Stress and Sleep Across the Onset of the COVID-19 Pandemic: Impact of Distance Learning on U.S. College Students' Health Trajectories

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Abstract

Study Objectives. This study examined associations between average and intraindividual trajectories of stress, sleep duration, and sleep quality in college students before, during, and after transitioning to online learning due to the COVID-19 pandemic.

Methods. One hundred and sixty-four first-year college students answered twice-weekly questionnaires assessing stress exposure and perception, sleep duration, and sleep quality from January until May, 2020 (*N*=4,269 unique observations).

Results. Multilevel growth modeling revealed that prior to distance learning, student stress was increasing and sleep duration and quality were decreasing. After transitioning online, students' stress exposure and perception trajectories immediately and continuously decreased; sleep quality initially increased but decreased over time; and sleep duration increased but then plateaued for the remainder of the semester. Days with higher stress exposure than typical for that student were associated with lower sleep quality, and both higher stress exposure and perception at the transition were linked with simultaneous lower sleep quality. Specific groups (e.g., females) were identified as at-risk for stress and sleep problems.

Conclusion. Although transitioning to remote learning initially alleviated college students' stress and improved sleep, these effects plateaued, and greater exposure to

academic, financial, and interpersonal stressors predicted worse sleep quality on both daily and average levels. Environmental stressors may particularly dictate sleep quality during times of transition, but adaptations in learning modalities may help mitigate short-term detrimental health outcomes during global emergencies, even during a developmental period with considerable stress vulnerability. Future studies should examine longer-term implications of these trajectories on mental and physical health.

Keywords: COVID-19, Pandemic, College Students, Stress, Sleep, Ecological Momentary Assessment

Statement of Significance

This study used twice-weekly assessments from January to May 2020 to prospectively examine trends and associations between sleep quality, sleep duration, and stress in 164 U.S. college students before, during, and after transitioning to distance learning due to the COVID-19 pandemic. Students demonstrated better sleep quality, longer sleep duration, and decreased stress immediately upon transitioning online, but effects plateaued. Greater stress exposure was associated with worse sleep quality on daily and average levels across the semester. Given that sleep is a restorative process susceptible to stress and predictive of student academic trajectories and health, clinicians, universities, and administrators may learn from the global transition online and promote student sleep by monitoring unique stressors and benefits associated with distance learning.

Introduction

With over 24,000 cases confirmed in the United States by March 21, 2020 [1], the novel coronavirus disease 2019 (COVID-19) prompted lockdowns of social, academic, and industry gatherings in at least 42 states by late April [2]. Almost all U.S. universities transitioned to distance learning, limited student gatherings, and reduced in-person contact for students by mid-March in response to state-mandated Stay-at-Home orders, a strategy used to mitigate community spread of the virus. Students faced immediate dormitory closures, job loss and financial strain, and suspension of in-person social activities inherent in young adult prosocial development [3], all while proceeding with expected academic obligations amid course-related confusion and frustration with coursework delivery [4]. The established consequences of social withdrawal on emerging adult well-being [5, 6], coupled with the COVID-19 pandemic's social distancing requirements and ensuing restrictions in learning environments, created a potential compounded vulnerability to problems in students' stress and sleep [7], two determinants of health that are particularly susceptible to biopsychosocial and contextual influences [8]. However, there is a dearth of longitudinal literature substantiating claims of the detrimental effects of the COVID-19 pandemic and the sudden transition to online learning on college student sleep and stress, despite the fact that both sleep and stress are critical mediators of mental well-being [9], and mental health problems in college students are prevalent prior to and since the beginning of the pandemic [10-12]. Cross-sectional studies have found both negative and positive stress and sleep outcomes in university students and adults after Stay-at-Home orders were enacted [13, 14], but longitudinal research has yet to demonstrate trajectories and interactions of these health indicators in college students before and after the onset of the pandemic's residual effects on learning modalities. In line with calls for attention to college student mental health in the COVID-19 pandemic [15, 16], this study used an intensive ecological momentary assessment

design to uncover how the transition to remote learning in the context of the pandemic may have altered intra-individual trends in college students' self-reported stress exposure, stress perception, sleep duration, and sleep quality, in addition to examining the covariation between average and intra-individual trends in stress and sleep across the semester of pandemic onset.

Sleep and Stress in College Students

Older adolescence, which often precedes the transition to college in the United States, is a developmental period characterized by unique susceptibility to biopsychosocial and contextual influences on sleep [8]. Although adolescents require about 9 hours of sleep [17, 18], later bedtimes and slower accumulation of sleep pressure are normative in as youth get older [19, 20], conflicting with the inherent demands of entering college during young adulthood. Sleep quantity [21] and quality improve overall across the emergence into adulthood and the transition to college, but students still sleep below developmental recommendations [22], almost 40% of college students report poor sleep quality on a regular basis, and first-year students experience the shortest sleep duration – particularly on weekdays (as opposed to weekends) – compared to upperclassmen [23, 24]. Indeed, both sleep quality and duration in college students typically improve on the weekends [24-26], potentially implicating school-related stressors or demands during the week as determinants of worse sleep across the transition to college. Truncated sleep duration and poorer subjective sleep quality in young adults in college are consequently directly and bidirectionally linked with greater depressive and anxiety symptoms [22] and poorer psychosocial functioning [27], and directly linked with worse academic performance [28].

Sleep is closely linked with stress, in that they function as opposing processes in a fluctuating cycle of arousal [29]. Where stress represents an increase in arousal and responsivity to environmental demands, sleep is a restorative process that occurs in the

parallel context of low arousal, but both processes are regulatory mechanisms that respond to an individual's biopsychosocial and contextual state [8]. Each are subject to dysregulation as a result of simultaneous problems with the other: one of the body's primary stress-regulation systems – the hypothalamic pituitary adrenal (HPA) axis – is a potential mechanism linking sleep and stress, the diurnal pattern of which oscillates opposite the sleep-related circadian rhythm. Deviations in HPA axis functioning as a result of acute or chronic stress may interrupt the body's ability to initiate and maintain sleep homeostasis [30, 31]. In turn, sleep difficulties negatively affect next-day cognitive and behavioral functioning, thus lowering an individual's distress tolerance and increasing sensitivity to stress exposure [32, 33].

Self-reported stress has been examined as a predictor of concurrent sleep quality and sleep duration in college students [23, 34, 35], and prior-night sleep problems likewise are linked with heightened next-day stress [36]. Delineating definitions of stress and their varying interactions with sleep in college students is key to understanding stress-sleep transactions: overall emotional responses to stress (i.e., stress *perception* [37]) may particularly influence sleep *quality*, which may better predict short-term physical and emotional health compared to sleep quantity [38]. Conversely, the presence of environmental stressors (i.e., stress *count or exposure*) may negatively affect sleep quantity or *duration* [39], a process that is likely linked with more long-term health outcomes [40]. Ecological momentary assessment studies (EMA), which involve repeated sampling of subjects' experiences in their natural environments to reduce recall bias and augment ecological validity [41], allow researchers to evaluate such isolated and transactional changes in sleep and stress on the individual- and group-level. Prior EMA studies reveal within-person patterns in students, such that greater daily stress exposure than what is typical for an individual was associated with shorter sleep duration *and* poor sleep quality, which in turn predicted greater subsequent stress [42]. Similar bidirectional models using daily diary

methods also link less sleep with prior day stressful demands and next-day increases in anxiety, depressive feelings, and fatigue [43], and poor quality sleep with more stressors the next day [44]. No study to date, to our knowledge, has isolated the potentially distinct interactions of stress exposure versus stress perception with sleep in the broader context of the global COVID-19 pandemic.

Large-scale studies *prior* to the COVID-19 pandemic reported that rates of anxiety, depression, and suicide were rising across college campuses, the prevalence of which may reflect increasing rates of academic, interpersonal, and financial stress, as well as sleep problems, among college students [45]. Thus, examining sleep and its biopsychosocial correlates (e.g., stress) during a time in which college students are being asked to drastically adjust their academic and interpersonal routines becomes imperative.

Sleep and Stress in College Students During the COVID-19 Pandemic

The COVID-19 pandemic has introduced novel challenges to managing both stress and sleep, but the majority of research to date has focused on cross-sectional, post-pandemic-onset designs in countries outside of the United States. International cross-sectional studies of adults [46, 47] and university students [13, 48, 49] confirm predictions of lower sleep quality, increased time in bed, delayed sleep time, and higher rates of insomnia after the onset of the pandemic, with some linking such sleep difficulties to greater concurrent stress [47]. However, such cross-sectional designs are unable to determine whether these changes represent true increases from pre-pandemic experiences, nor do they capture the timing and fluctuations of changes in stress or sleep. Longitudinal designs have the potential to provide causal inferences (as long as findings meet assumptions [50, 51]), but such paradigms that capture trends before and after the onset of the COVID-19 pandemic are currently sparse, particularly in young adult samples. Longitudinal studies of adults demonstrate mixed patterns, including increased objectively-measured sleep duration but decreased sleep quality

among older, predominantly male adults in France [52]; and unchanged and even improved sleep quality after the height of the pandemic, but worsened sleep quality in those with greater stress in the United States [14]. Studies of college students before and after the onset of COVID-19 have similarly found increased sleep duration after Stay-at-Home orders [53, 54] along with potentially unchanged sleep quality on average, but increased likelihood of depression among those with poor sleep quality [55], similar to cross-sectional studies linking sleep quality with depression and anxiety in young adults during the pandemic [56].

College students in the U.S. notably cite the transition to distance learning and social isolation as particular sources of stress after the start of the pandemic [57]. Indeed, distance learning has been shown to generate feelings of isolation even prior to the pandemic [58]. This attribution aligns with prior research elucidating the biopsychosocial consequences of social connection on both sleep and stress during transitional periods: young adults in their first year of college reporting greater daily social connection experienced next-day benefits in their HPA axis functioning (i.e., more robust cortisol awakening response), and within-person increases in daily social connection were associated with longer time spent in bed and more actual time asleep among those who scored high on trait-loneliness [5]. Similarly, sleep quality suffers during months when first-year college students see fewer friends [59]. As states enacted Stay-at-Home orders and universities shifted to online learning around mid-March 2020, college students were systematically restricted from seeing peers in classes, attending large gatherings, or even spending time with individual friends indoors, all activities that promote emotional and physical well-being, particularly during the emergence into adulthood [60, 61]. Students' sleep might have also suffered from increased exposure to their computers' blue light throughout the day [62], and both stress and sleep might have been particularly negatively impacted among those with attentional difficulties [63] or without substantial access to technological resources or adequate space. However, students

simultaneously experienced reductions in commuting time to class, fewer late-night social gatherings, and potentially fewer social stressors, providing more opportunities to go to bed earlier and get better quality sleep. Thus, the combination of social withdrawal and simultaneous environmental flexibility introduced by the shift to online learning may engender complex interactions of both global and day-to-day sleep and stress experiences among young adults, compounding both benefits and risks for long-term health repercussions among a significant portion of the future U.S. workforce.

Importantly, most studies of stress and sleep during the COVID-19 pandemic are limited to *between*-individual differences, but identifying *within*-individual changes is key to understanding sources of variation in a sample. Ecological momentary assessment studies can offer insight into how stress and sleep may be a function of time and intra-individual (i.e., observed within the same person across different times or situations) differences. Although sleep is considered a key restorative and regulatory mechanism for both daily and long-term mental and biological functioning [8, 29], and its interactions with stress exposure may exacerbate existing mental health and academic problems [31], no studies, to our knowledge, have demonstrated whether the sudden transition to online learning during the COVID-19 pandemic amplified trajectories of stress perceptions; financial, academic, and interpersonal stressors; and respective changes in sleep duration and quality in college students. In addition, no studies, to date, have examined whether sleep and stress patterns interacted across the semester of pandemic onset on both between- and within-person levels.

The Present Study

Leveraging diary data pre- and post-the transition to online schooling due to pandemic-related policy changes during the first year of college, the first aim of this study was to describe the overall trajectories of stress exposure and sleep across an academic semester, including before, during, and after transitioning online. We anticipated the

following: (*Hypotheses 1a and 1b*) stress exposure and stress perception would increase across the semester, with a marked increase in both stress outcomes immediately after the transition to school online [12, 64]; (*Hypothesis 2*) sleep quality would decrease across the semester [26], but there would be a marked decrease in sleep quality after the transition to school online [46], given that sleep quality in young adults might be particularly susceptible to the inherent social withdrawal associated with distance learning during a pandemic [56, 59]; and (*Hypothesis 3*) sleep duration would decrease across the semester [26] with a marked increase in sleep duration after the transition to school online [13, 53, 65], due to Stay-at-Home orders' reduction in environmental and social demands that typically require young adults to stay up late or get up early.

The second aim was to examine the covariation between stress and sleep to explore both within- and between-person associations across the semester and account for the transition to online schooling. Within-person analyses explored whether nights following greater stress count than usual were characterized by worse sleep quality and shorter sleep durations for each individual. Accounting for linear trajectories and the shift to online learning, (*Hypothesis 4*) we expected a negative within-person association between number of stressors and sleep quality and duration, as well as between stress perception and sleep quality and duration, such that on days when an individual reported more stressors or greater stress perception than was typical for them, they experienced lower sleep quality [14] and fewer sleep hours [66]. At the between-person level, we explored whether individuals who experienced more stress overall had worse sleep quality and lower sleep durations as compared to those who reported fewer stressors or lower perceptions of stress. Accounting for linear trajectories and the shift to online learning, we hypothesized (*Hypothesis 5*) a negative association between overall stress count and sleep parameters, such that individuals who reported more stressors over the semester would experience lower sleep quality and

shorter sleep duration [23]. (*Hypothesis 6*) We hypothesized similar direction of effects as stress count for the associations between overall stress perceptions and sleep quality and duration.

Methods

Participants

Two hundred and fifty-two incoming first-year undergraduate college students (54% female, M_{age}=19.7, SD=0.62) at a large Southwestern public university in the United States were recruited during the university's freshmen orientation and consented to a study examining daily and overall changes in identities and behaviors (e.g., stressors and other health-related behaviors) across the transition to college during the summer prior to beginning the academic year of 2019-2020. The 212 (84%) participants who fully completed the initial baseline survey were invited to participate in twice-weekly questionnaires. Individuals were excluded if they withdrew from the university (n=1), withdrew from select study procedures (n=5), or did not respond to any twice-weekly survey (n=5), resulting in 201 students who completed any diary questionnaire, with 164 participants who provided data of interest (i.e., answered stress and sleep variables in diary report) during the analytic window (January-May 2020). Eighty percent of participants were living in university housing (e.g., dorm) in the beginning of the Spring 2020 semester, compared with 15% living with parents and 6% living with other relatives, family friends, alone, or with friends in an apartment. Participants represented a diverse distribution of socioeconomic status and race/ethnicity (see Table 1), the proportions of which were similar to the university from which they were recruited.

Procedure

The university and funder institutional review boards approved all procedures. Participants provided written consent (from self or parent if under age 18) prior to participation. Participants were asked to complete a baseline questionnaire assessing demographic variables from June 5th to August 15th, 2019, and an additional survey between December 11th, 2019 and February 9th, 2020 assessing living situation. Beginning January 1st until May 6th, 2020, a total of 37 short (4-5 min.) twice-weekly online questionnaires assessing sleep duration, quality, and stress were sent on Sunday and Wednesday afternoons (*N*=4,317 unique observations; mean surveys completed per participant=25.95, *SD*=12.55). Participants were given 24 hours to respond and were sent regular text reminders to maintain compliance (mean response rate per survey period=57.8%, *SD*=3.24%). Survey responses that did not include answers about stress or sleep were excluded from analyses (48 survey responses out of 4,317 total surveys received; 1.1%). Thus, a total of 4,269 surveys from 164 participants were included in final analyses.

Measures

Sleep. In twice-weekly short surveys across the semester, participants reported the approximate time (hour and minute) they fell asleep the previous night and woke up that morning in relation to the session that they answered the questionnaire (i.e., for Sunday questionnaires, participants were asked to report Saturday night bedtime and Sunday morning wake time), which was used to calculate sleep duration. Sleep quality was assessed using five questions asking how participants slept last night, how refreshed they felt when they woke up that morning, how soundly they slept last night, how closely their sleep met their expectations for last night, and how easy it was to wake up that morning. Questions were framed in a day-specific format, referring to the same night as the sleep duration questions, and adapted from the Karolinska Sleep Diary, a standardized diary measure of self-reported sleep quality [67].

Participants responded to each question using a Likert scale ranging from 1 to 10 (10 being the best). A total mean score of sleep quality was calculated using responses to all five questions. Higher scores indicated better sleep quality (α=.90).

Stress Count. Participants were asked whether they experienced different stressors since the last survey period (e.g., if they were filling out the Sunday survey, they reported the stressors that applied to them since last Wednesday). The list of stressors included 12 common stressful events: feeling pressured by a partner, friends, or parents; arguments with a partner, friends, or parents; and worries about money, getting drunk, using drugs, exercising, how they look, or academic performance. Questions were adapted from the Adolescent Perceived Events Scale [68]. Exposure to greater daily hassles such as these is a common way to measure stress levels and has been linked with college student adjustment [69] and general health outcomes in both retrospective and ecological momentary assessment studies [70]. Adaptation to shorter forms using representative items is common for momentary assessment studies in order to reduce participant burden [41]. Higher stressor count indicated greater perceived exposure to stressors in that survey period.

Stress Perception. To assess stress *perceptions* (i.e., as opposed to number of stressors [37]) in diary surveys, participants were asked to report qualitatively on "the most stressful situation or event you encountered today" and subsequently report on, "How stressful was this event today (Sunday/Wednesday)?" Responses ranged from 0 (*not stressful at all*) to 10 (*extremely stressful*).

Transition to Online Schooling. A binary dummy code for school-in-person (0; January 1st through March 11th) versus school-online (1; March 12th through May 6th) reflected the timing of the email announcement that the university would be requiring remote learning for the remainder of the semester on the evening of March 11th, 2020. This indicator was used to represent the first tangible transition for university students in this southwestern

state, as infection rates did not peak in the state until late June [1]. The date of transition also coincided with the declaration of a statewide public health emergency (albeit with no restrictions on gatherings or access to public facilities enacted) on March 12th [71], and on March 30th, the state's governor declared a statewide closure for all schools with the option to finish the school year online, but the focal university had already enacted distance learning for the remainder of the semester on the evening of March 11th. It should be noted that students at this focal university were allowed to remain in residential halls during this period but had the option to move out (and receive monetary compensation if they chose to do so), the deadline of which was April 15th, 2020.

Covariates. Gender (0=male, 1=female), socioeconomic status, race/ethnicity, living situation (assessed between December 2019 and February 2020; 0=living with parents/relatives/family friends, 1=living on own/in apartment/university housing/other), and weekday/weekend differences [24, 53] were included as covariates. Socioeconomic status was a mean composite variable of parental education level, perceived socioeconomic class, and measures of Family Economic Hardship (α=.84) [72]. To account for potential disparities in the effects of the COVID-19 pandemic on individuals of color in the United States [73], race/ethnicity was coded as two dummy variables representing the largest non-White racial/ethnic subgroup in the present sample (Hispanic race/ethnicity) and non-Hispanic/non-White race/ethnicity, where all other racial/ethnic groups (not White or Hispanic) were coded as 1. White participants were coded as 0 for both dummy variables.

Data Analysis

Longitudinal sleep and stress data were analyzed in *Mplus* version 8.3 [74] using multilevel models to account for the dependency in the data due to their longitudinal nature. Missing data were handled using full information maximum likelihood estimation (FIML) [75]. Model 1 included Stress Count, Sleep Quality, and Stress Duration outcomes of interest,

whereas a separate model (Model 2) included Stress Perception, Sleep Quality, and Sleep Duration as outcomes of interest. Level-1 and level-2 models were run for each model. The level-1 equation in the multilevel model for each construct was specified as

$$y_{ti} = b_{0i} + b_{1i} \cdot month_{ti} + b_2 \cdot online_{ti} + b_3 \cdot month_{ti} \cdot online_{ti} + b_4 \cdot wkday_{ti} + e_{ti} \quad (1)$$

where y_{ti} is the outcome of interest (e.g., Sleep Quality, Sleep Duration, Stress Count or Perception) measured at assessment t for case i, $month_{ti}$ is the number of months relative to March 11, 2020 (the evening of which students were informed of transition to online learning), $online_{ti}$ is a binary variable that indicates whether the observation took place before ($online_{ti} = 0$) or after ($online_{ti} = 1$) the university moved to an online format, and $wkday_{ti}$ is a binary variable that indicates whether the observation took place on a weekday ($wkday_{ti} = 1$) or a weekend day ($wkday_{ti} = 0$). The model parameters have the following interpretations: b_{0i} is the random intercept and represents the expected outcome score for case i at the time of the transition to online schooling, b_{1i} is a random slope and represents the rate of change for case i prior to the transition to online school, b_2 is a fixed slope and represents the immediate effect of the transition to online school, b_3 is a fixed slope and represents the effect of the transition to online school on the random slope b_{1i}, b_4 is a fixed slope and represents the difference in the outcome when the survey was completed on Wednesday versus Sunday, and e_{ti} is the residual assessment t for case i that is assumed to be normally distributed with a zero mean and estimated variance.

The level-2 equation for this model was specified as

$$\begin{aligned} b_{0i} &= \beta_{00} + \beta_{01} \cdot female_i + \beta_{02} \cdot NonWH_i + \beta_{03} \cdot Hisp_i + \\ &\quad \beta_{04} \cdot liv\_ind_i + \beta_{05} \cdot SEScomp_i + d_{0i} \\ b_{1i} &= \beta_{10} + \beta_{11} \cdot female_i + \beta_{12} \cdot NonWH_i + \beta_{13} \cdot Hisp_i + \\ &\quad \beta_{14} \cdot liv\_ind_i + \beta_{15} \cdot SEScomp_i + d_{1i} \end{aligned} \quad (2)$$

where $female_i$, $Hisp_i$, $NonWH_i$, and liv_ind_i are binary variables indicating the sex of the participant, whether the participant is Hispanic, Non-White and Non-Hispanic, and whether the participant is living independently, and $SEScomp_i$ is the socioeconomic status composite variable. The level-2 parameters indicate the effects of these variables on the level of outcome during the transition to online school and the rate of change in the outcome. The level-2 disturbances (d_{0i} and d_{1i}) are assumed to be normally distributed with zero means, estimated variances, and covariance. Multivariate models were estimated to allow for the estimation of correlations between level-1 residuals (e_{ti}) indicating within-person associations between Sleep Quality, Sleep Duration, and Stress Count (or Stress Perception in Model 2), and correlations between level-2 disturbances (d_{0i} and d_{1i}) indicating between-person associations between Sleep Quality, Sleep Duration, and Stress Count or Stress Perception.

Results

Table 1 presents descriptive statistics. A total of 164 participants completed questions related to this study's primary variables in their twice-weekly diary reports: 160 participants completed 2,410 surveys (56.5%) before the transition online, and 144 participants completed 1,859 surveys (43.5%) after the transition online. One hundred and forty participants completed at least one survey both before and after the transition online (*M*=26 surveys total per participant; *SD*=12.6).

Aim 1

Level 1 — Within-individual trajectories.

Sleep quality and duration estimates were consistent in direction, magnitude, and statistical significance across Model 1 and Model 2. Results for stress count, sleep quality, and sleep duration trajectories were examined in Model 1 and are reported below. Fixed and random effect parameters of the unconditional models for Model 1 are found in Table 2.

Stress perception, sleep quality, and sleep duration trajectories were examined in Model 2, and Table 3 presents fixed and random effect parameters of the unconditional models. Figure 1 presents univariate trajectories across the semester.

Stress Count. Stress count was lower on weekdays compared with weekends (b=-.091, p<.01). Prior to the transition to online learning, stress was increasing, on average (b=.175, p<.01). When the university went online, stress decreased significantly (b=-.305, p<.001). The change in the slope after the transition online was significant (b=-.203, p<.001), such that average stress count was fairly constant after the transition to online learning (i.e., slope after transition was b=-.028, p=.54).

Stress Perception. Full results for Model 2 are in Table 3. Findings for sleep quality and sleep duration in Model 2 were consistent with Model 1 values. Level-1 within-individual trajectories of stress perceptions were consistent with stress count trends with respect to both direction and significance: prior to the transition to online learning, stress perception was increasing, on average (b=.676, p<.01). When the university went online, stress perception decreased significantly (b=-.493, p<.001), and the change in the slope after the transition online was negative (b=-.508, p<.001), such that average stress perception was continuing to increase but at a smaller magnitude after the transition (b=.168, p<.05). Weekend and weekday differences were not significant (b=-.024, p=.666).

Sleep Quality. Sleep quality was lower on weekdays as compared to weekends (b=-.157, p<.01). Prior to the transition to online learning, sleep quality did not change significantly, on average (b=.007, p=.91). When the university went online, sleep quality significantly improved (b=.418, p<.001). However, thereafter, the change in slope after the transition online was significant, such that the average sleep quality decreased over time (b=-.276, p<.01).

Sleep Duration. Overall sleep duration was lower on weekdays as compared to weekends (b=-.421, p<.001). Prior to the transition to online learning, sleep duration was significantly decreasing (b=-.125, p<.05). When the university went online, sleep duration increased significantly (b=.528, p<.001). The change in slope after the transition online was positive but not significant (b=.022, p=.80).

Level 2 — Covariates.

At the online transition, females reported greater stress count (b=.519, SE=.251, p<.05), whereas individuals identifying as non-White/non-Hispanic reported lower stress counts (b=-.877, SE=.274, p<.01). Females also experienced worse sleep quality (b=-.718, SE=.241, p<.01), but individuals reporting higher socioeconomic status reported better sleep quality (b=.374, SE=.175, p<.05). Living situation (i.e., living on one's own/in an apartment/on campus) was positively correlated with sleep duration (b=.519, SE=.186, p<.01). In Model 2 with stress perception as the stress outcome of interest, females experienced greater perceptions of stress at the online transition (b=.915, SE=.301, p<.01), and students reporting higher socioeconomic status experienced lower perceptions of stress at the online transition (b=-.697, SE=.215, p<.01). Participants who were living on their own, in an apartment, or in university housing experienced a significant decrease in stress perception across the semester (b=-.291, SE=.123, p<.05). None of the other covariates predicted changes in stress exposure or perception, changes in sleep quality, or changes in sleep duration across the study period.

Aim 2

Tables 4 and 5 present model variances and covariances at within- and between-individual levels for Models 1 and 2 respectively.

Within-individual associations. At the within-individual level, we report covariances between stress count, sleep quality, and sleep duration from Model 1. Higher stress count than was typical for an individual was significantly associated with lower sleep quality (c=-.073, p<.01), and longer sleep duration than usual was associated with greater sleep quality (c=.674, p<.001). The covariation between stress count and sleep duration was not significant (c=-.009, p=.72). In Model 2, within-individual associations between stress perception and sleep quality (c=.036, p=.425) and sleep duration were not significant (c=-.029, p=.552).

Between-individual analysis. At the between-individual level, we also report covariances for the associations between sleep quality, sleep duration, stress count, and their changes from Model 1. Participants with greater sleep duration at the online transition tended to have less decrease in sleep duration over the observation period (c=.057, p<.01). Participants reporting greater stress count at the online transition tended to report lower sleep quality at the transition (c=-.538, p<.01), but stress count at the online transition was not significantly associated with the slope of sleep quality, nor was it associated with sleep duration at the online transition (i.e., intercept) or with the rate of change in sleep duration across the semester (i.e., slope; see Table 4 for exact estimates). Participants with higher sleep quality at the online transition tended to have greater sleep duration at the online transition (c=.262, p<.05). Between-individual associations for stress perception from Model 2 were consistent with stress count models in both direction and statistical significance, such that participants reporting greater stress perception at the online transition tended to report lower sleep quality at the transition (c=-.939, p<.001), but no other associations between stress perception and sleep intercepts and slopes were significant (see Table 5).

Discussion

This study is the first, to our knowledge, to leverage intensive longitudinal data and multilevel growth models to identify sleep problem and stress trajectories, and the associations between these trajectories, in college students prior to, during, and after the transition to online learning associated with the COVID-19 pandemic. Findings revealed varying short- and longer-term trends after transitioning online, notably demonstrating overall short-term improvements in sleep and stress, but worse quality sleep after greater stress count on both daily levels across the semester and average levels at the online transition. In addition, worse average quality sleep at the online transition was associated with greater average *perceptions* of stress at the transition. Given U.S. first-year college students' attribution of online learning as a key stressor during the onset of the pandemic [57] – but the potential for distance learning to reduce daily environmental demands (e.g., commuting to class, late-night gatherings) – accommodations of learning methodologies during global crises may have contributed to ameliorating *immediate* student sleep health and stress experiences, but overall long-term trends in sleep quality, in particular, should be contextualized by students' individual exposures to stress.

The first goal of our study was to examine stress, sleep quality and sleep duration before, during, and after the transition to online learning. Trajectories of stress count, stress perception, and sleep duration *prior* to the transition online were consistent with our hypotheses and research on normative trends across an academic semester [26, 76]. Further in line with hypotheses, sleep duration increased once the university announced remote learning; however, it then plateaued (rather than decreased, as hypothesized) as the semester continued, indicating an initial and long-term potentially promotive association between the transition to remote learning and the ability to get more sleep, perhaps due to less time spent commuting and fewer evening social gatherings as a result of statewide restrictions. Exposure

to stress experiences, as well as perceptions of stress experiences, also demonstrated short-term reductions after the transition online, and both stress parameters continued to increase at significantly *lower* magnitudes as school continued online compared to the beginning of the semester, contradicting our hypotheses and suggesting that remote learning and the onset of the pandemic may have coincided with a reduction of academic, financial, and interpersonal stress – as well as lower perceptions of stress – in college students both immediately and over the proceeding academic semester online. The finding that stress count during weekdays was lower than on weekends overall was unexpected, particularly given that students did not report differences in stress *perception* across the week. Such changes in stress exposure, in particular, could reflect heightened exposures to familial, interpersonal, or financial stressors over the weekend; an apparent shift in weekend expectations from normative weekend activities to social isolation during the pandemic's restrictions; or changes in routine to prepare for the beginning of the week.

Although sleep quality did not demonstrate marked decreases prior to the transition online as expected, it decreased during the latter half of the semester. Sleep quality initially improved after the transition online, contrary to our predictions but accordant with recent findings of improved sleep quality in a small sample of high school students after transitioning online [77]. Such short-term increases in sleep quality may have represented the novelty of having a break from everyday academic and social demands, but the long-term decreases in sleep quality, which ultimately regressed to pre-pandemic levels, may have also coincided with end-of-semester final projects and exams, an accumulation of typical daily demands in addition to simultaneous increases in local COVID-19 cases, or a natural adaptation to socially-distant lifestyles and remote learning.

Findings from the first aim of our study support preliminary evidence that the onset of the pandemic significantly altered sleep and stress experiences [78]; however, we illuminate

the potentially adaptive consequences of remote learning during the pandemic among college students, findings which may aid in monitoring and mitigating future mental health crises in the COVID-19 era and beyond [15]. These results build off of biopsychosocial and contextual models of sleep [8], revealing that certain deviations in the expected cycle of young adult circadian and homeostatic rhythms may result from widespread changes in daily routine (e.g., distance learning) and societal changes (e.g., global pandemic). Indeed, we corroborate cross-sectional findings suggesting that rates of stress and sleep problems were high during the onset of the pandemic [13, 47-49], but our findings offer a pre-pandemic point of comparison centered at the transition to online learning, elucidating how stress and sleep problems may *not* necessarily have *increased* among college students, and previously increasing trends of stress exposure, stress perception, and sleep duration prior to pandemic onset may have actually improved after transitioning online. Health professionals and university administrators should note that adapted learning with remote options during a global crisis may have both short- and long- term benefits on students' stress exposure, stress perception, and sleep duration; however, maintaining good *quality* sleep, in particular, may not be sustainable as the repercussions of crises (e.g., cases and deaths due to COVID-19) increase [1] and students take classes online without necessary peer interactions and support [59].

The second goal was to examine intraindividual and average associations between stress and sleep over the five-month period. Our hypotheses of within-individual associations were partially supported: periods with higher stress exposure were associated with worse subsequent sleep quality. We also found that days with high sleep quality were also linked with simultaneous longer sleep duration. Surprisingly, we did not find any significant within-individual associations between sleep and stress *perception*, perhaps indicating that daily changes in exposures to stress experiences are more robustly associated with indicators of immediate sleep. Between-individual differences also supported our hypotheses: higher stress

exposure and perception were associated with worse sleep quality at the online transition. Sleep quality and duration at the transition were also positively associated. However, the absence of an association between stress exposure or perception and sleep duration at both within-and between-individual levels across the semester conflicted with our predictions. These findings may be attributed to differential or quadratic sleep duration trends [79] in response to general or daily stress, such that some students might sleep more or less in response to stress. In addition, some research has shown that sleep quality – but not necessarily quantity – is associated with next-day HPA axis stress response [80]. We also note that, after Mid-March, the transition to online learning may have resulted in a diminution of environmental restrictions (e.g., accountability to be on time for class) that would obstruct sleep duration, such that sleep quality would suffer more than duration in response to stress in this context. Together, within- and between-individual results indicate that stress on both a daily and average basis, centered at the online transition, is associated with insufficient sleep quality in first year college students during and across the onset of the COVID-19 pandemic.

Public Health Implications. Transitioning to online learning and related changes in environmental, social, and academic demands may have unintentionally contributed to buffering student stress and sleep patterns for a short period during the COVID-19 pandemic. However, in line with other studies [15, 78], we encourage caregivers, administrators, and peers to be aware of the long-term negative impact of social isolation and stress on sleep quality, in particular. Attention should be paid to the significant daily and average effects of stress *exposure* on sleep quality – compared with stress *perception's* effects on average sleep quality only. Specifically, cognitive or behavioral interventions targeting individuals' appraisals of stressful events (i.e., stress perception) during the shift to online learning (or during a global crisis) may help with students' overall sleep quality, but exposures to

academic, financial, interpersonal, and environmental stressors – which are often influenced by sociocultural factors (e.g., socioeconomic status, familial emphasis on academics) beyond an individual's control – may be particularly detrimental to college students' daily and overall sleep health. Given our findings that the transition online was associated with a reduction in exposure to some environmental stimuli (e.g., social or academic pressures), universities and institutions interested in promoting students' long-term sleep quality may consider flexibility in learning modalities as a useful tool for reducing stress and promoting sleep health, particularly during times of global stress. In addition, given significant findings that stress exposure (rather than stress perception) was linked with sleep quality on multiple levels, universities and institutions may also consider structural reforms (e.g., financial aid, programs with psychoeducation on healthy relationships) to provide opportunities to reduce daily stress exposures.

In addition, specific student demographics are particularly at-risk for detrimental outcomes. While non-White/non-Hispanic ethnical/racial minority students reported fewer stressors overall, students who identified as female and students reporting lower socioeconomic status experienced increased stress perception and worse sleep quality at the transition to distance learning. Findings related to gender are consistent with prior literature highlighting increased stress and overall wellbeing vulnerabilities among female college students across the pandemic onset [16]. In addition, as almost 60% of college students report decreasing food security as a result of the COVID-19 pandemic (often due to employment and housing changes) [81], ongoing attention should be paid to the sleep health and stress experiences of students at-risk for significant financial concerns even after the pandemic. Leaders in universities and resource centers should consider these demographics when tailoring outreach and program development to support student mental health during and after

the COVID-19 era [16]. Further, students who were living on their own or in university/campus housing slept more overall than those living at home or with family. Although familial support during the COVID-19 pandemic has been linked with decreased anxiety and depression [82], living with family may introduce additional obligations (e.g., caretaking, assistance with schooling) that potentially obstruct students' abilities to get to sleep or sleep in. Thus, it is in the interest of professors, staff, families, and clinicians to consider a student's living situation during remote learning when setting expectations for class performance.

Limitations. Our study would be enhanced by objective measurements of sleep (e.g., actigraphy) rather than our use of self-report measures to reduce recall bias; however, subjective diary reports have been shown to be accurate when reporting certain sleep parameters (e.g., duration) [83]. In terms of our indicator of stress count, participants were asked to recall stress-related experiences across 2-3 days prior to their twice-weekly assessment which introduced the potential for recall bias. Although we adapted our measure from a validated survey to include common stressors experienced by young adults, our interpretation of stress count was potentially more closely reflective of the *types* of stress exposures rather than stress levels. In addition, while participants were asked to recall stress exposures across the most recent few days (i.e., "since the last survey"), they were asked to report sleep from the past night, and the timespan of stress experiences precluded the ability to establish directional associations between stress and sleep indicators. However, the stress *perception* variable assessing same-day stress confirmed stress count trends, strengthening our confidence in characterizing stress as a whole across the semester. Although the study design aimed to represent weekend and weekday differences and capture the broadest range of experiences by using Sunday and Wednesday questionnaires, our data were limited to the

same respective weekday and weekend day each week, thus potentially restricting our ability to better capture daily variability, particularly related to sleep duration and quality differences across the week [24]. Future long-term EMA studies may consider variable interval sampling throughout the week [41]. Furthermore, assessing student access to technology during the transition to remote learning, whether students have been diagnosed with COVID-19, have been experiencing COVID-19 related symptoms or COVID-19 related stress, or have had close relatives affected by COVID-19, would have provided more robust information regarding unique sources of stress during this time period. Although our sample was representative of university demographics, and the study likewise had large proportions of both Hispanic/Latino and White students, we had a small proportion of non-White and non-Hispanic ethnic/racial groups, and the sample was limited to students attending one large university in the U.S. Southwest, thus restricting our ability to generalize trends to different racial/ethnic groups and individuals living in states that were differentially impacted by COVID-19 in the pandemic (e.g., with earlier peak-rates of infections, such as states in the Northeastern region of the U.S.).

Of importance, this was the first study to intensively document and identify trajectories of both sleep and stress and their covariation in college students before and after the transition to online learning due to the COVID-19 pandemic. The transition to online learning may have coincided with ameliorated trends in student stress and sleep problems overall, but worse sleep quality during the transition online was associated with greater simultaneous academic, financial, and interpersonal stress, altogether qualifying prior predictions of the pandemic's negative biopsychosocial and contextual impacts on youth [7] and young adult sleep to include *both* positive and deleterious health outcomes in a population at-risk for sleep problems. Particular groups of students (e.g., females, lower

income) may be uniquely vulnerable to derivatives of the COVID-19 pandemic restrictions. Health professionals and leaders in higher education should aim to alleviate instances of increased stress and its associated sleep problems in college students during and after the COVID-19 era. Future studies should examine long-term implications of variations of stress and sleep and the extent to which these trends predict mental and physical health outcomes as students progress through a generational epoch of adapted online learning.

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Figures

Figure 1.

Univariate plots of stress count, stress perception sleep quality, and sleep duration trajectories during the Spring 2020 academic semester.

Caption: *Note:* Trajectories modeled using 37 survey periods (twice-weekly assessments from January 1st until May 6th, 2020). Shift in intercept and slope centered at the university's transition to online learning on March 11th, 2020.

Table 1. Summary of demographic information and study variable descriptive statistics.

Demographic summary	***n***	***%***
Gender		
Female	**98**	**59.8%**
Male	**65**	**39.6%**
Other	**1**	**.6%**
Race/ethnicity[a]		
White/European American	**116**	**70.7%**
Hispanic/Latino(a)/Latinx	**43**	**26.2%**
Mexican/Mexican American	**35**	**21.3%**
Asian/Indian/Asian American	**24**	**14.6%**
Black/African American	**14**	**8.5%**
Native American/Alaska Native	**6**	**3.7%**
Middle Eastern/Arab/Arab American	**5**	**3.0%**
Other	**1**	**.6%**
Perceived socioeconomic class[b]		
Upper/Upper-middle class	**51**	**31.1%**
Middle class	**80**	**48.8%**
Lower-middle/Working class	**32**	**19.5%**
Other/Unsure	**1**	**.6**

Study variables	***M***	***SD***	**Range**	**Correlations**		
				1	*2*	*3*
1. Overall stress count[c]	3.15	1.90	1.00 — 11.00	--		
2. Overall stress perception	5.48	2.75	0.00 — 10.00	.18*	--	
3. Overall sleep quality	5.97	2.22	0.00 — 10.00	-.13*	-.06*	--
4. Overall sleep hours (duration)	8.10	1.85	0.00 — 17.75	-.03*	-.05*	.24*

Note: Analytic *N*=164; 4,269 total completed surveys. [a]Participants reported multiple racial/ethnic groups, resulting in a proportion greater than 100%. [b]Socioeconomic status measured in analyses as composite of subjective family social class, parent education level, and Family Economic Hardship scale. [c]Overall stress count: number of stressors endorsed since the last survey. *, $p<.05$.

Table 2. Parameter estimates of the unconditional multilevel models for stress count, sleep duration, and sleep quality.

Parameters	**Stress Count** *b*(SE)	**Sleep Duration** *b*(SE)	**Sleep Quality** *b*(SE)
Fixed Effects			
Intercept, b_{0i}	3.365(.132)**	8.1(.096)**	5.998(.138)**
Rate of change prior to transition to online, b_{1i}	.175(.037)**	-.125(.053)*	.007(.056)
Immediate effect of transition, b_{2i}	-.305(.061)**	.528(.107)**	.418(.100)**
Effect of transition online on rate of change, b_{3i}	-.203(.051)**	.022(.089)	-.276(.083)**
Weekday, b_{4i}	-.091(.030)**	-.421(.053)**	-.157(.049)**
Random Effects			
Variances of between-individual random intercept, $b_{0i} \leftrightarrow b_{0i}$	2.369(.281)**	.533(.079)**	2.177(.265)**
Variances of between-individual random slope, $b_{1i} \leftrightarrow b_{1i}$	.060(.011)**	.016(.010)	.104(.020)**
Covariance between random intercept random slope, $b_{0i} \leftrightarrow b_{1i}$	-.063(.040)	.057(.020)**	-.016(.052)
Residual variance from within-individual, $e_{ti} \leftrightarrow e_{ti}$	.845(.020)**	2.829(.065)**	2.487(.057)**

Note: Analytic *N*=164; 4,269 total completed surveys. ↔, nondirective relationship/random effect such as a variance or covariance. *, significant parameter at $p<.05$; **, significant parameter at $p<.01$.

Table 3. Parameter estimates of the unconditional multilevel models for stress perception, sleep duration, and sleep quality.

Parameters	**Stress Perception** *b*(SE)	**Sleep Duration** *b*(SE)	**Sleep Quality** *b*(SE)
Fixed Effects			
Intercept, b_{0i}	6.228(.174)**	8.098(.096)**	5.994(.138)**
Rate of change prior to transition to online, b_{1i}	.676(.067)**	-.127(.053)*	.006(.056)
Immediate effect of transition, b_{2i}	-.493(.113)**	.529(.107)**	.419(.100)**
Effect of transition online on rate of change, b_{3i}	-.508(.094)**	.021(.089)	-.278(.083)**
Weekday, b_{4i}	-.024(.056)	-.421(.053)**	-.156(.049)**
Random Effects			
Variances of between-individual random intercept, $b_{0i} \leftrightarrow b_{0i}$	3.666(.456)**	.533(.079)**	2.180(.265)**
Variances of between-individual random slope, $b_{1i} \leftrightarrow b_{1i}$	.181(.033)**	.016(.010)	.105(.021)**
Covariance between random intercept random slope, $b_{0i} \leftrightarrow b_{1i}$	-.085(.091)	.056(.020)**	-.015(.052)
Residual variance from within-individual, $e_{ti} \leftrightarrow e_{ti}$	2.975(.070)**	2.828(.065)**	2.486(.057)**

Note: Analytic *N*=164; 4,269 total completed surveys. ↔, nondirective relationship/random effect such as a variance or covariance. *, significant parameter at $p<.05$; **, significant parameter at $p<.01$.

Table 4. Aim 2 unconditional model variances and covariances among stress count, sleep duration, and sleep quality.

a. Within-Individual Random Effects Variances and Fixed Effects Covariances

	Stress Count	Sleep Quality	Sleep Duration
Stress Count	.845(.020)**		
Sleep Quality	-.073(.024)**	2.487(.057)**	
Sleep Duration	-.009(.026)	.674(.047)**	2.829(.065)**

Note: Analytic *N*=164; 4,269 total completed surveys. Within-person effects while controlling for growth before, during, and after transition online. Diagonal elements indicate variances of Level 1 within-individual random-effects of each outcome; off-diagonal elements indicate fixed-effects covariances between within-individual outcomes (Level 2). *, significant parameter at $p<.05$; **, significant parameter at $p<.01$.

b. Between-Individual Random Intercept and Random Slope Variances and Covariances

	Stress Count Intercept	Stress Count Slope	Sleep Qual. Intercept	Sleep Qual. Slope	Sleep Dur. Intercept	Sleep Dur. Slope
Stress Count Intercept	2.369(.281)**					
Stress Count Slope	-.063(.040)	.060(.011)**				

Sleep Qual. Intercept	-.538(.204)**	.038(.039)	2.177(.265)**			
Sleep Qual. Slope	.071(.056)	-.012(.010)	-.016(.052)	.104(.020)**		
Sleep Dur. Intercept	-.022(.106)	-.006(.020)	.262(.104)*	-.010(.028)	.533(.079)**	
Sleep Dur. Slope	.031(.039)	-.010(.007)	.053(.036)	.017(.010)	.057(.020)**	.016(.010)

Note: Analytic *N*=164; 4,269 total completed surveys. Diagonal elements indicate variances of random intercept and random slope for each outcome variable; off-diagonal elements indicate covariance between random intercept and random slope for each process. *, significant parameter at $p<.05$; **, significant parameter at $p<.01$.

Table 5. Aim 2 unconditional model variances and covariances among stress perception, sleep duration, and sleep quality.

a. Within-Individual Random Effects Variances and Fixed Effects Covariances

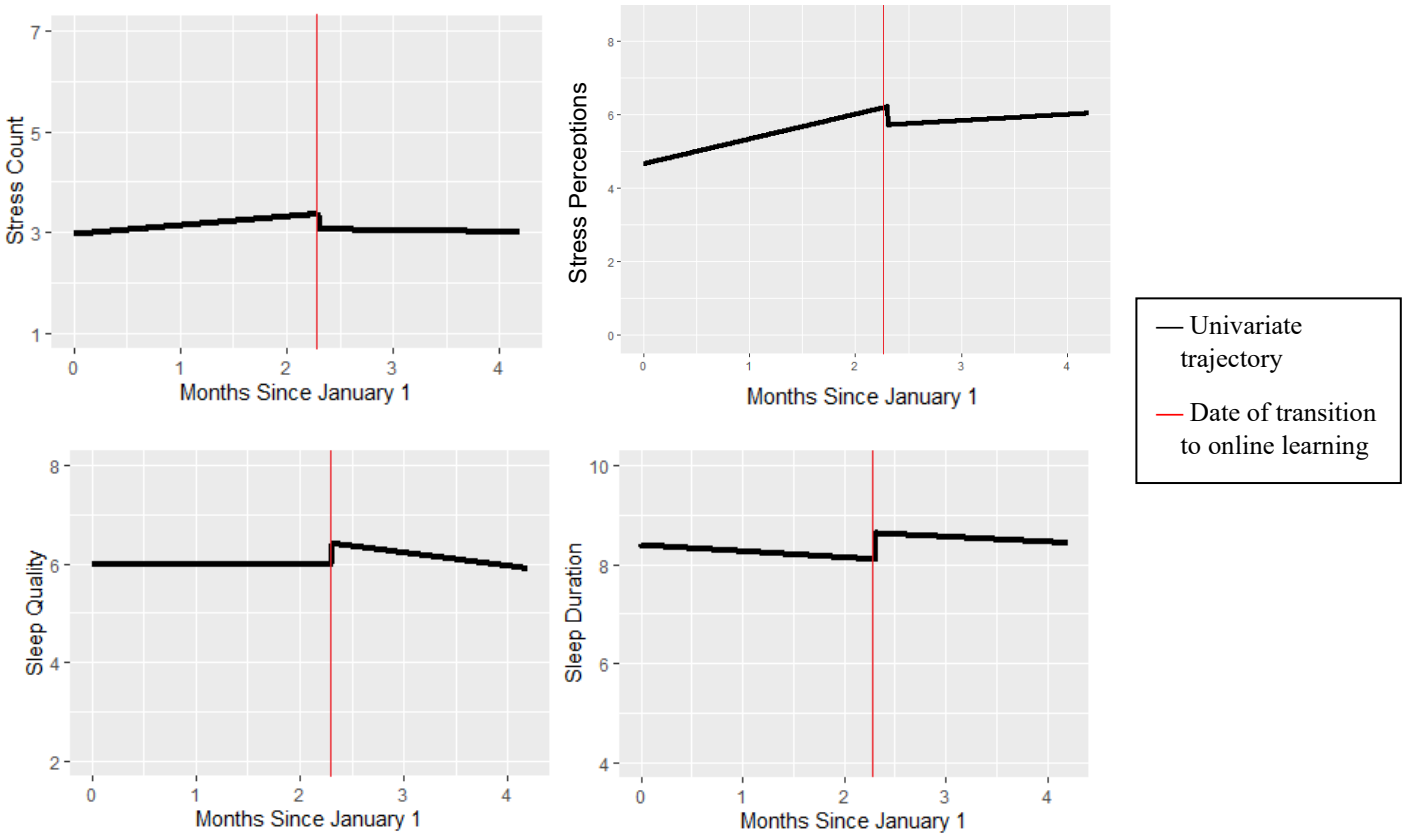
	Stress Perception	Sleep Quality	Sleep Duration
Stress Perception	2.975(.070)**		
Sleep Quality	.036(.045)	2.486(.057)**	
Sleep Duration	-.029(.049)	.673(.047)**	2.828(.065)**

Note: Analytic *N*=164; 4,269 total completed surveys. Within-person effects while controlling for growth before, during, and after transition online. Diagonal elements indicate variances of Level 1 within-individual random-effects of each outcome; off-diagonal elements indicate fixed-effects covariances between within-individual outcomes (Level 2). *, significant parameter at $p<.05$; **, significant parameter at $p<.01$.

b. Between-Individual Random Intercept and Random Slope Variances and Covariances

	Stress Per. Intercept	Stress Per. Slope	Sleep Qual. Intercept	Sleep Qual. Slope	Sleep Dur. Intercept	Sleep Dur. Slope
Stress Per. Intercept	3.66(.456)**					
Stress Per. Slope	-.085(.091)	.181(.033)**				
Sleep Qual. Intercept	-.939(.257)**	.029(.068)	2.180(.265)**			
Sleep Qual. Slope	.050(.069)	.012(.018)	-.015(.052)	.105(.021)**		
Sleep Dur. Intercept	.002(.134)	.008(.036)	.258(.104)*	-.010(.028)	.533(.079)**	
Sleep Dur. Slope	.008(.048)	-.012(.013)	.053(.037)	.018(.011)	.056(.020)**	.016(.010)

Note: Analytic *N*=164; 4,269 total completed surveys. Diagonal elements indicate variances of random intercept and random slope for each outcome variable; off-diagonal elements indicate covariance between random intercept and random slope for each process. *, significant parameter at $p<.05$; **, significant parameter at $p<.01$.


Stress Count
Months Since January 1
Stress Perceptions
Months Since January 1
Sleep Quality
Months Since January 1
Sleep Duration
Months Since January 1
— Univariate trajectory
— Date of transition to online learning