 95% CI: 0.1, 0.6). Similar patterns were observed with the CBCL. The associations of chronotype with somatic complaints and social problems were stronger in boys than they were in girls. Later chronotype was related to social jetlag but social jetlag was only associated with somatic complaints and attention problems, and mediated 16% and 26% of their corresponding associations with chronotype. In conclusion, later chronotype is associated with behavior problems in adolescence. Social jetlag does not substantially mediate these associations.

ARTICLE HISTORY
Received 1 December 2022
Revised 16 May 2023
Accepted 17 May 2023

KEYWORDS
Internalizing behavior; externalizing behavior; social problems; anxious/depressed behavior; later chronotype; social jetlag

Introduction

Mental health problems affect 10–20% of children and adolescents worldwide and are associated with adverse health outcomes in the short and long terms (Kieling et al. 2011; Prince et al. 2007). Of them, behavior problems are among the most pervasive. Often diagnosed in adolescence (Patton et al. 2016), behavior problems may lead to behavior disorders which substantially contribute to disability, low quality of life, and early mortality (Kessler et al. 2007; Roza et al. 2003). Elucidating the determinants of behavior problems in adolescence could contribute to the prevention of future severe disorders.

Chronotype, the behavioral manifestations of a person's circadian rhythm through the sleep-wake cycle (Roenneberg et al. 2007), has been related to behavior problems (Schlarb et al. 2014), but the nature of this association is not fully understood. A later chronotype, defined as a delayed midpoint between bedtime and waketime during free days (Roenneberg et al. 2007), is associated with both externalizing (e.g. aggressive and rule-breaking behaviors) (Schlarb et al. 2014) and internalizing (e.g. depressive symptoms) (Bauducco et al. 2020) behavior problems in adolescence.

The mechanisms explaining the potential role of chronotype on adolescent behavior are not completely elucidated. Adolescents have a naturally delayed endogenous circadian sleep-wake rhythm that often misaligns with that imposed by external obligations including school start-times and afterschool recreational or work-related activities (Widome et al. 2020; Wittmann et al. 2006). This misalignment leads to a difference in sleep timing between weekdays and weekends days known as social jetlag (Wittmann et al. 2006). Social jetlag is worsened by later chronotypes (Roenneberg et al. 2019). Adolescents with later chronotypes have later bedtimes but must wake up early on weekdays, usually due to early school-start times; this results in insufficient sleep on weekdays which leads to compensatory oversleeping on weekends, further delaying the circadian phase (Gradisar et al. 2011). Social jetlag has been associated with behavior problems including attention problems, impulsivity, depression,

CONTACT Mia Q. Zhu mqzhu@umich.edu Department of Epidemiology, University of Michigan School of Public Health, 1420 Washington Heights, Ann Arbo, MI 48109
Supplemental data for this article can be accessed online at https://doi.org/10.1080/07420528.2023.2216790.

and substance abuse (Hasler et al. 2012; McGowan et al. 2020). Thus, social jetlag could mediate the association between late chronotype and behavior problems in adolescence, but the magnitude of this potential mediating effect is unknown. In two previous cross-sectional studies of young adults, associations of chronotype with attention deficit hyperactivity disorder (ADHD) (McGowan et al. 2016) and poor academic performance (Haraszti et al. 2014) were attenuated after adjustment for social jetlag, which suggests a mediating effect. To our knowledge, social jetlag has not been formally studied as a mediator of the relation between chronotype and behavior problems.

The objectives of this study were to examine whether later chronotype and social jetlag are independently related to increased behavior problems in adolescence, and whether social jetlag mediates the associations of chronotype with behavior problems. If social jetlag mediates a substantial proportion of the chronotype-behavior association, it could become a point of intervention to ameliorate the burden of adolescent behavior problems attributable to chronotype.

Methods

Study design, population, and data collection

We conducted a cross-sectional study using data from the adolescence follow-up of participants in the Bogotá School Children Cohort (BoSCCo). Details on the cohort design and baseline procedures have been previously reported (Arsenault et al. 2009; Robinson et al. 2020). In brief, in February 2006 we recruited 3202 children aged 5–12 y from primary public schools in Bogotá, Colombia, using random selection. These schools enrolled children of low- and middle-income backgrounds; thus, the sample pertains to these groups. At enrollment, we collected sociodemographic information through a study-specific parental self-administered questionnaire (90% maternal, 5% paternal, 5% by other relatives) and obtained anthropometry from the children using standardized methods.

Between 2011 and 2015, an in-person follow-up assessment (adolescence follow-up) was conducted in a randomly chosen sample of approximately one-third of the cohort ($n = 1139$). These assessments occurred primarily at schools, or at home if the participant was absent from school or during school breaks. At this time, parents completed a study-specific self-administered survey that updated baseline information on maternal and household characteristics including the number of household assets, the level of food insecurity per a validated Spanish version of the USDA Household Food Security Survey module (Harrison et al. 2003), and the socioeconomic status as categorized by the local government for public services fees and tax purposes.

Adolescent behavior problems were measured using the Spanish language versions of the Youth Self Report (YSR) and the Child Behavior Checklist (CBCL), which were completed by the adolescent and the parent, respectively. Each instrument consists of 112 similar statements on behaviors and feelings that the respondents may mark as false, sometimes true, or very/often true. Using these responses, software provided by the tests developers computed continuous scores in eight behavior problem subscales (Achenbach 2000), standardized by age and sex from a reference US population. The subscales include aggressive behavior, rule-breaking behavior, anxious/depressed, withdrawn/depressed, somatic complaints, attention problems, social problems, and thought problems. The software also provided composite scores for externalizing and internalizing problems. Total externalizing problems comprise the aggressive behavior and rule-breaking behavior subscales while total internalizing problems consist of the anxious/depressed, withdrawn/depressed, and somatic complaints subscales. The YSR has been validated for use in adolescents aged 11–18 y and the CBCL has been validated in children and adolescents aged 5–18 y (Achenbach and Rescorla 2001). Both instruments have been widely administered in Latin American settings (Rescorla et al. 2012).

Bedtimes and waketimes were assessed through a study-specific adolescent self-administered survey with separate questions for weekdays and weekend days. To assess bedtimes, the question for weekdays was: "Normally, at what time do you fall asleep at night during weekdays," with fields for time in hours and minutes. A separate question replaced "weekdays" with "weekend days." To assess waketimes, a separate set of questions replaced "fall asleep at night" with "wake up in the morning." In the same questionnaire, adolescents were asked to report the estimated daily time spent watching television or playing video games and the time spent playing outdoors, in hours and minutes. Adolescents' height was measured without shoes to the nearest 1 mm using portable wall mounted Seca 202 stadiometers (Seca Hanover, MD) and weight was measured in light clothing to the nearest 0.1 kg using Tanita H5301 electronic scales (Tanita, Arlington Heights, IL).

Informed consent was obtained from the primary care givers prior to enrollment. The children provided assent to participate. The study protocol was approved by the Ethics Committee of the National University of Colombia Medical School. The University of Michigan Institutional Review Board approved the use of data from the study.

Data analysis

Outcomes

The primary outcomes of interest were total externalizing and internalizing behavior scores and scores from the eight behavior problem subscales per the YSR. Secondary outcomes were the same scores calculated from responses to the CBCL.

Exposures

The primary exposure was chronotype, assessed as the midpoint of sleep on free days, sleep-debt corrected (MSF_{sc}). We used the midpoint between bedtime and waketime on weekends as a proxy for free days, corrected for the difference in the average sleep duration on free days and on all days according to the formula $MSF_{sc} = MSF_i - 0.5 \times (SleepFree_i - SleepAll_i)$ (Bai et al. 2021; Roenneberg et al. 2007). MSF_i refers to the midpoint between bedtime and waketime on free days for individual i; $SleepFree_i$ refers to the average sleep duration over free days, and $SleepAll_i$ refers to the average sleep duration on all days calculated as the weighted average of weekday and weekend sleep. This adjustment compensates for the excess sleep duration incurred on free days due to low sleep duration on weekdays (sleep debt), which reduces overrepresentation of later chronotypes (Roenneberg et al. 2007). Higher MSF_{sc} values reflect greater eveningness. MSF_{sc} was used to assess chronotype in categories per the distributions of the Munich Chronotype Questionnaire, as extremely early (≤ 1), moderately early (> 1 to < 3), intermediate (3–4), moderately late (> 4 to < 6), and extremely late (≥ 6) (Roenneberg et al. 2019). The intermediate category was set as the reference. MSF_{sc} was also considered as a continuous variable.

Social jetlag was a secondary exposure. It was defined as the absolute difference in midpoint of sleep onset and sleep offset between weekends and weekdays (Roenneberg et al. 2019). Higher values reflect greater differences in the midpoint of sleep on weekends versus weekdays. Social jetlag was considered both as a categorical and a continuous exposure. Categories (hours) were defined as < 1, 1 to < 2, 2 to < 3, and ≥ 3.

Covariates

Adolescent's height and body mass index (BMI, kg/m^2)-for-age Z scores at the time of exposure assessment were calculated according to the World Health Organization growth reference for children and adolescents (Onis et al. 2007). Stunting was height-for-age Z <–2 and overweight was BMI-for-age Z > 1. Screen time was the weekly number of hours spent watching television or playing video games. We also estimated the weekly number of hours spent playing outdoors as a proxy of habitual physical activity. Household food insecurity was defined as severe when participants responded affirmatively to ≥ 13 of the survey's 16 questions on adverse food security experiences.

Statistical analysis

Of the 1139 participants followed-up in adolescence, 1061 had either valid YSR ($n = 1042$) or CBCL ($n = 854$) assessments. Of them, 957 had bedtime and waketime data (YSR, $n = 957$; CBCL, $n = 847$) and these constituted the analytic sample.

We first examined correlates of chronotype by comparing the distributions of background characteristics, including adolescent, maternal, and sociodemographic characteristics, between chronotype categories (Table 1). Next, we compared the continuous distributions of total externalizing and internalizing behavior problem scores and their subscales between chronotype categories using means and SD. We conducted tests for linear trend by introducing a variable representing ordinal chronotype categories into a linear regression model as a continuous covariate. We then estimated adjusted mean differences in behavior scores with 95% confidence intervals (CI) between chronotype categories with intermediate chronotype as the reference, using multiple linear regression models. Adjustment variables included sociodemographic and behavioral characteristics that were related to the exposure but were not its consequence, or that were known independent predictors of behavior problems in this population (Robinson et al. 2018). These included age, sex, screen time, time playing outdoors, stunting, and food insecurity with severe hunger. We also estimated mean adjusted differences with 95% CI in the outcomes per one hour difference in chronotype, assuming linearity in the associations. Analyses were conducted separately for outcomes assessed with the YSR and the CBCL. Finally, we examined whether the associations with behavior outcomes per the YSR differed between girls and boys through stratification since the effects of sleep on health outcomes may vary by sex (Leadbeater et al. 1999). Interaction terms between sex and chronotype as a continuous variable were tested with use of χ^2 Score tests.

Analysis of the associations between social jetlag and behavior outcomes proceeded analogously as those for chronotype; these analyses pertained to outcomes assessed with the YSR only, due to limited statistical power with the CBCL. Multiple linear regression models with social jetlag also included chronotype as an adjustment covariate. Because the associations of chronotype with behavior outcomes could be mediated through social jetlag, we conducted causal mediation analyses

Table 1. Sociodemographic characteristics and chronotype in adolescence in the Bogotá school children cohort.

	Chronotype (hours past midnight)[b]					
Characteristics[a]	Extremely early (≤1) *n* = 23	Moderately early (>1 to <3) *n* = 366	Intermediate (3–4) *n* = 298	Moderately late (>4 to <6) *n* = 223	Extremely late (≥6) *n* = 47	*P*, trend[c]
Adolescents						
Sex, % female	56.5	58.2	54.4	52.5	57.5	0.30
Age (y)	13.9 ± 1.9	14.5 ± 1.8	14.7 ± 1.6	14.6 ± 1.6	14.6 ± 1.8	0.29
Height-for-age Z score[d]	−0.9 ± 1.3	−0.8 ± 0.9	−0.8 ± 0.9	−0.6 ± 0.9	−0.7 ± 0.9	0.09
Stunted[e], %	26.1	9.3	10.7	6.3	10.6	0.13
Body mass index-for-age Z score[d]	0.1 ± 1.0	0.1 ± 1.0	0.0 ± 0.9	0.1 ± 1.0	−0.1 ± 0.9	0.76
Overweight[f], %	21.7	18.6	13.8	20.2	12.8	0.68
Screen time (hours/week)[g]	18.5 ± 14.1	18.4 ± 13.7	21.8 ± 14.3	22.8 ± 16.3	21.8 ± 12.6	0.0003
Time playing outdoors (hours/week)	8.7 ± 12.8	6.6 ± 8.1	6.2 ± 7.0	6.0 ± 6.6	4.2 ± 5.4	0.03
Overall nighttime sleep (hours/night)	8.8 ± 1.2	8.5 ± 1.2	8.7 ± 1.5	9.1 ± 1.7	8.6 ± 1.8	0.0004
Social jetlag[h]	1.2 ± 0.6	1.9 ± 0.9	2.3 ± 1.1	2.2 ± 1.4	3.3 ± 2.1	<0.0001
Socioeconomic status						
Maternal education	9.6 ± 3.9	9.1 ± 3.7	9.4 ± 3.7	9.6 ± 3.1	10.2 ± 3.0	0.03
Home ownership, %	47.8	42.7	44.6	49.1	52.2	0.11
Number of household assets[i]	4.9 ± 1.4	4.9 ± 1.2	4.8 ± 1.3	4.9 ± 1.1	4.9 ± 1.3	0.95
Food insecurity with severe hunger, %	13.0	3.8	2.4	1.4	4.3	0.04
Socioeconomic status[j]	2.3 ± 0.8	2.6 ± 0.6	2.5 ± 0.6	2.6 ± 0.6	2.6 ± 0.6	0.93

[a]Data are means ± SD unless noted otherwise.
[b]MSF_{sc}, midpoint between sleep onset and sleep offset during weekends, adjusted for compensatory sleep. Higher values indicate more eveningness.
[c]For dichotomous variables, Cochran-Armitage test. For continuous variables, Wald test for an ordinal variable representing chronotype categories, introduced into a linear regression model as a continuous predictor.
[d]According to the World Health Organization growth reference for children and adolescents.
[e]Height-for-age Z score <−2.
[f]Body mass index-for-age Z score >1.
[g]Time spent watching television or playing video games.
[h]Absolute difference in midpoint of sleep between weekends and weekdays.
[i]From a list that included refrigerator, bicycle, blender, television, stereo, and washing machine.
[j]Per the local government's classification for tax and public services fees.

under the assumptions of a counterfactual framework as described before (Valeri and VanderWeele 2013). In these analyses, we first regressed social jetlag on chronotype and then each behavior outcome on chronotype, social jetlag, and their interaction term as continuous variables using multivariable adjusted linear regression models. Indirect and natural direct effects and the proportion of the chronotype-behavior association mediated through social jetlag were calculated according to Valeri and VanderWeele's formulas (Valeri and VanderWeele 2013). All analyses were performed using Statistical Analysis Software version 9.4 (SAS Institute, Cary, NC).

Results

Mean ± SD age of the adolescents was 14.6 ± 1.7 y; 56% were female. The proportion of adolescents with extremely early, moderately early, intermediate, moderately late, and extremely late chronotypes was 2%, 38%, 31%, 23%, and 5% respectively. Adolescents with later chronotypes had more screen time ($p = .0003$), spent less time playing outdoors ($p = 0.03$), slept longer ($p = .0004$), and had more social jetlag ($p < .0001$), compared with those with earlier chronotypes (Table 1). They also had better educated mothers ($p = .03$), and experienced less food insecurity ($p = .04$).

Chronotype and externalizing behavior

Later chronotype was related to externalizing behavior in a dose-response manner (Table 2). Every hour difference in MSF_{sc} was associated with an adjusted 1.0 (95% CI: 0.6, 1.5) units higher externalizing behavior score per the YSR. This association was driven by both the aggressive and rule breaking behavior subscales. Every hour difference in MSF_{sc} was associated with an adjusted 0.8 (95% CI: 0.3, 1.3) units higher externalizing behavior score per the CBCL (Supplemental Table S1). The associations did not differ significantly by sex (Supplemental Table S2).

Chronotype and internalizing behavior

Later chronotype was positively, linearly associated with internalizing behavior (Table 2). Every hour difference in MSF_{sc} was related to an adjusted 0.6 (95% CI: 0.2, 1.1) units higher internalizing behavior score per the YSR (Table 2). The association was driven by the somatic complaints and the anxious/depressed subscales. Every MSF_{sc} hour was associated with an adjusted 0.3 (95% CI: 0.0, 0.7) units higher internalizing behavior score per the CBCL (Supplemental Table S1). The association between chronotype and somatic complaints was stronger in boys than it was in girls (Supplemental Table S2).

Table 2. Chronotype and behavior problems in adolescence per the youth self-report in the Bogotá school children cohort.

Behavior problems	Chronotype (hours past midnight)[a] Extremely early (≤1) *n* = 23	Moderately early (>1 to <3) *n* = 366	Intermediate (3–4) *n* = 298	Moderately late (>4 to <6) *n* = 223	Extremely late (≥6) *n* = 47	*P*, trend[b]	Per 1 hour[c]
Externalizing problems							
Total							
Mean ± SD	48.3 ± 9.3	51.3 ± 9.7	52.4 ± 9.5	53.7 ± 9.5	56.6 ± 10.0	< 0.0001	1.2 (0.8, 1.7)
Adjusted difference (95% CI)[d]	−2.5 (−6.4, 1.5)	−0.9 (−2.3, 0.6)	Reference	1.4 (−0.3, 3.0)	4.2 (1.2, 7.1)	< 0.0001	1.0 (0.6, 1.5)
Aggressive behavior							
Mean ± SD	54.0 ± 6.0	55.4 ± 6.9	55.9 ± 7.0	57.0 ± 7.7	59.4 ± 9.7	0.0001	0.8 (0.4, 1.2)
Adjusted difference (95% CI)	−1.1 (−3.7, 1.5)	−0.2 (−1.2, 0.9)	Reference	1.2 (−0.1, 2.5)	3.5 (0.7, 6.4)	0.001	0.7 (0.4, 1.0)
Rule breaking behavior							
Mean ± SD	51.9 ± 2.4	53.9 ± 4.6	54.5 ± 5.0	54.7 ± 5.3	56.3 ± 5.3	< 0.0001	0.5 (0.3, 0.8)
Adjusted difference (95% CI)	−1.9 (−3.0, −0.8)	−0.4 (−1.1, 0.3)	Reference	0.3 (−0.6, 1.1)	1.8 (0.3, 3.3)	0.0009	0.5 (0.2, 0.7)
Internalizing problems							
Total							
Mean ± SD	51.7 ± 9.5	52.8 ± 10.0	53.6 ± 10.2	54.3 ± 9.4	56.7 ± 9.3	0.003	0.7 (0.3, 1.2)
Adjusted difference (95% CI)	−1.0 (−5.2, 3.2)	−0.5 (−2.0, 1.0)	Reference	0.9 (−0.8, 2.6)	3.5 (0.6, 6.4)	0.007	0.6 (0.2, 1.1)
Anxious/depressed							
Mean ± SD	53.6 ± 5.6	55.1 ± 6.4	55.7 ± 6.8	56.0 ± 6.9	56.8 ± 7.1	0.02	0.4 (0.1, 0.7)
Adjusted difference (95% CI)	−1.8 (−4.2, 0.7)	−0.4 (−1.4, 0.6)	Reference	0.4 (−0.8, 1.6)	1.4 (−0.8, 3.5)	0.03	0.4 (0.1, 0.7)
Withdrawn/depressed							
Mean ± SD	54.2 ± 5.1	55.5 ± 6.2	55.5 ± 6.2	55.3 ± 6.2	56.7 ± 8.0	0.48	0.2 (−0.2, 0.5)
Adjusted difference (95% CI)	−0.6 (−2.8, 1.6)	0.2 (−0.8, 1.1)	Reference	−0.1 (−1.2, 1.0)	1.3 (−1.1, 3.8)	0.72	0.1 (−0.2, 0.4)
Somatic complaints							
Mean ± SD	56.4 ± 7.3	56.1 ± 7.2	56.7 ± 7.2	57.6 ± 7.3	60.0 ± 8.2	0.0007	0.6 (0.3, 1.0)
Adjusted difference (95% CI)	0.0 (−3.0, 3.1)	−0.5 (−1.6, 0.6)	Reference	0.9 (−0.4, 2.1)	3.4 (0.8, 6.0)	0.002	0.6 (0.2, 0.9)
Other problems							
Attention problems							
Mean ± SD	51.4 ± 3.8	52.0 ± 3.6	51.9 ± 3.1	52.3 ± 3.7	52.9 ± 3.7	0.10	0.2 (0.0, 0.4)
Adjusted difference (95% CI)	−0.2 (−1.8, 1.3)	0.2 (−0.3, 0.7)	Reference	0.5 (−0.1, 1.0)	1.0 (−0.1, 2.1)	0.15	0.2 (0.0, 0.3)
Social problems							
Mean ± SD	54.8 ± 6.5	55.9 ± 6.6	56.7 ± 7.6	56.3 ± 6.8	58.9 ± 7.8	0.02	0.5 (0.1, 0.8)
Adjusted difference (95% CI)	−1.7 (−4.5, 1.0)	−0.6 (−1.7, 0.5)	Reference	−0.4 (−1.6, 0.8)	2.3 (−0.1, 4.7)	0.048	0.4 (0.1, 0.8)
Thought problems							
Mean ± SD	52.9 ± 3.3	54.1 ± 5.5	54.5 ± 6.0	54.9 ± 6.1	55.6 ± 6.2	0.01	0.3 (0.1, 0.6)
Adjusted difference (95% CI)	−1.4 (−2.9, 0.1)	−0.3 (−1.2, 0.5)	Reference	0.5 (−0.5, 1.6)	1.2 (−0.7, 3.1)	0.01	0.3 (0.1, 0.6)

[a]MSF_{sc}, midpoint between sleep onset and sleep offset during weekends, adjusted for compensatory sleep. Higher values indicate more eveningness.
[b]Wald test for an ordinal variable representing chronotype categories, introduced into a linear regression model as a continuous predictor.
[c]From linear regression with chronotype (hours past midnight) as a continuous predictor.
[d]From multiple linear regression adjusted for age, sex, screen time, hours playing outdoors, stunting, and food insecurity with severe hunger. Robust estimates of variance were specified in all models. Complete case analysis (*n* = 950).

Chronotype and attention, social, and thought problems

Later chronotype was positively related to attention, social, and thought problems (Table 2). Every MSF_{sc} hour was associated with an adjusted 0.2 (95% CI: 0.0, 0.3) units higher attention problems score, an adjusted 0.4 (95% CI: 0.1, 0.8) units higher social problems score, and an adjusted 0.3 (95% CI: 0.1, 0.6) units higher thought problems score per the YSR. Every MSF_{sc} hour was associated with an adjusted 0.2 (95% CI: 0.0, 0.5) units higher attention problems score, an adjusted 0.4 (95% CI: 0.1, 0.8) units higher social problems score, and an adjusted 0.6 (95% CI: 0.2, 0.9) units higher thought problems score per the CBCL (Supplemental Table S1). The association of chronotype with social problems was stronger in boys than it was in girls (Supplemental Table S2).

Social jetlag and behavior problems

Mean ± SD of social jetlag was 2.1 ± 1.2 hrs. Adolescents with more social jetlag were less stunted, slept less, and had later chronotypes. Additionally, they were from households with higher SES (Supplemental Table S3). Social jetlag was associated with increased somatic complaints and attention problems scores (Table 3).

Mediation of social jetlag of the association between chronotype and behavior problems

Social jetlag mediated 12% and 16% of the associations of chronotype with internalizing behavior and somatic complaints, respectively (Table 4; Supplemental Figure S1). In addition, social jetlag mediated 26% of the association between chronotype and attention problems (Table 4; Supplemental Figure S1).

Table 3. Social jetlag and behavior problems in adolescence per the youth self-report in the Bogotá school children cohort.

Behavior problems	Social jetlag (hours)[a] <1 n = 154	1 to <2 n = 266	2 to <3 n = 289	≥3 n = 235	P, trend[b]	Per 1 hour[c]
Externalizing problems						
Total						
Mean ± SD	51.5 ± 10.6	52.2 ± 9.2	52.1 ± 9.7	53.8 ± 9.4	0.03	0.6 (0.1, 1.1)
Adjusted difference (95% CI)[d]	Reference	1.3 (−0.6, 3.3)	1.0 (−0.9, 3.0)	1.8 (−0.3, 3.8)	0.16	0.3 (−0.3, 0.8)
Aggressive behavior						
Mean ± SD	56.2 ± 7.7	55.8 ± 6.7	55.8 ± 7.2	56.8 ± 7.9	0.31	0.3 (−0.1, 0.7)
Adjusted difference (95% CI)	Reference	0.0 (−1.4, 1.4)	0.0 (−1.5, 1.5)	0.4 (−1.2, 2.0)	0.59	0.1 (−0.4, 0.5)
Rule breaking behavior						
Mean ± SD	54.1 ± 4.6	54.0 ± 4.8	54.3 ± 4.9	55.0 ± 5.2	0.04	0.3 (0.0, 0.5)
Adjusted difference (95% CI)	Reference	0.2 (−0.7, 1.1)	0.4 (−0.5, 1.3)	0.6 (−0.4, 1.6)	0.21	0.1 (−0.2, 0.4)
Internalizing problems						
Total						
Mean ± SD	52.2 ± 10.6	53.1 ± 9.9	54.0 ± 9.5	54.5 ± 9.6	0.02	0.5 (0.0, 1.0)
Adjusted difference (95% CI)	Reference	1.0 (−1.0, 2.9)	1.9 (−0.1, 3.9)	1.7 (−0.4, 3.7)	0.07	0.3 (−0.3, 0.8)
Anxious/depressed						
Mean ± SD	55.2 ± 6.5	55.2 ± 6.5	55.6 ± 6.7	55.8 ± 6.7	0.27	0.2 (−0.2, 0.5)
Adjusted difference (95% CI)	Reference	0.0 (−1.3, 1.3)	0.4 (−0.9, 1.7)	0.3 (−1.1, 1.6)	0.54	0.0 (−0.3, 0.4)
Withdrawn/depressed						
Mean ± SD	55.9 ± 7.5	55.1 ± 5.6	55.5 ± 6.0	55.6 ± 6.5	0.92	0.0 (−0.3, 0.4)
Adjusted difference (95% CI)	Reference	−0.7 (−2.0, 0.6)	−0.5 (−1.8, 0.9)	−0.3 (−1.8, 1.1)	0.89	−0.1 (−0.4, 0.3)
Somatic complaints						
Mean ± SD	55.5 ± 6.5	56.8 ± 7.3	56.9 ± 7.3	57.7 ± 7.6	0.003	0.5 (0.2, 0.9)
Adjusted difference (95% CI)	Reference	1.4 (0.1, 2.7)	1.8 (0.5, 3.1)	1.8 (0.4, 3.2)	0.02	0.4 (0.0, 0.8)
Other problems						
Attention problems						
Mean ± SD	51.8 ± 3.1	51.8 ± 3.0	51.9 ± 3.1	52.8 ± 4.5	0.006	0.2 (0.0, 0.4)
Adjusted difference (95% CI)	Reference	0.1 (−0.5, 0.7)	0.1 (−0.5, 0.7)	1.0 (0.2, 1.8)	0.01	0.2 (0.0, 0.4)
Social problems						
Mean ± SD	56.5 ± 7.9	55.9 ± 6.2	56.2 ± 7.0	57.0 ± 7.3	0.33	0.1 (−0.3, 0.5)
Adjusted difference (95% CI)	Reference	−0.5 (−1.9, 0.9)	−0.2 (−1.7, 1.3)	0.3 (−1.3, 1.9)	0.56	0.0 (−0.4, 0.4)
Thought problems						
Mean ± SD	54.7 ± 5.9	54.4 ± 5.5	54.1 ± 5.8	54.9 ± 6.1	0.79	0.0 (−0.3, 0.3)
Adjusted difference (95% CI)	Reference	−0.3 (−1.4, 0.9)	−0.6 (−1.8, 0.6)	−0.1 (−1.3, 1.2)	0.78	−0.1 (−0.4, 0.2)

[a]Absolute difference in sleep midpoint between weekends and weekdays.
[b]Wald test for an ordinal variable representing chronotype categories introduced into a linear regression model as a continuous predictor.
[c]From linear regression with social jetlag (hours) as a continuous predictor.
[d]From multiple linear regression adjusted for age, sex, screen time, hours playing outdoors, stunting, food insecurity with severe hunger, and chronotype. Robust estimates of variance were specified in all models. Complete case analysis ($n = 937$).

Discussion

In this cross-sectional study of Colombian adolescents, later chronotype was associated with externalizing and internalizing behavior problems, and with attention, social, and thought problems.

The association between later chronotype, measured using MSF_{sc}, and externalizing problems through both aggressive and rule breaking behavior is consistent with that reported in previous studies of children, adolescents, and young adults, as reviewed before (Schlarb et al. 2014). A causal explanation of this association could involve an indirect effect of chronotype through sleep duration or quality, both recognized correlates of behavior problems (Tzischinsky and Shochat 2011; van den Berg et al. 2018). Later chronotypes are related to shorter sleep duration and insomnia, and to sleep medication use (Grummon et al. 2021; Merikanto et al. 2012) In turn, shorter sleep and insomnia have been linked to increased production of hormones related to highly aggressive behavior including testosterone and cortisol, and lower concentration of serotonin, a negative correlate of aggression, in the brain. (Kamphuis et al. 2012; Randler and Schaal 2010; Randler et al. 2012; Susman et al. 2007). Non-causal explanations are also plausible. Later chronotype and externalizing behavior could be associated through reverse causation since a propensity for rule breaking or aggressive behavior could push back bedtime as externalizing behavior may be more likely to occur later at night (Manfredini et al. 2019). Due to the cross-sectional nature of this analysis, we are unable to disentangle the direction of causation.

We observed a positive association between later chronotype and internalizing behavior, driven by somatic complaints and anxious/depressed behavior. This is consistent with previous observational and experimental research showing associations between later chronotype or eveningness and mood disorders like depression, as summarized in a recent review that included adolescent populations (Bauducco et al. 2020). One posited mechanism to explain this association has to do with light exposure. Light may have a positive effect on mood both directly and indirectly through

Table 4. Mediation of social jetlag on the association between chronotype and behavior per the youth self-report in the Bogotá school children Cohort.[a]

Behavior problems	Adjusted difference (95% CI) Direct chronotype-behavior problem association[b]	Adjusted difference (95% CI) Indirect chronotype-behavior problem association through social jetlag	Percentage of association mediated	Chronotype-social jetlag interaction Adjusted difference (95% CI)
Externalizing problems				
Total	1.4 (0.8, 1.9)	0.1 (−0.1, 0.2)	6%	−0.2 (−0.5, 0.0)
Aggressive behavior	0.7 (0.4, 1.1)	0.0 (−0.1, 0.1)	3%	−0.2 (−0.4, 0.0)
Rule breaking behavior	0.4 (0.2, 0.7)	0.0 (0.0, 0.1)	6%	−0.1 (−0.2, 0.1)
Internalizing problems				
Total	0.7 (0.2, 1.1)	0.1 (−0.1, 0.2)	12%	−0.3 (−0.6, 0.0)
Anxious/depressed	0.4 (0.1, 0.8)	0.0 (−0.1, 0.1)	3%	−0.1 (−0.3, 0.0)
Withdrawn/depressed	0.2 (−0.1, 0.5)	0.0 (−0.1, 0.9)	0%	−0.1 (−0.3, 0.1)
Somatic complaints	0.5 (0.2, 0.9)	0.1 (0.0, 0.2)	16%	−0.1 (−0.3, 0.1)
Other Problems				
Attention problems	0.1 (0.0, 0.3)	0.1 (0.0, 0.1)	26%	−0.1 (−0.2, 0.0)
Social problems	0.5 (0.1, 0.8)	0.0 (−0.1, 0.1)	1%	−0.2 (−0.4, 0.0)
Thought problems	0.4 (0.1, 0.7)	0.0 (−0.1, 0.1)	0%	−0.1 (−0.2, 0.1)

[a]Adjusted differences and 95% CI from multivariable linear regression models. Chronotype-social jetlag associations were modeled with multivariable linear regression. Covariates included age, sex, screen time, hours playing outdoors, stunting, food insecurity with severe hunger, and chronotype. A chronotype-social jetlag interaction term was included in all models. All associations on behavior problems scores are estimated for a 1-hour chronotype difference from the baseline level of 3 hours past midnight.

[b]Estimated with social jetlag set to 1.

modification of the circadian cycle (Stephenson et al. 2012), and persons with later chronotypes are exposed to less light in their waking hours. Hence, adolescents with later chronotypes could be less exposed to the beneficial mood-modulating effects of light. Rumination may be another explanatory mechanism of the association between chronotype and internalizing problems. Rumination, or a tendency to harbor repetitive negative thoughts, in the evening is strongly associated with depressive symptoms (Takano and Tanno 2011). People with later chronotypes would be awake for more hours in the night, and, thus, have more time for evening rumination than those with earlier chronotypes, which can exacerbate their depressive symptoms. Reverse causation cannot be ruled out with this study design; sleeping late, or conciliation insomnia, is a documented symptom of internalizing problems like depression (Nutt et al. 2008).

We found that a late chronotype was associated with increased social jetlag and, in turn, social jetlag was related to increased somatic complaints and attention problems, consistent with previous research (McGowan et al. 2020; Wittmann et al. 2006). Social jetlag is defined as the difference between natural sleep-wake cycles and restricted sleep-wake cycles imposed by social or work constraints (Roenneberg et al. 2007). Adolescents have delayed sleep preferences driven by their pubertal development (Carskadon et al. 1993). This conflicts with their relatively early school-start times making them particularly vulnerable to social jetlag (Widome et al. 2020). In this study, social jetlag mediated 16% and 26% of the associations of later chronotype with somatic complaints and attention problems, respectively. Few previous studies had quantitatively assessed the mediating role of social jetlag. The relatively small mediation of social jetlag in the association between chronotype and behavior problems suggests the presence of other causal pathways. One could involve sleep duration. Short sleep duration is a potential mediator of the association between late chronotype and attention problems; late chronotype is associated with shorter sleep duration which is, in turn, associated with attention problems (Gruber et al. 2012). Conversely, a direct path between chronotype and attention is also possible. Persons with later chronotype, irrespective of sleep deprivation status, displayed decreased activation of regulatory regions in the prefrontal cortex which can negatively influence attention span (Song et al. 2019).

Previous twin studies indicate that chronotype is influenced by both genetic and environmental factors, 52% and 48% respectively (Barclay et al. 2010). Other high risk sleep phenotypes such as poor sleep quality share overlapping genetic polymorphisms with chronotype (Barclay et al. 2010). Despite the heritability of these sleep phenotypes, lifestyle factors can modify the risks associated with chronotype. Persons with evening chronotypes are more likely to use stimulants, such as caffeine and nicotine, (Siudej and Malinowska-Borowska 2021) and eat larger meals close to bedtime (Maukonen et al. 2017). These poor sleep hygiene practices are associated with sleep problems (Irish et al. 2015) and present potential modifiable pathways between chronotype and behavior. As evidence of the role of modifiable factors on chronotype, a randomized controlled study among young adults successfully shifted the sleep time of evening chronotypes by 2 h through interventions targeting caffeine intake, mealtimes, exercise, and light exposure; this shift in sleep timing was associated with significant improvements to internalizing problems, such as depression (Facer-Childs et al. 2019).

There are several strengths to this study. First, outcomes were assessed using two complementary instruments involving both self- and parental report. The consistency of the findings between the two outcome assessment methods indicates high internal validity. Second, the modeling strategy reduced confounding for many adolescent, maternal, and household factors. Third, considering chronotype and social jetlag as both categorical and continuous measures allowed us to assess potentially non-linear associations. Finally, the study was conducted in a low- and middle-income Latin American population. Since behavior can be culturally specific, results in this unique population support the generalizability of previous findings.

Some weaknesses are also worth noting. First, reverse causation is a possibility. It is difficult to establish the temporal directionality of associations given the cross-sectional design. Second, residual confounding cannot be ruled out. Although we adjusted the associations for many factors related to sleep and behavior, we lacked information on potential confounders like stage of pubertal development and genetics. Genetic confounding is a possibility because chronotype and behavior may share genetic causes (Barclay et al. 2011). Third, bedtime data were collected through self-report. These questions had not been validated in this population and may be subject to reporting biases. Fourth, the questions about bedtime and waketime do not specify an exposure period. Thus, responses may be influenced by recency bias and misrepresent the overall sleeping habits. Fifth, sleep exposure was self-reported and may not be as accurate as objective measures of sleep such as actigraphy. For example, self-reported bedtimes may not take into consideration the time it takes for a person to fall asleep. Sixth, we used bedtimes and waketimes on weekends as a proxy for bedtimes and waketimes on free days. However, adolescents may be subjected to other obligations on weekends that may influence their bedtimes and waketimes. Seventh, there may be error in the measurement of covariates. Playing outdoors is significantly correlated with objective measures of physical activity in children (Burdette et al. 2004), but it may be an imperfect measure of physical activity in adolescents. Finally, the results of this study may not be widely generalizable to populations with different characteristics.

In conclusion, later chronotype is associated with externalizing, internalizing, attention, social, and thought problems in adolescence. The associations with internalizing problems, somatic complaints, and attention problems are partially mediated through social jetlag. Future identification of potential mediating factors in the pathways between chronotype and behavior could allow the design of interventions to decrease the burden of behavior problems related to eveningness.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The work was supported by the ASISA Foundation.

Data availability statement

The data used in this study are available from the senior author, EV, upon reasonable request.

References

Achenbach T. 2000. Manual for the assessment data manager program (ADM) for the CBCL/4-18, YSR, TRF, YASR, YABCL, CBCL/2-3, CBCL/1 1 2 -5, & C-TRF. In: Achenbach system of empirically based assessment (ASEBA). 2nd ed. Burlington, VT: University Medical Education Associates.

Achenbach T, Rescorla L. 2001. Manual for the ASEBA school-age forms & profiles: Child behavior checklist for ages 6-18, teacher's report form, youth self-report. In: An integrated system of multi-informant assessment. Burlington, VT: ASEBA.

Arsenault JE, Mora-Plazas M, Forero Y, López-Arana S, Marín C, Baylin A, Villamor E. 2009. Provision of a school snack is associated with vitamin B-12 status, linear growth, and morbidity in children from Bogotá, Colombia. J Nutr. 139:1744. doi:10.3945/JN.109.108662.

Bai S, Karan M, Gonzales NA, Fuligni AJ. 2021. A daily diary study of sleep chronotype among Mexican-origin adolescents and parents: Implications for adolescent behavioral health. Dev Psychopathol. 33:313–322. doi:10.1017/S0954579419001780.

Barclay NL, Eley TC, Buysse DJ, Archer SN, Gregory AM. 2010. Diurnal preference and sleep quality: Same genes? A study of young adult twins. Chronobiol Int. 27:278–296. doi:10.3109/07420521003663801.

Barclay NL, Eley TC, Maughan B, Rowe R, Gregory AM. 2011. Associations between diurnal preference, sleep quality and externalizing behaviours: A behavioural genetic analysis. Psychol Med. 41:1029–1040. doi:10.1017/S0033291710001741.

Bauducco S, Richardson C, Gradisar M. 2020. Chronotype, circadian rhythms and mood. Curr Opin Psychol. 34:77–83. doi:10.1016/J.COPSYC.2019.09.002.

Burdette HL, Whitaker RC, Daniels SR. 2004. Parental report of outdoor playtime as a measure of physical activity in preschool-aged Children. Archives of Pediatrics & Adolescent Medicine. 158:353–357. doi:10.1001/ARCHPEDI.158.4.353.

Carskadon MA, Vieira C, Acebo C. 1993. Association between puberty and delayed phase preference. Sleep. 16:258–262. doi:10.1093/SLEEP/16.3.258.

Facer-Childs ER, Middleton B, Skene DJ, Bagshaw AP. 2019. Resetting the late timing of "night owls" has a positive impact on mental health and performance. Sleep Med. 60:236–247. doi:10.1016/J.SLEEP.2019.05.001.

Gradisar M, Gardner G, Dohnt H. 2011. Recent worldwide sleep patterns and problems during adolescence: A review and meta-analysis of age, region, and sleep. Sleep Med. 12:110–118. doi:10.1016/J.SLEEP.2010.11.008.

Gruber R, Michaelsen S, Bergmame L, Frenette S, Bruni O, Fontil L, Carrier J. 2012. Short sleep duration is associated with teacher-reported inattention and cognitive problems in healthy school-aged children. Nat Sci Sleep. 4:33. doi:10.2147/NSS.S24607.

Grummon AH, Sokol RL, Lytle LA. 2021. Is late bedtime an overlooked sleep behaviour? Investigating associations between sleep timing, sleep duration and eating behaviours in adolescence and adulthood. Public Health Nutr. 24:1671–1677. doi:10.1017/S1368980020002050.

Haraszti RÁ, Ella K, Gyöngyösi N, Roenneberg T, Káldi K. 2014. Social jetlag negatively correlates with academic performance in undergraduates. Chronobiol Int. 31:603–612. doi:10.3109/07420528.2013.879164.

Harrison GG, Stormer A, Herman DR, Winham DM. 2003. Development of a spanish-language version of the U.S. household food security survey module. J Nutr. 133:1192–1197. doi:10.1093/JN/133.4.1192.

Hasler BP, Dahl RE, Holm SM, Jakubcak JL, Ryan ND, Silk JS, Phillips ML, Forbes EE. 2012. Weekend-weekday advances in sleep timing are associated with altered reward-related brain function in healthy adolescents. Biol Psychol. 91:334. doi:10.1016/J.BIOPSYCHO.2012.08.008.

Irish LA, Kline CE, Gunn HE, Buysse DJ, Hall MH. 2015. The role of sleep hygiene in promoting public health: A review of empirical evidence. Sleep Med Rev. 22:23. doi:10.1016/J.SMRV.2014.10.001.

Kamphuis J, Meerlo P, Koolhaas JM, Lancel M. 2012. Poor sleep as a potential causal factor in aggression and violence. Sleep Med. 13:327–334. doi:10.1016/J.SLEEP.2011.12.006.

Kessler RC, Angermeyer M, Anthony JC, Graaf DE, Demyttenaere R, Gasquet K, I. DG, Gluzman G, Gureje S, Haro O et al, 2007. Lifetime prevalence and age-of-onset distributions of mental disorders in the World Health Organization's World Mental Health Survey Initiative. World Psychiatry. 6:168–176. http://www.ncbi.nlm.nih.gov/pubmed/18188442.

Kieling C, Baker-Henningham H, Belfer M, Conti G, Ertem I, Omigbodun O, Rohde LA, Srinath S, Ulkuer N, Rahman A. 2011. Child and adolescent mental health worldwide: Evidence for action. Lancet. 378:1515–1525. doi:10.1016/S0140-6736(11)60827-1.

Leadbeater BJ, Kuperminc GP, Blatt SJ, Hertzog C. 1999. A multivariate model of gender differences in adolescents' internalizing and externalizing problems. Dev Psychol. 35:1268–1282. doi:10.1037/0012-1649.35.5.1268.

Manfredini R, Fabbian F, Cappadona R, de Giorgio R, Grassi L. 2019. A time of day for aggressive behavior? Possible insights for ED personnel. Am J Emerg Med. 37:153–155. doi:10.1016/J.AJEM.2018.05.014.

Maukonen M, Kanerva N, Partonen T, Kronholm E, Tapanainen H, Kontto J, Männistö S. 2017. Chronotype differences in timing of energy and macronutrient intakes: A population-based study in adults. Obesity. 25:608–615. doi:10.1002/OBY.21747.

McGowan NM, Uzoni A, Faltraco F, Thome J, Coogan AN. 2020. The impact of social jetlag and chronotype on attention, inhibition and decision making in healthy adults. J Sleep Res. 29:e12974. doi:10.1111/JSR.12974.

McGowan NM, Voinescu BI, Coogan AN. 2016. Sleep quality, chronotype and social jetlag differentially associate with symptoms of attention deficit hyperactivity disorder in adults. Chronobiol Int. 33:1433–1443. doi:10.1080/07420528.2016.1208214.

Merikanto I, Kronholm E, Peltonen M, Laatikainen T, Lahti T, Partonen T. 2012. Relation of chronotype to sleep complaints in the general Finnish population. Chronobiol Int. 29:311–317. doi:10.3109/07420528.2012.655870.

Nutt DJ, Wilson S, Paterson L. 2008. Sleep disorders as core symptoms of depression. Dialogues Clin Neurosci. 10:329. doi:10.31887/DCNS.2008.10.3/DNUTT.

Onis MD, Onyango AW, Borghi E, Siyam A, Nishida C, Siekmann J. 2007. Development of a WHO growth reference for school-aged children and adolescents. Bull World Health Organ. 85:660. doi:10.2471/BLT.07.043497.

Patton GC, Sawyer SM, Santelli JS, Ross DA, Afifi R, Allen NB, Arora M, Azzopardi P, Baldwin W, Bonell C et al, 2016. Our future: A Lancet commission on adolescent health and wellbeing. Lancet. 387:2423–2478. doi:10.1016/S0140-6736(16)00579-1.

Prince M, Patel V, Saxena S, Maj M, Maselko J, Phillips MR, Rahman A. 2007. No health without mental health. Lancet. 370:859–877. doi:10.1016/S0140-6736(07)61238-0.

Randler C, Ebenhöh N, Fischer A, Höchel S, Schroff C, Stoll JC, Vollmer C. 2012. Chronotype but not sleep length is related to salivary testosterone in young adult men. Psychoneuroendocrinology. 37:1740–1744. doi:10.1016/J.PSYNEUEN.2012.02.008.

Randler C, Schaal S. 2010. Morningness–eveningness, habitual sleep-wake variables and cortisol level. Biol Psychol. 85:14–18. doi:10.1016/J.BIOPSYCHO.2010.04.006.

Rescorla L, Ivanova MY, Achenbach TM, Begovac I, Chahed M, Drugli MB, Emerich DR, Fung DSS, Haider M, Hansson K, et al. 2012. International epidemiology of child and adolescent psychopathology II: Integration and applications of dimensional findings from 44 societies. J Am Acad Child Adolesc Psychiatry. 51:1273–1283.e8. doi:10.1016/J.JAAC.2012.09.012.

Robinson SL, Marín C, Oliveros H, Mora-Plazas M, Lozoff B, Villamor E. 2020. Vitamin D deficiency in middle childhood is related to behavior problems in adolescence. J Nutr. 150:140–148. doi:10.1093/jn/nxz185.

Robinson SL, Marín C, Oliveros H, Mora-Plazas M, Richards BJ, Lozoff B, Villamor E. 2018. Iron deficiency, anemia, and low vitamin B-12 serostatus in middle childhood are associated with behavior problems in adolescent boys: Results from the Bogotá school children cohort. J Nutr. 148:760–770. doi:10.1093/JN/NXY029.

Roenneberg T, Kuehnle T, Juda M, Kantermann T, Allebrandt K, Gordijn M, Merrow M. 2007. Epidemiology of the human circadian clock. Sleep Med Rev. 11:429–438. doi:10.1016/J.SMRV.2007.07.005.

Roenneberg T, Pilz LK, Zerbini G, Winnebeck EC. 2019. Chronotype and social jetlag: A (self-) critical review. Biology. 8:54. doi:10.3390/BIOLOGY8030054.

Roza SJ, Hofstra MB, Ende JVD, Verhulst FC. 2003. Stable prediction of mood and anxiety disorders based on behavioral and emotional problems in childhood: a 14-year follow-up during childhood, adolescence, and young adulthood. Am J Psychiatry. 160:2116–2121. doi:10.1176/APPI.AJP.160.12.2116.

Schlarb AA, Sopp R, Ambiel D, Grünwald J. 2014. Chronotype-related differences in childhood and adolescent aggression and antisocial behavior – a review of the literature. Chronobiol Int. 31:1–16. doi:10.3109/07420528.2013.829846.

Siudej K, Malinowska-Borowska J. 2021. Relationship between chronotype and consumption of stimulants. Chronobiol Int. 38:1549–1556. doi:10.1080/07420528.2021.1935989.

Song J, Feng P, Wu X, Li B, Su Y, Liu Y, Zheng Y. 2019. Individual differences in the neural basis of response inhibition after sleep deprivation are mediated by chronotype. Front Neurol. 10:514. doi:10.3389/fneur.2019.00514.

Stephenson KM, Schroder CM, Bertschy G, Bourgin P. 2012. Complex interaction of circadian and non-circadian effects of light on mood: Shedding new light on an old story. Sleep Med Rev. 16:445–454. doi:10.1016/J.SMRV.2011.09.002.

Susman EJ, Dockray S, Schiefelbein VL, Herwehe S, Heaton JA, Dorn LD. 2007. Morningness/Eveningness, morning-to-afternoon cortisol ratio, and antisocial behavior problems during puberty. Dev Psychol. 43:811–822. doi:10.1037/0012-1649.43.4.811.

Takano K, Tanno Y. 2011. Diurnal variation in rumination. Emotion (Washington, DC). 11:1046–1058. doi:10.1037/A0022757.

Tzischinsky O, Shochat T. 2011. Eveningness, sleep patterns, daytime functioning, and quality of life in Israeli adolescents. Chronobiol Int. 28:338–343. doi:10.3109/07420528.2011.560698.

Valeri L, VanderWeele TJ. 2013. Mediation analysis allowing for exposure-mediator interactions and causal interpretation: Theoretical assumptions and implementation with SAS and SPSS macros. Psychol Methods. 18:137. doi:10.1037/A0031034.

van den Berg JF, Kivelä L, Antypa N. 2018. Chronotype and depressive symptoms in students: An investigation of possible mechanisms. Chronobiol Int. 35:1248–1261. doi:10.1080/07420528.2018.1470531.

Widome R, Berger AT, Iber C, Wahlstrom K, Laska MN, Kilian G, Redline S, Erickson DJ. 2020. Association of delaying school start time with sleep duration, timing, and quality among adolescents. JAMA Pediatr. 174:697–704. doi:10.1001/jamapediatrics.2020.0344.

Wittmann M, Dinich J, Merrow M, Roenneberg T. 2006. Social jetlag: Misalignment of biological and social time. Chronobiol Int. 23:497–509. doi:10.1080/07420520500545979.