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SCHOOL START TIMES

# Longitudinal Outcomes of Start Time Delay on Sleep, Behavior, and Achievement in High School

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**Study Objectives:** To establish whether sleep, health, mood, behavior, and academics improved after a 45-minute delay in high school start time, and whether changes persisted longitudinally.

**Methods:** We collected data from school records and student self-report across a number of domains at baseline (May 2012) and at two follow-up time points (November 2012 and May 2013), at a public high school in upstate New York. Students enrolled during academic years (AY) 2011–2012 and 2012–2013 completed the Pittsburgh Sleep Quality Index; the DASS-21; the "Owl-Lark" Scale; the Daytime Sleepiness Index; and a brief self-report of health. Reports from school records regarding attendance, tardiness, disciplinary violations, and academic performance were collected for AY 2010–2011 through 2013–2014.

**Results:** Students delayed but did not extend their sleep period; we found lasting improvements in tardiness and disciplinary violations after the start-time delay, but no changes to other variables. At the first follow-up, students reported 20 minutes longer sleep, driven by later rise times and stable bed times. At the second follow-up, students maintained later rise times but delayed bedtimes, returning total sleep to baseline levels. A delay in rise time, paralleling the delay in the start time that occurred, resulted in less tardiness and decreased disciplinary incidents, but larger improvements to sleep patterns may be necessary to affect health, attendance, sleepiness, and academic performance.

**Conclusions:** Later start times improved tardiness and disciplinary issues at this school district. A delay in start time may be a necessary but not sufficient means to increase sleep time and may depend on preexisting individual differences.

**Commentary:** A commentary on this article appears in this issue on page 267.

**Keywords:** sleep, school start time, adolescence, education, behavioral, academic performance, tardiness, attendance, sleepiness, individual differences, high school

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**Significance**

US high schools have utilized later start times to improve student success in the classroom, but few longitudinal studies have examined this tactic. We used longitudinal methodology to follow changes to sleep, mood, health, and academics in a high school that delayed start time by 45 minutes. Initially, students lengthened sleep by 20 minutes. At one year follow-up, total sleep time returned to baseline, although the timing of sleep was significantly and persistently delayed. Lasting reductions in tardiness and disciplinary incidents were observed despite a lack of change in total sleep, suggesting a delay in sleep period can in itself improve daytime behaviors. Longer sleep times, coupled with delayed timing, may be necessary to improve mood, health, or academic performance.

## INTRODUCTION

In the U.S. and many other countries, secondary schools are free to set the time when first period starts. For high school students, typical start times range from 07:20 to 08:55.[1–3] Recently, however, communities and legislatures have lobbied both on local and national levels to delay school start times.[2,4,5] On school days, first period start times dictate when students awaken and when they are most active during the day.[6] High school students in particular are disadvantaged by early start times because their sleep-wake cycle undergoes significant delay as a result of puberty, predisposing them to later bedtimes and wake times and delaying peak performance till later in the day.[7,8] Thus, early school start times result in truncated sleep, and most high school students already get less sleep than they need: two-thirds or more of adolescents in nationally representative samples report that they sleep between 7.25 and 8.75 hours, which is 0.5–2 hours less than what is needed for optimal functioning in adolescence.[9–12] Insufficient or poor quality sleep is associated with physical and emotional distress, decreased cognitive functioning and academic performance, and a host of behavioral problems.[11,13,14] Ensuring that adolescents get enough sleep, therefore, should be a priority for parents and educators.

The evidence from the accumulating body of literature suggests that later school start times result in longer, higher-quality sleep.[6,8,15–17] Other benefits include improved attendance and retention rates,[18,19] elevated mood and motivation,[17] and in some cases, better academic performance.[19–23] A decrease in vehicular accidents has also been reported.[24,25] Many of these benefits are driven by longer sleep made possible by later school start times: even a delay of 30 minutes has been shown to result in increased sleep, motivation, and class attendance, with a concomitant decrease in daytime sleepiness and depressed mood in high school students at boarding schools.[17] Similar results have been reported for middle school students.[21,26] Because of these findings, the American Academy of Pediatrics has recommended that school start times be delayed until no earlier than 08:30.[12]

While the evidence highlighting wide-ranging benefits of later school start times is convincing, published research (both peer-reviewed and not) conducted to date has generally fallen into two categories: first, studies that compare outcomes from before and shortly after a delay in school start times has been instituted,[3,16,17,24] and second, studies that examine these differences in cross-sectional samples.[3,19,21,25,27] Little is known, however, about whether the initial benefits persist over the long term, although there are indications that this may indeed be the case for select outcomes in both middle school[6,18,21,26] and high school students.[3,19] The present research employs a longitudinal design to address this gap in knowledge.

The current study compared student performance over a four year period at a high school in Glens Falls, NY. We examined data from school years (SY) 2010–2011 and 2011–2012, when the start time was 07:45, and data from SY 2012–2013 and 2013–2014, after first period start time was delayed by 45 minutes to 08:30. The Glens Falls school district is a "walking district": all students are designated as living within walking distance of the school and no buses are used for transportation.

Data from the following domains were considered: sleep and sleep-related outcomes, physical health, mood/anxiety/stress reports, and circadian preference. These analyses compared responses of students during the 07:45 start times in Spring 2012 with responses provided during the later start times, Fall 2012 and Spring 2013. Importantly, we collected data at the same time of year in Spring 2012 and Spring 2013 to control for the effects of seasonality. Additionally, we examined absence and tardy rates, disciplinary violations (e.g., fighting, insubordination), and grades and standardized test scores from 2010 to 2014. For measures where data could be linked with specific students, statistical analyses controlled for within-subject effects.

We also considered how individual differences variables, such as gender, age/grade level, socioeconomic status, and circadian preference, might affect student variables in the school system when start times are changed. For instance, economically disadvantaged students or students at the lower end of the performance spectrum may be particularly likely to benefit from increases in total sleep time that might result from later school schedules.[21,28] Student outcomes may also vary with circadian preference: individuals who describe themselves as *larks* (prefer mornings as the time of greatest productivity and well-being) generally have more positive outcomes than do *owls* (those who report an evening preference) in a number of domains, including lower rates of depression, better grades in college, and better physical health.

## METHODS

### Participants and Design

All data were collected at Glens Falls, NY, high school, a public school in a middle-sized community of about 14,000, 94% Anglo-American. The community's median household income was $45,600 (New York state median income is $58,000). About 14% of Glens Falls residents' incomes are at or below the poverty level, compared to New York State's average of 15.3%.[29] Enrollment at the high school varied from between ~650 to ~800 during the course of the study. Students in grades 9 through 12 completed questionnaires that recorded demographic variables, physical and mental health, sleep quality, daytime sleepiness, and circadian preference before the change in school start times (Wave 0, last 2 weeks of May 2012) as well as twice after the change (Wave 1: first 2 weeks of November 2012; Wave 2: last 2 weeks of May 2013). A total of 597 participants completed questionnaires in Wave 1: 120 9$^{th}$ graders, 126 10$^{th}$ graders, 110 11$^{th}$ graders, and 112 12$^{th}$ graders; additionally, 129 8$^{th}$ graders completed the surveys in Wave 0. A total of 410 students in grades 9–12 completed Wave 1 and 372 completed Wave 2. All enrolled students were invited to participate in each wave, regardless of which (if any) wave they had already completed.

### Procedure

Students were notified of the study through announcements and fliers, including those posted on the school's website. Parents and guardians received fliers through the mail when quarterly report cards were sent, a month before data collection. IRB approval permitted passive consent from parents/guardians (i.e., they could affirmatively opt out their children from participation; otherwise, students were approached for consent to participate directly). The students whose parents did not opt out (all but 2) and who volunteered to participate in the study provided informed consent to complete questionnaires online and to link their answers across administrations of the questionnaires. After providing consent, students used a login identification assigned by the school to access the website for completion of questionnaires. Online sessions occurred during computer labs, "open" periods (study halls or uncommitted time blocks), lunch, or other classes in which a block of time was made available (e.g., physical education). Students were paid for participation in each wave.

### Survey Measures

At each wave, the students completed a brief demographic survey and the following questionnaires (Cronbach $\alpha$ for each ranged from 0.70 to 0.89): Health Survey, where frequency of illnesses and hospitalizations, days/classes missed for illness, as well as overall health were reported; Depression, Anxiety and Stress Scale (DASS-21), a 21-item scale measuring depressed mood, anxiety, and stress experienced in the past week.[30]

We utilized the Pittsburgh Sleep Quality Index (PSQI) at all 3 waves to estimate sleep parameters. Participants reported typical sleep/wake patterns, total sleep time, sleep onset latency, use of sleep medications, daytime symptoms such as fatigue, and sleep disturbances.[31] We also asked students to complete a second measure of sleep parameters, added at Wave 1 and continued at Wave 2, for later comparison purposes. In this second measure, students reported earliest and latest bed time and wake time over the last 2 weeks. These items are derived from the "Sleep Habits Survey," a measure often used in adolescent populations (Wolfson and Carskadon.[1] Note that for Baseline, only PSQI estimates were completed.) Total sleep time estimates, bedtimes, and wake times all showed close correspondence with PSQI-derived sleep estimates: correlations ranged from 0.52 to 0.76 ($P < 0.001$) for TST, BT, and WT. Our data support use of PSQI estimates of sleep times, as well as wake and rise times, and thus we conclude that the PSQI yielded reliable and valid estimates of sleep schedules, which were adequate for the purposes of our study. The Daytime Sleepiness Index (DSI)[1,32] was also administered, addressing daytime sleepiness and sleep-wake behavior problems; this scale has been used extensively in adolescent samples generally, and high-school students in particular. The sum of the standardized responses to each question formed the Daytime Sleepiness Index; higher scores correspond to increased sleepiness.[32] Lastly, we also administered the Owl-Lark Scale, a measure of morning or evening circadian preference.[33] The responses to the Health and the Daytime Sleepiness Index were each transformed into composite measures before analyses.

**Table 1**—Marginal means (with standard errors) adjusted for grade at baseline, circadian preference, and nightly sleep length and results of statistical comparisons for the survey data.

| | Baseline (Spring 2012) | | Fall 2012 | | Spring 2013 | | Gender Differences | Effect of Covariates (Direction) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SE | Mean | SE | Mean | SE | (P < 0.05) | Grade at Baseline | Morningness | Sleep Duration |
| Age | 16.07 | 0.05 | 16.41* | 0.05 | 16.89*,^ | 0.05 | ns | n/a | n/a | n/a |
| Bedtime (decimalized, PSQI) | 22.63 | 0.04 | 22.59 | 0.05 | 22.96*,^ | 0.06 | M later | + | − | − |
| | (22 h 38 min, SD = 65 min) | | (22 h 35 min, SD = 74 min) | | (22 h 58 min, SD = 76 min) | | | | | |
| Rise time (decimalized, PSQI) | 30.63 | 0.03 | 30.92* | 0.04 | 31.03* | 0.04 | M later | ns | − | + |
| | (6 h 38 min, SD = 42 min) | | (6 h 55 min, SD = 50 min) | | (7 h 02 min, SD = 50 min) | | | | | |
| Sleep duration (hours, PSQI) | 7.34 | 0.05 | 7.70* | 0.06 | 7.29^ | 0.07 | ns | − | + | n/a |
| | (7 h 20 min; SD = 73 min) | | (7 h 42 min; SD = 68 min) | | (7 h 17 min, SD = 75 min) | | | | | |
| % of students getting 8+ hours of sleep per night | 40.30 | | 60.20* | | 49.70*,^ | | n/a | n/a | n/a | n/a |
| % of students getting < 7 hours of sleep per night | 26.50 | | 21.00* | | 27.20^ | | n/a | n/a | n/a | n/a |
| Latency to fall asleep (minutes; PSQI) | 24.35 | 0.90 | 22.64 | 0.85 | 21.66 | 1.04 | F longer | ns | − | − |
| Sleep problems (PSQI global score) | 5.98 | 0.13 | 5.50* | 0.14 | 6.03^ | 0.16 | F greater | − | − | n/a |
| Dissatisfaction with sleep (PSQI sleep quality) | 0.93 | 0.03 | 0.94 | 0.04 | 0.99 | 0.04 | M greater | − | + | + |
| Number of all-nighters (past 2 weeks) | 0.59 | 0.08 | 0.42 | 0.04 | 0.35* | 0.05 | ns | − | − | − |
| Daytime sleepiness composite (standardized) | 0.03 | 0.02 | −0.01 | 0.02 | −0.02 | 0.02 | F greater | ns | − | − |
| Health problems composite (standardized) | 0.00 | 0.02 | −0.03 | 0.02 | −0.01 | 0.02 | F greater | ns | − | − |
| Amount of exercise | 2.95 | 0.08 | 2.96 | 0.09 | 2.78 | 0.09 | M greater | ns | + | ns |
| Depression (DASS) | 5.24 | 0.40 | 4.48 | 0.31 | 5.64^ | 0.40 | F greater | ns | − | − |
| Anxiety (DASS) | 4.54 | 0.35 | 4.40 | 0.27 | 4.65 | 0.32 | F greater | ns | − | − |
| Stress (DASS) | 6.70 | 0.43 | 6.42 | 0.32 | 7.20 | 0.38 | F greater | ns | − | − |

Later start times were instituted Fall 2012. *P < 0.05 compared to baseline (Sidak familywise alpha). ^P < 0.05 for comparison between the first (Fall 2012) and second (Spring 2013) post-transition measurement occasion (Sidak familywise alpha). For the effect of covariates, + indicates a positive association with the criterion variable; − indicates a negative association. Post hoc tests were conducted only when the main effect of the measurement occasion was significant. *Daytime Sleepiness* and *Health Problems* are standardized composite scores. PSQI, Pittsburgh Sleep Quality Index; DASS, Depression-Anxiety-Stress Scale.

### School Records

We analyzed school records of tardy arrivals, absences, early dismissals, disciplinary violations, and academic performance for 2010–2014—that is, for 2 years prior and 2 years following the change in school start times. These data were analyzed for all enrolled students regardless of their participation in the online portion of the study.

## RESULTS

### Survey Results

The SPSS mixed procedure was used to estimate fixed-effects models examining changes in sleep, behavioral, and academic variables between baseline (earlier school start time) and the 2 post-transition periods (later school start time). This procedure allows error residuals to co-vary across measurement occasions and enables the inclusion of all participants in the analyses as long as they have contributed data to at least one measurement wave. Preliminary comparisons indicated that the respondents' circadian preference was significantly lower—that is, more "owlish"—during the fall post-transition (Wave 1; mean = 46.62, standard error [SE] = 0.38) than both baseline (Wave 0; mean = 49.09, SE = 0.32) and the spring post-transition (Wave 2; mean = 48.89, SE = 0.40), P < 0.001, which did not differ from each other, P = 0.93, $F_{2,398}$ = 33.98, P < 0.001. Therefore, circadian preference was entered as a covariate in the analyses of survey responses described below.

Respondents' grade at baseline (a proxy for age) and average nightly sleep duration (based on PSQI estimates) were also added as covariates in a mixed-effects model that was specified for each dependent variable of interest using the measurement occasion and gender as fixed factors.

Table 1 summarizes the results of these analyses and presents means and standard errors of variables in each measurement wave, adjusted for values of the covariates. Later school start times in the first post-transition period (Fall 2012) were associated with a 20-min increase in sleep duration driven by a 20-min delay in rise times, along with slightly shorter latency to fall asleep and fewer sleep problems, as indicated by the global PSQI score. No changes were evident in student bedtimes or daytime sleepiness. At Wave 2 (Spring 2013), however, sleep duration returned to pre-transition levels as bedtimes became delayed, while rise times and latency to fall asleep remained stable. An increase in sleep problems at Wave 2, compared to Wave 1, was also evident in the Global PSQI scores. Moreover, scores on the DASS were higher at Wave 2 than at Wave 1 (but neither differed from baseline), while no discernible change was seen in levels of exercise and physical health problems across all measurement occasions. There was, however, a slight decrease in the incidence of all-nighters in the two weeks prior to survey administration at Wave 1 (P = 0.12) and a significant decrease at Wave 2 (P = 0.02), compared to baseline.

Thus, while there were immediate sleep benefits associated with a shift toward later school start times, few of these benefits were long-lasting. Furthermore, we found no evidence to

**Table 2**—Means (and standard deviations) of sleep and behavioral variables across the three measurement occasions for participants who either gained or lost sleep from Baseline (before start time change) to the first post-transition follow-up.

| | Post-transition Sleep Gain (46% of sample) | | | Post-transition Sleep Loss (30% of sample) | | |
|---|---|---|---|---|---|---|
| | **Baseline** | **Wave 1** | **Wave 2** | **Baseline** | **Wave 1** | **Wave 2** |
| Morningness (Owl-Lark) | 48.37 (8.14) | 46.09 (8.83)* | 49.30 (8.50)^ | 50.98 (8.58) | 47.21 (8.86)* | 49.50 (9.41)^ |
| Bedtime (PSQI) | 22.77 (1.18)<br>(22 h 46 min) | 22.53 (1.12)<br>(22 h 32 min) | 22.94 (1.37)^<br>(22 h 56 min) | 22.35 (0.84)<br>(22 h 21 min) | 22.79 (1.13)*<br>(22 h 47 min) | 22.91 (1.33)*<br>(22 h 55 min) |
| Rise Time (PSQI) | 30.46 (0.62)<br>(6 h 28 min) | 31.00 (0.79)*<br>(7 h 00 min) | 31.03 (0.84)*<br>(7 h 02 min) | 30.73 (0.85)<br>(6 h 44 min) | 30.96 (0.65)<br>(6 h 58 min) | 30.89 (0.86)<br>(6 h 53 min) |
| Sleep Duration (hours, PSQI) | 6.83 (1.24)<br>(6 h 50 min) | 8.07 (1.19)*<br>(8 h 04 min) | 7.41 (1.27)*,^<br>(7 h 25 min) | 8.17 (1.09)<br>(8 h 10 min) | 7.01 (1.24)*<br>(7 h 01 min) | 7.28 (1.27)*<br>(7 h 17 min) |
| Latency to Fall Asleep (minutes; PSQI) | 28.15 (27.88) | 21.66 (17.55)* | 21.53 (18.02)* | 20.96 (14.76) | 27.32 (24.36) | 23.51 (23.01) |
| Sleep Problems (PSQI Global Score) | 6.57 (3.44) | 5.22 (2.87)* | 5.83 (3.09) | 4.32 (2.62) | 5.89 (3.69)* | 5.41 (3.26)* |
| Daytime Sleepiness Composite (standardized) | −0.05 (0.33) | 0.04 (0.43) | 0.01 (0.34) | 0.03 (0.49) | 0.03 (0.58) | 0.00 (0.45) |
| Health Problems Composite (standardized) | 0.04 (0.49) | −0.06 (0.45) | 0.01 (0.46) | −0.11 (0.43) | −0.03 (0.51) | 0.03 (0.50) |
| Amount of Exercise | 3.02 (1.81) | 2.98 (1.92) | 2.48 (1.57) | 2.88 (2.02) | 3.10 (2.14) | 2.86 (1.96) |
| Mental Health Problems (DASS total score) | 11.29 (13.47) | 12.07 (13.80) | 13.89 (17.22) | 10.29 (10.87) | 11.83 (19.91) | 12.25 (16.48) |

*P < 0.05 compared to baseline (Bonferroni-adjusted); ^P < 0.05 for comparison between the first (Wave 1; Fall 2012) and second (Wave 2; Spring 2013) post-transition measurement occasion (Bonferroni-adjusted). Groups were created on the basis of either a positive change in PSQI TST (reflecting sleep gains) or a negative change (reflecting sleep losses), omitting individuals whose sleep times held steady from Baseline to Wave 1. *Daytime Sleepiness* and *Health Problems* are standardized composite scores. PSQI, Pittsburgh Sleep Quality Index; DASS, Depression-Anxiety-Stress Scale.

suggest that physical and mental health, or health-related behaviors like exercise, benefited from the delay in start times.

A number of other findings emerge from these comparisons. First, male students were more likely to report later bedtimes and rise times, shorter latencies to sleep, and greater dissatisfaction with sleep, whereas female students were more likely to experience daytime sleepiness, as well as sleep, health, and emotional problems. However, none of the analyses revealed an interaction between gender and measurement occasion, suggesting that behavioral changes after a delay in school start times were comparable for male and female respondents. Second, morning preference was associated with a wide range of benefits, both with respect to length and quality of sleep, as well as physical and mental health. However, follow-up analyses suggested that the delay in school start times did not differentially affect the trends in sleep and health outcomes exhibited by "larks" compared to "owls" across the 3 measurement periods, as indicated by the absence of interaction between circadian preference and wave for any of the survey variables. Finally, younger students reported earlier bedtimes, longer sleep, and greater sleep satisfaction; students in higher grades were less likely to stay awake all night.

### Post-Transition Sleep Schedules

Few students reported receiving the recommended amount of sleep for this age group (~9.25 h/night), and the mean TST was 7.34 hours. We expected, therefore, that students would mostly extend sleep when given that chance. Many students, however, did not use the start time delay as an opportunity to do so, introducing significant variability of response to the start time change. Table 2 provides means (and standard deviations) for those who gained and those who lost sleep post-transition for several key variables. To understand the characteristics of individuals who gained or lost sleep as a result of the change in start times, we conducted a series of 2×3 mixed ANOVAs with Bonferroni post hoc tests with group (gained vs. lost sleep from Baseline in Spring 2012 to Wave 1 in Fall 2012) and the 3 measurement periods (before the start time changes in Spring 2012 [Baseline] and after the transition in Fall 2012 [Wave 1] and Spring 2013 [Wave 2]) as factors. For these analyses, we only used the data from those who participated in all 3 waves of the study (n = 194) and determined sleep gain/loss on the basis of PSQI total sleep times.

Two observations emerge from these analyses. First, those who gained sleep in the first post-transition (Wave 1) did so by advancing bedtimes (P = 0.10) and delaying rise times (P < 0.001), as well as reducing the SOL (P = 0.04), for a net gain of almost 75 minutes (P < 0.001). The gains were associated with a reduction in sleep problems (P < 0.001). However, these gains had attenuated by Wave 2, as the Sleep-gain group delayed bedtimes by 24 min (P = 0.005). Sleep problems showed an uptick (P = 0.06) while rise times held steady. Conversely, those in the Sleep-loss group delayed bedtimes (P = 0.006) and rise times (by a modest 14 min; P = 0.08), with a concomitant increase in sleep problems (P < 0.001), for a net loss of almost 70 min of sleep (P < 0.001). Essentially, many of those who increased their TST at Wave 1 subsequently lost that sleep by Wave 2 while those who decreased TST at Wave 1 held TST steady (see Table 2). At Wave 2, after subdividing the sample as described above into 3 groups (those who gained sleep, those who lost sleep, and those whose sleep was static), we examined mean TST for each group. Notably, all means converged and were within 12 min of each other.

The second observation to emerge from the analysis of the differences in participants following the transition to later start times is that participants in these 3 groups exhibit meaningful individual differences in sleep need and circadian preference.

Students in the Sleep-gain group were more likely to have an evening chronotype (P = 0.06), they reported mean TST at < 7 h per night (P < 0.001), and they indicated more sleep problems (P < 0.001) and more health problems (P = 0.07) compared to those in the Sleep-loss group. Essentially, the "sleepy Owls," experiencing a multitude of symptoms secondary to inadequate sleep, were more likely to extend sleep when start times changed. The Sleep-gain group did gain 84 min of sleep after the start time delay, and sleep problems decreased significantly, but neither mental health nor physical health showed changes at Wave 1.

### Attendance Records

Student records for 2011–2013 were examined to determine whether the change in school start times was associated with a reduction in absences, tardiness, and rates of early dismissal for athletic events. Repeated-measures models using the SPSS mixed procedure were fit to these variables after converting them to ratios (days absent/days enrolled) to adjust for school year length for students who did not complete the entire academic year (i.e., transferred in or out) at the school. We restricted all analyses to students enrolled for at least half of the academic year and controlled for student age. The comparison between the pre-transition and the post-transition years revealed that the rates of excused, unexcused, and total absences increased after the start time change. The increase was from 0.044 to 0.051 for excused absences, $F_{1,595} = 7.19$, P = 0.008; from 0.041 to 0.062 for unexcused absences, $F_{1,466} = 30.06$, P < 0.001; and from 0.085 to 0.113 for all absences, $F_{1,505} = 35.47$, P < 0.001, which translates into an increase of nearly 5 days per year. Restricting the analyses to students who attended the school both in the year before and the year after the transition to later start times (n = 487) led to a similar increase in the rate of all absences, which rose from 12.8 days per year in 2011–2012 to 17.7 days per year in 2012–2013, $F_{1,485} = 33.56$, P < 0.001. Notably, examining absence rates for the entire student roster in either academic year (again, for students enrolled for at least half the year) without accounting for repeated measures on these participants produces a slight (less than half-day) *decrease* in all absences from 2011–2012 (a ratio of 0.095) to 2012–2013 (a ratio of 0.093), which can lead to erroneous conclusions. Incidentally, this analytic approach was used in all cross-sectional and several longitudinal analyses[3,19] of the effects of school start time change in the past.

Examination of tardies indicated that the rate of excused tardies remained unchanged from 2011–2012 to 2012–2013; similarly, the rate of early dismissals did not change significantly. A pronounced decline was observed for unexcused tardies, $F_{1,573} = 23.98$, P < 0.001, and total tardies, $F_{1,560} = 12.34$, P < 0.001. The magnitude of the decline was from 0.066 to 0.05 and from 0.088 to 0.075, respectively, equivalent to a difference of 3 school days; the older students were more likely to be tardy. Thus, delaying school start times had a small but robust effect on decreasing tardiness, particularly unexcused tardies that often result from oversleeping.[17]

### Disciplinary Violations

To determine whether the change in school start times affected school-related disciplinary problems, we examined the aggregate number of offenses for the 2 years prior to the school start time change (2010–2012), as well as the 2 years following the transition (2012–2014) (Table 3). Chi-square tests revealed a significant reduction in 9 class/school discipline violation categories after the transition. Only one type of offense—cutting detention—increased following the new school start times. No change in the remaining categories was observed, including in the more serious offenses reportable to the state which showed a numeric decline that was not statistically significant, $\chi^2(1) = 0.95$, P = 0.33. Thus, these data indicate that transitioning to a later school start time may have substantially reduced the incidence of many nonviolent offenses and can potentially contribute to the diminishment of the more serious offenses.

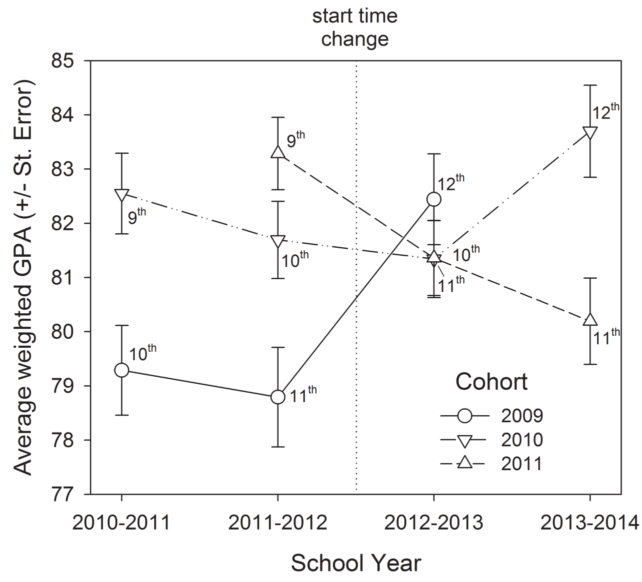


**Figure 1**—Average 2010–2014 weighted GPA for each cohort of students who experienced the change in school start times (each line connects points for a given cohort). For the 2009 cohort, the two years prior to start time change (10th and 11th grades) are plotted along with one year after change (12th grade). For the 2010 cohort, two years prior (9th and 10th grades) and two years after the time change (11th and 12th grades) are plotted. For the 2011 cohort, one year prior to the time change (9th grade) and two years after the time change (10th and 11th grades) are plotted.

### Academic Performance

To determine whether the transition to later school start times was associated with change in academic performance, we conducted two sets of analyses: a cohort-sequential comparison of grades from 2010 to 2014 focusing on the student cohorts that experienced the change, and a cross-sectional comparison of grades and standardized assessment scores in the years before and after the change (2011–2012 versus 2012–2013). We analyzed both overall GPA presented on a 100-point scale (see Figure 1 for means and standard errors) and GPA in specific disciplines (English, science, mathematics, social studies, art, music, foreign language, and health studies). Only half- and full-year courses that offered 0.5–1 units of credit and resulted

**Table 3**—Disciplinary incidents for the two years prior and the two years following the change in school start times.

| | Number of Offenses | | |
|---|---|---|---|
| | 2010–2012 | 2012–2014 | Chi-square Statistic |
| **Offenses Reportable to the State** | | | |
| Assault with physical injury or threat of injury | 5 | 4 | 0.01 |
| Assault with serious physical injury | 1 | 0 | 0.86 |
| Intimidation, harassment, menacing, or bullying | 7 | 9 | 0.65 |
| Minor altercations: physical contact without physical injury | 26 | 16 | 1.12 |
| Other disruptive incidents | 1 | 0 | 0.86 |
| Use, possession or sale of drugs | 17 | 11 | 0.54 |
| Weapons possession only | 5 | 4 | 0.01 |
| **Total** | 62 | 44 | 0.95 |
| **Non-Reportable Offenses** | | | |
| Alcohol | 5 | 0 | **4.30** |
| Cutting detention | 47 | 82 | **15.59** |
| Cutting class | 512 | 351 | **10.74** |
| Disorderly conduct | 302 | 131 | **44.48** |
| Disrespectful behavior | 328 | 158 | **36.82** |
| Drugs, except alcohol | 5 | 4 | 0.01 |
| Electronic device violation | 383 | 145 | **74.84** |
| Fighting | 26 | 9 | **5.93** |
| Insubordination | 690 | 261 | **135.05** |
| Larceny/theft | 8 | 6 | 0.06 |
| Teacher time out | 456 | 45 | **279.68** |
| Threat/intimidation | 25 | 19 | 0.16 |
| Tobacco | 6 | 2 | 1.45 |
| Vandalism | 4 | 2 | 0.40 |
| Other* | 362 | 232 | **12.31** |
| **Total** | 3,159 | 1,447 | 406.85 |

The expected values of $\chi^2$ were adjusted by the average number of students enrolled in 2010–2012 (n = 778) and 2012–2014 (n = 669), calculated by averaging enrollments for each month during the 2 comparison periods.*Offenses not reflected in any other category, such as disruptive behavior, inappropriate language, plagiarism, verbal altercations, and computer use violations, as well as incidents of intimidation/harassment that do not meet the criteria for state-reportable offences. Bold print: $P < 0.05$.

in a numeric grade were included in the analyses. Grades were weighted by the credit units before averaging. Furthermore, we excluded students who took fewer than 3 courses that assigned a grade as well as courses where a grade was not issued (e.g., due to withdrawal). Finally, we evaluated whether gender and poverty status (as indicated by qualification to receive free/reduced lunch) moderated the change in academic performance.

***Longitudinal Comparisons***

Longitudinal changes in GPA were analyzed for each cohort that experienced both the earlier and later start times (i.e., the cohorts entering high school in 2009, 2010, and 2011). Mixed-effects analyses revealed a significant change in GPA as a function of grade for each of these cohorts: GPA has consistently risen from grade 11 to grade 12 but declined/remained unchanged from grade 9 to grade 11 (Figure 1). Importantly, these trends were seen regardless of when in their high school career (i.e., in what grade) the students experienced the start time change. There was also an effect of gender, such that GPA of male students was consistently lower than GPA of female students for all 3 cohorts (Ps ranged from 0.011 to 0.059). Furthermore, GPA of students who qualified for free lunch was lower compared to those who did not for the 2009 and 2011 cohorts (Ps < 0.001), but the trends in the change in their GPA did not vary differentially across school years. Finally, for the 2011 cohort, the GPA of male students had a steeper decline from grades 9 to 11 than that of females ($P = 0.005$). None of the other main effects or interactions were statistically significant, and no obvious pattern of change in course grades emerged across the individual disciplines beyond that found in the analysis of overall GPA: Seniors tended to enjoy an advantage in grades over juniors and sophomores in English, the sciences, mathematics, and foreign languages, regardless of the school start times. In other disciplines (particularly art, music, and health studies), there was less variability in grades, and the differences between upper- and lowerclassmen were less pronounced within each cohort. Overall, we find no evidence to suggest that a change in school start times from earlier to later was associated with either improvement or decline in academic performance.

**Table 4**—Grade-point average (GPA) of students in the four grades before (2011–2012) and after (2012–2013) the change in school start times.

| Grade | Cohorts Compared | Before Time Change Mean (SD) | After Time Change Mean (SD) | *t*-statistic* | P value |
|---|---|---|---|---|---|
| 9 | 2011 vs 2012 | 83.29 (7.68) | 82.59 (8.12) | $t_{264} = 0.72$ | 0.470 |
| 10 | 2010 vs 2011 | 81.69 (8.55) | 81.36 (8.12) | $t_{280} = 0.34$ | 0.737 |
| 11 | 2009 vs 2010 | 78.79 (11.11) | 81.34 (8.70) | $t_{295} = 2.20$ | 0.028 |
| 12 | 2008 vs 2009 | 82.54 (8.95) | 82.44 (10.37) | $t_{327} = 0.09$ | 0.931 |

These are cross-sectional analyses comparing performance of students in each of the four high school grades before and after the change in start times. *Independent-samples *t*-tests.

We also examined the ratio of failing grades (defined as final numeric grade of less than 60%) entered for the 2 years prior and the 2 years following the delay in start times in students who experienced the change. The failure rates were as follows: 4.72% for 2010–2011, 4.49% for 2011–2012, 6.04% for 2012–2013, and 4.39% for 2013–2014, $\chi^2(3) = 14.31$, P = 0.003. There is a noticeable increase in the number of failing grades entered in 2012–2013, the year the change in school start times was implemented, although the rate returns to baseline levels the following year. Notably, examining all grades assigned to all enrolled students for every course regardless of unit value or type for the 2 years prior and the 2 years after the change in start times also does not indicate that course failure rates, which were 5.06% for 2010–2011, 3.59% for 2011–2012, 3.57% for 2012–2013, and 6.76% for 2013–2014, changed with delayed start times.

### *Cross-Sectional Comparisons*

We also compared GPA of students in each of the 4 grades in the year before, and the year after, the change in start times (see Table 4 for descriptive and inferential statistics; see also Figure 1). These analyses compare 2 groups of individuals of the same age and grade level born one year apart; thus, the results are prone to cohort effects. Nonetheless, the findings are consistent with the claim that the transition to later school start times had little impact on academic performance. There were no statistically significant differences between the achievement of 9$^{th}$, 10$^{th}$, and 12$^{th}$ graders before and after the change was implemented; 11$^{th}$ graders saw a small, albeit significant, increase in GPA after the change. Notably, the GPA of students receiving free lunch at each grade level (approximately 18% of the sample) was lower (by 4–5 points on a 100-point scale) than students who did not receive free lunch, as indicated by significant main effects of free lunch status when this variable was entered along with the year (pre- and post-change) into an ANOVA (all Ps < 0.003). This analysis could not be conducted for grade 12, for which no records of free lunch were available for 2011–2012.

The cross-sectional analyses of grades in the individual disciplines also failed to reveal a consistent change in academic performance: the comparisons of students who were in 10$^{th}$ grade the year prior and the year of the change, and analogously of 12$^{th}$ graders, revealed no differences in grades in any of the disciplines. For the 11$^{th}$ graders, the younger cohort had significantly higher scores (P < 0.05) in English and art and marginally higher scores (P = 0.06) in social studies. For 9$^{th}$ grade performance, the older cohort had significantly higher scores in English and science (P < 0.05) while the younger cohort earned marginally higher grades in foreign language courses (P = 0.08).

### *Standardized Assessment Scores*

Scores on standardized assessments (Regents exams) in 2011–2012 (before schedule change) were compared with scores in 2012–2013 cross-sectionally. After excluding exams completed by < 5 students, 2 of the 20 subject tests (10$^{th}$ grade Earth Science and 11$^{th}$ grade Algebra) resulted in significant differences between groups (P < 0.007; all other Ps > 0.06); scores on both were higher in the pre-transition year. Thus, there is no compelling evidence to indicate that the change in school start times resulted in a positive shift in standardized assessment scores, and cohort effects may account for the effects observed with the two tests that did reach statistical significance.

## DISCUSSION

In this study we examined a range of variables affecting sleep, health, school performance, and behavior, both before and after a 45-min delay in start time at a public high school; variables included self-reports of sleep, mental and physical well-being, attendance and tardiness records, disciplinary violations, and academic records. We found significant and lasting improvements in tardiness rates and disciplinary violations, but few meaningful or consistent changes in sleep, mental or physical well-being, academic achievement, or attendance. At the first follow-up after the delayed start time, students reported an initial 20-minute increase in sleep time, driven by later wake times and stable bed times. At the second follow-up, students delayed bed times, although wake times remained later, essentially returning total sleep time to baseline amounts.

Female students reported earlier bedtimes, earlier wake times, longer sleep latencies, more sleep problems, and more daytime sleepiness. They also reported more complaints about mental health and less exercise than male students. No interactions between gender and start time were detected for other variables. We also co-varied circadian preference scores and grade at baseline. Morningness was associated with earlier bed times, earlier rise times, shorter sleep latency, less frequent incidence of all-nighters, fewer sleep and health problems, less sleepiness, and fewer mental health complaints. Thus morningness conferred benefits across virtually all domains investigated, but "owls" and "larks" did not systematically experience changes to either costs or benefits as a function of the start-time delay. Younger students had earlier bedtimes, longer sleep, better satisfaction with sleep, and more all-nighters.

Our findings replicate past research suggesting that later start times can improve tardiness and also decrease behavioral and disciplinary problems during the school day; however, findings in the areas of attendance, mental health, physical health, and sleepiness were absent, more modest, or mixed.

#### Attendance

Neither unexcused nor excused absences improved after the delay in start times was implemented—in fact, our data indicated a slight increase in absences post-transition. These findings contrast with at least 2 other reports done in public school settings wherein attendance rates improved: Wahlstrom reported that high school attendance improved by between 1% and 5% of yearly attendance rates, but only for "non-continuously" enrolled students (students moving into and out of the schools during the school year). Consistent with our findings, however, no significant improvements were detected in *continuously* enrolled students.[19] In Wahlstrom's results from 2014,[3] attendance was improved in the 9$^{th}$ graders, but no changes were detected in the 10$^{th}$, 11$^{th}$, or 12$^{th}$ graders. Owens's findings[17] indicated that tardies/absences experienced a 45% drop, but as these were not reported in separate categories, the decline might have been primarily due to a decrease in tardiness, similar to our findings. The Owens study was undertaken at a private boarding school, limiting direct comparisons or speculation about why our findings differed.

#### Tardiness

Virtually every school that delays start times has shown decreases to tardiness in students, whether in "walking district" schools or in busing districts, and our results were no exception: rates of unexcused tardies decreased 20% in the year after the start time change. Both Owens[17] and Boergers[15] reported significant decreases in tardiness, although some of these data were school-reported and some were self-reported. In Wahlstrom's 2002 comparison study,[19] tardiness was lower in the districts with later start times; in a later study, which examined tardy rates in six schools, delays to start times resulted in decreased rates of tardiness in four of the five schools where tardy rates were available.[3] Thus, improvements to tardiness, whether measured by self-report or by the school's records, appear reliable and persistent.

#### Academics and Standardized Test Performance

We found no differences in academic performance after the start time change, whether we examined specific grades, overall GPA, or standardized test scores. No patterns were detectable with respect to cohorts, with one exception: seniors appeared to enjoy a "bump" in GPA (Figure 1). Boergers[15] and Owens[17] also failed to detect any improvements to grades. As no data regarding course grades or grade point averages were available in the Wahlstrom studies (and no $\alpha$ levels for significance were provided), it was difficult to compare findings, but it appeared that few differences in grades as a function of start time delay were detected in either of these reports: in the 2014 summary report, 3 of 6 schools included in the survey saw *some* improvements in *some* grade levels; two schools showed mixed results, and one district showed no changes.[3] Results on standardized tests in those reports were likewise mixed, with few schools showing changes to test scores; no patterns overall in the changes were apparent.

#### Sleep and Sleep-Related Variables

In most examinations of sleep variables after start time changes are implemented, students have slept later in the morning and held bedtimes constant, leading to a net gain of sleep that sometimes exceeds the amount by which the start time was delayed.[15,17] In our study, this did not occur: students did initially hold bedtimes roughly steady, and slept later, but by Wave 2, one year after the change in start times, bedtime had delayed again (although students continued to sleep later, as they had done right after the transition to later start times at Wave 1). Although the sample reported 20 minutes longer total sleep time at Wave 1, these gains returned to baseline by Wave 2, and we detected no changes in sleepiness, physical health, mental health, or sleep satisfaction compared to baseline levels.

Overall, then, students' report of total sleep time showed initial gains, followed by loss of those gains. This result is in contrast to many of the findings discussed earlier when high school start times have been delayed. In part to discover more about the length of the sleep period in this study, we compared the patterns over time by examining the percent of students getting $\geq$ 8 hours of sleep a night (i.e., sufficient sleep for this age group) and those getting $\leq$ 7 hours of sleep per night (i.e., insufficient sleep). At Baseline, 40% of students reported $\geq$ 8 hours a night, and at Wave 1, this increased significantly to 60%. At Wave 2, the percent reporting $\geq$ 8 hours a night dropped back to 50% (see Table 1), for a net gain to the proportion of students getting sufficient sleep, examined longitudinally. Thus, although most of the students did not utilize the delayed start time to lengthen the sleep period, about 10% of the student sample did report persistent gains to total sleep time one year after the change. The proportion of students getting insufficient sleep—$\leq$ 7 hours of sleep per night—fell significantly by about 5%, but this improvement was lost by Wave 2.

Patterns in this study for the *first* follow-up are similar, although less robust, to those found by Owens[17] and Boergers,[15] who found that when students increased sleep, substantially more of them were getting "sufficient" sleep. Although some students extended their total sleep time in our study, most did not maintain gains. These findings may suggest that in a public school, students may be less willing to allocate available time for sleep, or it may be that a year-long follow-up is a better indication of long-term outcomes in sleep patterns after start-times are changed. More longitudinal follow-up studies should be initiated to understand why students fail to make, or fail to conserve, gains made in total sleep time.

#### Changes in Students Who Lost Sleep vs. Those Who Gained Sleep Post-Transition

The students who participated in *all three waves* of the study were divided into three groups according to whether they gained, lost, or experienced no change in sleep following the transition in order to examine differences in the response to the start time delay with more precision. The analyses of the Sleep-gain group reveal the characteristics of those who may be more likely to make changes to their sleep periods, and thus those who may benefit from changes to start times: the Sleep-gain group comprised those who were getting less sleep initially, with both later bedtimes and earlier rise times, who reported more "all-nighters," and who were more evening-type in circadian preference. The Sleep-gain group also reported more mental health symptoms. However, increasing their TST did not result in improvements to these domains at Wave 1, and we should not be surprised that they, too, failed to conserve the changes to their sleep schedule. In the end, the pattern detected—those with less sleep increased TST while those with more sleep decreased TST—is best described as a simple regression to the mean. We suggest therefore that, in our sample, the delayed start time was not a powerful inducement to make changes, or to maintain changes, to the total amount of sleep most students received. In support of an individual-differences interpretation of our results, improvements across domains did not occur for most students, despite the fact that all students experienced the start time delay. Our earlier observations (Table 2) suggest that our participants exhibit meaningful individual differences in sleep need and circadian preference. These differences affect how students experience sleep deprivation and may drive students' decisions about choices made regarding sleep schedules and other domains. Research in adult populations suggests that individuals experience sleep loss in myriad ways, and that response to sleep loss in one neurobehavioral domain (e.g., cognition) is often uncorrelated to responses in other domains (e.g., subjective sleepiness, long term health), suggesting a complex of traits that are impacted differently by sleep loss.[34,35] Similar to findings in adult populations, we suggest that our findings point to a broader picture, wherein each student's profile of cognitive, physical, and mental health may improve, remain stable, or deteriorate according to each student's specific traits and profiles of vulnerability/resilience to sleep loss. The response to the start time delay would then plausibly vary considerably from student to student, depending in part on chronotype preference and amount of sleep deprivation prior to the change in start time.

Differences in methodology might further explain the discrepancy in our findings as compared to others in the literature. Our second follow-up data collection (Wave 2) was completed during the same season, one year later, as our initial data collection. In contrast, Owens[17] examined pre- and post-start time delay using data sets collected 2–3 months apart. Asarnow[9] and Boergers[15] also compared total sleep times with weeks to months intervening between study comparison dates. Sleep length may vary systematically with the seasons, with increased sleep seen in fall compared to spring,[36,37] which suggests that collecting comparison data should best be done in the same season. Thus, our study represents one of the only longitudinal examinations of changes after a start-time delay which follows changes within the same school district, in the same week, and of the same season in which baseline data were established while also adjusting for repeated measurements. Because of the difference in sampling schedules, of course, it is impossible to tell whether sleep gains in Owens,[17] Boergers,[15] or Arsanow[9] might have been maintained or returned to baseline, as happened in our sample.

### Alignment of Circadian Preference

One additional consideration of chronotype as a potential source of individual differences in response to the start time delay is that of circadian alignment. The only consistent net effect of the delay in start time was to shift the sleep period forward by 25–30 minutes (later rise times combined with short sleep onset latencies, Table 1). Students with evening chronotypes may have found that a delay of the sleep period aligned them more closely with their circadian preference. One indication that students prefer to sleep later in the circadian day (as opposed to longer) is that virtually all of the students in our sample did adjust wake times to conform to a later start time, and then held wake times later, regardless of circadian preference, total time asleep, or other variables measured. Although the delay to the sleep period represents a modest change, any benefits that might have accrued might be due to this closer alignment: Owls, compared to Larks, tend to do less well when schedules require early hours, even when mean TST is held constant.[38,39] Better performance can occur when circadian preference is synchronized to time of task.[39–41] Other behaviors are also implicated, as evening-preference adolescents are at higher risk for aggressive and behavioral adjustment problems.[38]

### Limitations to the Study

Our study relied on self-report of sleep, fatigue, mood, and health; these reports can be unreliable, due to issues with memory inaccuracy and bias. Follow-up studies should consider using more objective measures of sleep (e.g., actigraphic measures of sleep) to increase both reliability and validity of sleep length estimates. A further limitation was the measurement of sleep quantity and quality by participants using the PSQI, which has not been validated in adolescent populations. The PSQI, however, is a simple, easily comprehended measure, and the correlations of the PSQI variables with other measures in our study, and intra-correlations among our participants' data, give us confidence that the results are both reliable and valid. Anecdotal reports indicate that some of the students were strongly in favor of the delay while others were strongly against it; polarized attitudes and response sets may have biased the students' responses on select variables. Participation in the study was voluntary for students, and a number of the variables we analyzed were self-reported; thus some selection bias may have influenced the pattern of answers that serve as the basis for our conclusions. We expect, however, that data reported by the school, rather than self-report (i.e., academic performance, attendance, and behavioral problems), to be less affected by biased attitudes or the possibility of increased error secondary to self-report.

Another limitation to the study concerned the sample: the Glens Falls school district uses no busing, being a "walking district," and the sample was homogenous with respect to race

(94% Anglo-American); the median income in this sample was below the average for that of New York State. These three parameters for our sample may limit comparisons to districts that use busing transportation or to districts which are more heterogeneous or better-resourced. Countering this limit to generalizability, however, we also consider that the lack of a bus schedule simplifies the interpretation of results of the change: when fewer variables need to be considered in the end results, we have more confidence that the start time delay was a potent reason for the changes seen at this school. Improvements to tardiness and decreased delinquent and disruptive behaviors cannot be related to problems in bus schedules because there are no bus schedules.

## CONCLUSIONS

The conclusions of our study suggest that a 45-minute delay in start times was initially associated with an increase in students' reported sleep length which was subsequently lost. A shift to a later sleep period was the only persistent change to *sleep* that we detected. This delay in the timing of the sleep period may, therefore, have been an important factor when considering the decreases to tardiness and improvements to disciplinary and behavioral problems that our study detected. However, the outcomes in which educators, students, and parents are often most interested in—attendance and academic performance—did not change. Importantly, the 20-minute change in total sleep time (at Wave 1 only) did not decrease sleepiness. Improving sleepiness may be the key to improvements in other domains, especially for younger children.[42] Without a change to sleepiness, changes in well-being that transcend the influence of individual differences may be difficult to realize. A further consideration for this district was the lack of "buy-in" expressed by many in the district itself to the delay in start time; the community was somewhat polarized around the issue. A longer and more comprehensive effort to educate and persuade the constituents of the multitude of benefits that can occur when sleep is improved in this age group may have resulted in more gains across other domains we examined. Although a start time delay is the first—and necessary—step to improved sleep health, clearly a delay in start time alone may not be sufficient to achieve the kinds of changes to student performance and well-being that are the targets for changes to school schedules.

In summary, a school district's decision to delay start times should include an appreciation for the significant and persistent improvements that will likely occur in tardiness and disciplinary problems in the school, and an awareness of the range of benefits that may accrue when students achieve *longer* sleep, as well as better *quality* sleep. These changes are meaningful with respect to the safety, morale, ease and efficiency of operation for most school systems: when students are delinquent and aggressive, late and insubordinate, learning cannot occur. Improvements in other domains, however, may be predicated on the students' awareness of the benefits of longer sleep, the severity of sleep deprivation that individual students experience, chronotype preference, and other variables, which will interact with each other and with the possible individual differences in sleep need that each student experiences.

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