Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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Day-to-day associations between nightly sleep and next-day well-being amid the COVID-19 pandemic in North America

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ABSTRACT

Objective: Sleep may be especially important for maintaining health and well-being in daily life amid the stress of the coronavirus disease 2019 (COVID-19) pandemic. This preregistered study examined the associations of sleep quality, duration, and efficiency with next-day physical symptoms, affect, and stressors during the COVID-19 pandemic in North America, in addition to evaluating individual differences in COVID-19 threat as a moderator.
Method: From mid-March to early August 2020, 1025 adults from Canada and the United States aged 18-91 reported COVID-19 threat at baseline and subsequently completed twice-daily diaries for one week about their sleep, negative affect, stressors, and physical symptoms.
Results: Within-persons, nights with better-than-usual sleep quality predicted lower next-day negative affect, physical symptoms, and stressor occurrence. Better-than-usual sleep efficiency and longer-than-usual sleep duration also predicted lower next-day physical symptoms. COVID-19 threat ratings moderated several of these associations, such that individuals with higher COVID-19 threat showed weaker within-person associations of sleep duration and efficiency with next-day well-being, compared to individuals with lower-to-moderate levels of COVID-19 threat. For the reversed direction of association, stressor occurrence predicted shorter-than-usual sleep that night, but no other links between daily well-being and subsequent sleep were observed.
Discussion: Sleep quality, efficiency, and duration were important predictors of daily health and well-being during the COVID-19 pandemic, but the protective associations between sleep and next-day well-being were attenuated among people with higher COVID-19 threat. These findings highlight the role of heightened stress contexts when considering the benefits of sleep on daily health and well-being.

Introduction

Poor sleep quality and short sleep duration are major public health concerns. Approximately one-third of adults in the United States and Canada report sleep durations of less than 6 or 7 hours per night,[1,2] which contribute to many leading causes of death (eg, cardiovascular disease, diabetes, hypertension).[3] Prospective studies have consistently demonstrated associations of short sleep duration and/or poor sleep quality with greater risks for affective disorders and chronic health conditions.[4,5]

Given the severe disruptions to day-to-day life as a result of the novel coronavirus 2019 (COVID-19) pandemic,[6] it is critical to consider the ways in which various aspects of sleep may have promoted psychological adjustment during the crisis. Recent research suggests that individuals experienced heightened perceived stress during the pandemic compared to pre-pandemic levels,[7] including work and family stress, financial worries, and health concerns.[8,9] Thus, the current study aimed to evaluate the day-to-day associations of sleep indices with psychological and health functioning amid the COVID-19 pandemic, in addition to evaluating appraisals of COVID-19 threat as a potential moderator.

Sleep and well-being in daily life

In recent years, there has been growing interest in examining the connections between sleep (eg, in terms of quality, duration, efficiency, and other dimensions) and daily well-being using naturalistic methods in the field. Much of the existing literature has focused on between-person associations for sleep indices and well-being (eg, *Do people with poorer sleep quality tend to have higher negative affect [NA]?*). In contrast,

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a within-person approach asks, *does a person's NA differ on days when their prior-night sleep quality was poorer than their average sleep quality?* By using repeated assessments, the within-person approach provides valuable information about deviations from one's average level and is also well-suited for examining the direction of association. Studies using daily diaries or experience sampling have consistently linked shorter or poorer quality sleep—measured using self-report and actigraphy—with worse next-day functioning within-persons, including greater NA,[10] physical symptoms (eg, fatigue, pain[11]), and exposure and reactivity to stressors.[12,13] Evidence also supports the reversed direction of association: Daily experiences, such as elevated stress, are related to poorer subsequent self-reported and behavioral measures of sleep.[12] Although research supports the role of sleep as both an antecedent and a consequence of daily psychosocial experiences, studies that have tested both directions of association and have stringently controlled for lagged effects show more consistent evidence that sleep is a stronger predictor of next-day experiences than vice versa.[10,13,14] Given the importance of sleep for psychological and physical health, it is critical to investigate whether the benefits of sleep on daily well-being were present during the COVID-19 pandemic.

A number of studies have found that people experienced more frequent sleep difficulties as a consequence of pandemic-related distress.[6,15] For example, individuals who reported more COVID-19-related adversity and worries (eg, financial problems) had lower sleep quality across 10 months.[16] Some existing studies on this topic have focused on between-person associations linking psychological distress and sleep in the wake of COVID-19, but to our knowledge, no research to date has investigated within-person fluctuations in multiple dimensions of sleep and next-day functioning during the pandemic.

Individual differences in COVID-19 threat

People differ from one another in the extent to which sleep is related to their next-day experiences,[17] and vice versa. For example, Drake and colleagues found that a person whose sleep is more disrupted by stress is at greater risk for developing insomnia and depression, compared to persons who are less vulnerable to stress-related sleep disturbances.[18] Given the disproportionate toll of the pandemic (eg, financial insecurity, isolation, health vulnerabilities[7-9,16]), it is possible that the protective benefits of sleep were either enhanced or attenuated based on stress appraisals of the pandemic (ie, COVID-19 threat may moderate the link between sleep and daily experiences). On the one hand, sleep may have been more protective for health and well-being among individuals who felt especially threatened by the COVID-19 pandemic because sleep could have provided emotional, cognitive, and physical resources to cope with elevated stress and uncertainty. For example, previous research has shown that following nights when sleep was longer than one's usual sleep duration, positive affect was maintained in the face of next-day stressors.[13] On the other hand, drawing on ideas from the *blunting hypothesis*[19]—which posits that the link between protective factors (eg, sleep) and well-being could be weakened in the presence of heightened negative experiences (eg, stress)—it is possible that the psychological impacts of COVID-19 were so intractable that night-to-night improvements in sleep were insufficient for reducing negative states. Thus, the benefits of sleep for next-day psychological and health outcomes could have been diminished for people who perceived the COVID-19 pandemic to be more threatening. A better understanding of the role of COVID-19 threat in sleep and daily well-being would be valuable for informing strategies to promote health in the context of major life stress.

Current study

The primary aim of this study was to examine the relationships between self-reported sleep (quality, duration, and efficiency) and next-day health and well-being outcomes (physical symptoms, NA, and stressors) during the COVID-19 pandemic. We conducted a preregistered analysis using daily diary data collected from over 1000 adults across Canada and the United States between March to August 2020. Better subjective quality, longer, and more efficient sleep were hypothesized to predict fewer physical symptoms, lower NA, and reduced stressor exposure at both the between- and within-person levels. Furthermore, we evaluated the reversed direction of association (ie, daily well-being predicting subsequent sleep) but did not have a priori hypotheses, given that some previous studies have produced null results[10,13] but others have linked higher daytime or evening stress to shorter sleep.[12,20] On an exploratory basis, we also sought to evaluate whether individual differences in COVID-19 threat moderated the within-person relationship between sleep and well-being. Given the lack of previous research on major stress as a moderator, we had no predictions about whether people with greater COVID-19 threat would show stronger vs. weaker associations between sleep dimensions and next-day health and well-being.

Methods

Sample and design

The current research used data from an online daily diary study about coping with the COVID-19 outbreak, collected between March 18, 2020 and August 3, 2020. Participants were recruited using popular print, television, and radio news outlets in North America, in addition to social media (eg, university media channels), community organizations (eg, YMCA), and institutions (eg, local hospitals). No monetary incentives were offered for participation. Participants were eligible to enroll in this daily diary study if they were 18 years of age or older and residing in Canada or the United States. All participants provided informed consent and the procedures were approved by the Behavioral Research Ethics Board at the University of British Columbia. The data analysis plan was preregistered on the Open Science Framework website (https://osf.io/cg4r3/?view_only=6aaea9add4a44873963b1af4f2e9b385); deviations from the preregistration were described in Supplementary Table S1.

Participants aged 18-91 (N = 1206 participants; 7602 days of observation) first completed a baseline questionnaire and then were invited to complete a weeklong daily diary protocol. For 7 consecutive days, participants were instructed to complete surveys in the mornings and evenings. Participants completed their first daily diary survey an average of 1.27 days (median = 0 days) after completing the baseline questionnaire. The links to the morning and evening surveys were sent via email at 7 AM and 7 PM local time, respectively, containing a link to the Qualtrics survey platform. The morning survey consisted of questions regarding prior-night sleep, and the evening survey consisted of questions about the day's stressors, affect, and physical symptoms.

Repeated assessments were needed to capture within-person fluctuations in sleep and well-being in daily life; thus, participants were excluded if they completed fewer than 2 complete days of surveys (n = 120). Additionally, participants (n = 20) were excluded if they did not complete surveys from at least 2 *consecutive* days because our analyses required lagged data from the prior day. Forty-one participants were also excluded for missing data on demographic information and key variables: age (n = 2), gender (n = 14), race (n = 21), education (n = 1), and COVID-19 threat (n = 3). To reduce the influence of outliers due to total sleep loss or very long sleep duration, we further excluded days of observation when self-reported sleep duration was zero hours or over 16 hours (272 observations, ~3% of daily diary days). Our final analytic sample consisted of 1025 participants (85% of people in full sample) and 7175 days of observation (94% of days in the full sample). On average, the 1025

Table 1
Means (standard deviations) of study variables by low vs. high COVID-19 threat

Variable	Mean (SD) or N (%)			p value
	Full sample (N = 1025)	Low COVID-19 threat (n = 548)	High COVID-19 threat (n = 477)	
Age, years	46.02 (16.07)	**48.81 (16.48)**	**42.81 (14.97)**	**<.001**
Women (%)	903 (88.1%)	**471 (85.9%)**	**432 (90.6%)**	**.023**
White (%)	926 (90.3%)	493 (90.0%)	433 (90.8%)	.661
Less than 4-year bachelor's degree	322 (31.4%)	**155 (28.3%)**	**167 (35.0%)**	**.021**
Presence of chronic condition (yes)	229 (22.3%)	123 (22.4%)	106 (22.2%)	.932
Surveys completed on weekends (%)	24% (15%)	25% (15%)	23% (15%)	.090
Depressive symptoms	13.31 (7.33)	**9.81 (6.26)**	**17.31 (6.35)**	**<.001**
No. of daily physical symptoms	2.38 (2.24)	**2.14 (2.13)**	**2.65 (2.33)**	**<.001**
Daily negative affect (0-100 scale)	25.79 (16.16)	**21.74 (15.2)**	**30.45 (15.95)**	**<.001**
Percent of days with any stressors	57.3% (29.6%)	**54.3% (30.6%)**	**60.8% (28.0%)**	**<.001**
COVID-19 threat (1-4 scale)	2.42 (0.60)	**1.97 (0.33)**	**2.93 (0.38)**	**<.001**
Sleep quality (0-100 scale)	58.27 (17.90)	**60.55 (17.88)**	**55.65 (17.59)**	**<.001**
Sleep duration (hours)	7.64 (1.03)	7.69 (1.00)	7.58 (1.07)	.086
Sleep efficiency (%)	88.1% (8.3%)	**88.9% (8.1%)**	**87.3% (8.4%)**	**<.001**
Sleep onset latency (min)	21.52 (21.30)	**19.55 (20.96)**	**23.78 (21.48)**	**.001**
Wake after sleep onset (min)	18.09 (21.46)	17.43 (19.31)	18.85 (23.69)	.291
Terminal wakefulness (min)	18.63 (17.17)	**17.04 (15.15)**	**20.46 (19.08)**	**.001**
Time in bed (hours)	9.14 (1.57)	9.10 (1.49)	9.20 (1.65)	.323

Note. COVID-19 threat was grouped into categories for descriptive purposes in this table. In the subsequent multilevel models, COVID-19 threat was entered as a continuous variable. Ratings of < 2.4 were considered low COVID-19 threat, and ratings ≥ 2.4 were considered high COVID-19 threat. Chi-squared tests and *t* tests were used to compare group differences.
Bolded text indicates significant difference between groups.

participants in the analytic sample were older than the 181 participants who were excluded from analyses (46 years vs. 39 years, $p < .05$). However, there were no differences between the analytic sample vs. excluded participants based on gender, race, educational attainment, presence of chronic conditions, or COVID-19 threat (p's $> .05$). The final analytical sample consisted of adults ages 18 to 91, who predominantly identified as women and White (Table 1).

Measures

COVID-19 threat

As part of the baseline questionnaire, participants rated 8 items regarding the perceived threat of COVID-19 to various life domains.[8] Specifically, participants were asked about their level of concern regarding the threat of COVID-19 on (a) their own physical health and safety, (b) the physical health and safety of loved ones, (c) their own emotional well-being, (d) the emotional well-being of loved ones, (e) not achieving important work goals, (f) not achieving something important to them, (g) strain on financial resources, and (h) losing the approval or respect of others. Items were rated on a 4-point scale (1 = *not at all*, 2 = *a little*, 3 = *a moderate amount*, 4 = *a great deal*). Scores were averaged across the 8-items to create a composite variable for COVID-19 threat ($\alpha = .73$).

Daily sleep measures

Each morning, participants completed the Consensus Sleep Diary,[21] which assessed bedtime, sleep onset latency (SOL), wake after sleep onset (WASO), terminal wakefulness (TWAK), and rise time. Sleep duration was calculated by subtracting total wake time (SOL + WASO + TWAK) from time in bed (TIB; interval between bedtime and rise time). Sleep efficiency was calculated by dividing sleep duration by TIB and multiplying by 100. Subjective sleep quality was assessed using a visual analogue scale ranging from 0 (*very poor*) to 100 (*very good*).

Daily physical symptoms

Daily physical symptoms were assessed in the evening surveys using a checklist of 29 physical symptoms, including aches (eg, headache, backache), upper respiratory symptoms (eg, shortness of breath, sore throat), and gastrointestinal symptoms (eg, nausea, diarrhea). The items were summed to obtain the number of daily physical symptoms.[22]

Daily negative affect

In the evening surveys, participants indicated the extent that they had felt 7 negative emotions (*anxious, sad, angry, frustrated, disgusted, lonely, ashamed*) using a visual analogue scale ranging from 0 (*Not at all*) to 100 (*Extremely*).[23] The items were averaged to create a composite daily NA variable. Reliability was satisfactory at both the within-person ($R_C = 0.74$) and between-person levels ($R_{KF} = 0.98$).

Daily stressors

Daily stressors were assessed in the evening surveys using a modified version of the Daily Inventory of Stressful Events.[24] Participants reported whether they experienced each of 8 types of stressors that day: (a) *argument, conflict, or disagreement;* (b) *family or home stress;* (c) *work or school stress*; (d) *financial problem;* (e) *traffic or transportation stress;* (f) *health problem or accident;* (g) *stressful event that happened to close friends or family;* and (h) *other stressful event*. Because people reported an average of less than one stressor per day (mean = 0.86, SD = 0.98), we created a dichotomous variable to indicate the occurrence of any stressors each day (1 = yes, 0 = no).[8] At the between-person level, this dichotomous variable was averaged across diary days to indicate the percent of days on which the person reported any stressors.

Covariates

All models covaried for study day (0 = first study day, to 6 = final day), age (centered), gender (men vs. women), education (less than 4-year college degree vs. 4-year college degree or more), race (white vs. non-white), self-reported presence of a chronic condition (yes or no), and weekday vs. weekend. To account for the potential confounding effect of psychological distress, we covaried for depressive symptoms in the past week, which were assessed in the baseline questionnaire using the 10-item short form version of the Center of Epidemiological Studies-Depression Scale.[25] Furthermore, the outcome variable measured on the prior day (eg, yesterday's daytime NA) could be associated with both the prior-day predictors (eg, poorer subsequent sleep) and current-day outcomes (eg, higher

current-day NA).[10] We therefore covaried for the outcome variable measured on the prior day. Lastly, we controlled for the month of data collection (ie, coded as 0 = March, 1 = April, etc.) to account for potential month-to-month changes in daily life during the pandemic.

Analytic strategy

Analyses were conducted using R version 4.0.1. For descriptive purposes only, participants were categorized as "Higher COVID-19 Threat" and "Lower COVID-19 Threat" (based on a median split of 2.4) to examine group differences in study variables. COVID-19 threat was subsequently examined as a continuous variable in the primary analyses.

Two-level models with restricted maximum likelihood estimation were run using the lmerTest package in R.[26] First, unconditional means models were run to partition the variance at the between- and within-person levels and to calculate intraclass correlation coefficients (ICC; between-person variation/total variation). Next, 2-level linear models were run to examine between- and within-person sleep measures as predictors of next-day physical symptoms and NA, whereas logistic multilevel models were run to predict the dichotomous outcome for stressor occurrence (ie, stressor day vs. non-stressor day). An analogous set of multilevel models were run to evaluate the relationship between daily well-being and subsequent sleep. Predictors were centered at the person-mean (ie, group-mean) and entered at Level 1 (day-level). COVID-19 threat and person-means of predictor variables were grand mean-centered and entered at Level 2 (person-level). The wide 0-100 scale for sleep quality led to large eigenvalues and convergence difficulties; we therefore scaled[27] the sleep quality variable by dividing by 10.

All models included random slopes for the lagged prior-day outcome variable to account for differences in their autoregressive effects. Models for sleep predicting daily physical symptoms and daily NA included a random effect for within-person-centered sleep to allow participants to differ from one another in their within-person associations. However, due to convergence difficulties, random slopes were not included for multilevel logistic models predicting daily stressor occurrence. Likewise, the analyses for daily well-being predicting same-night sleep included random slopes for within-person-centered daily well-being variables, but these random effects were omitted from models when they produced convergence problems.

For exploratory analyses focusing on COVID-19 threat as a between-person moderator, we included interactions for COVID-19 threat x sleep measures (between- and within-persons) in each of the multilevel models. Significant interaction effects were followed-up with simple slope analyses for participants with lower (−1 SD = 1.81 from mean of 2.4) vs. higher (+1 SD = 3.00) COVID-19 threat.

Results

Descriptives

Descriptive statistics are provided in Table 1, with participants categorized based on a median split for COVID-19 threat. The participants in the analytic sample (N = 1025) had a mean age of 46 (SD = 16.07) and predominantly identified as women (88.1%) and White (90.3%). Compared to those with lower ratings of COVID-19 threat, participants with higher COVID-19 threat were more likely to be women, younger, less educated, and they reported more daily physical symptoms, higher NA, and more frequent daily stressors. Those with higher COVID-19 threat also had relatively lower subjective sleep quality, longer SOL, longer TWAK, and lower sleep efficiency. However, there were no significant differences in sleep duration, WASO, and time in bed based on COVID-19 threat ratings. We further characterized the sample based on short (<7 hours), moderate (7-9 hours), and long (>9 hours) average sleep duration in Supplementary Table S2. Short sleepers reported more daily physical symptoms than people with moderate or long average sleep duration. Short and long sleepers both had higher mean daily negative affect than those with moderate sleep duration. However, levels of COVID-19 threat did not differ among the sleep duration groups.

Within- and between-person correlations among daily diary variables of interest are included in Supplementary Table S3. ICCs showed that 76% of the variation in physical symptoms, 62% for NA, and 24% for daily stressor occurrence were attributable to differences between-persons. ICCs for sleep measures ranged from 24% to 36%, indicating that there was a substantial degree of variation from day-to-day.

Sleep quality, duration, and efficiency as predictors of daily well-being

Daily physical symptoms

Table 2 shows the results from 3 separate multilevel models examining sleep measures as predictors of the number of next-day physical symptoms, with COVID-19 threat included as a moderator. At the between-person level, fewer physical symptoms were reported on average by people with higher average sleep quality, longer sleep duration, and higher sleep efficiency. Similarly, within-person main effects suggested that physical symptoms were lower following nights with better, longer, and more efficient sleep, compared to one's usual level of physical symptoms and sleep. COVID-19 threat moderated the within-person associations of sleep duration and efficiency with next-day physical symptoms. As shown in Fig. 1, simple slope analyses revealed that among individuals with higher COVID-19 threat (+1 SD from mean), sleep duration and sleep efficiency were not associated with next-day physical symptoms (sleep duration: Est. = −0.04, SE = 0.03, $p = .11$; sleep efficiency: Est. = −0.003, SE = 0.004, $p = .37$). By contrast, those with lower COVID-19 threat reported fewer physical symptoms following nights with longer-than-usual sleep duration (Est. = −0.15, SE = 0.03, $p < .001$) and higher-than-usual sleep efficiency (Est. = −0.02, SE = 0.004, $p < .001$).

Negative affect

People with better average (between-person) sleep quality, longer sleep duration, and higher sleep efficiency tended to have lower average daily NA (Table 3). At the within-person level, higher-than-usual sleep quality was associated with lower-than-usual NA the next day. However, there were no within-person associations between sleep duration or efficiency and NA. COVID-19 threat did not moderate any of the within-person associations between sleep and next-day NA.

Stressor occurrence

Results from the logistical multilevel models examining the association between sleep and stressor occurrence are presented in Table 4. At both the between- and within-person levels, better sleep quality predicted lower odds of experiencing daily stressors. Sleep duration and efficiency were linked to less-frequent daily stressors between-persons, but not within-persons. Between-person sleep quality interacted with COVID-19 threat (Fig. 2, left panel). Simple slope analyses revealed that average sleep quality was inversely associated with stressor occurrence for people at all levels of COVID-19 threat, although this association was weaker among people with higher ratings of COVID-19 threat (lower threat [−1 SD]: Est. = −0.23, SE = 0.04, $p < .001$; higher threat [+1 SD]: Est = −0.12, SE = .04, $p < .01$).

Within-persons, a significant sleep duration (within-person) x COVID-19 threat interaction was observed (Fig. 2, right panel), such that longer-than-usual sleep duration predicted lower odds of next-day stressors among people with lower COVID-19 threat (Est. = −0.14, SE = 0.05, $p = .005$), but not among people with higher COVID-19 threat (Est. = 0.02, SE = 0.05, $p = 0.69$). COVID-19 threat did not moderate the within-person associations of sleep quality or sleep efficiency with daily stressor occurrence.

Table 2
Multilevel model results for sleep quality, duration, and efficiency predicting next-day number of physical symptoms

	Sleep quality model			Sleep duration model			Sleep efficiency model		
Predictors	Est.	95% CI	*p*	Est.	95% CI	*p*	Est.	95% CI	*p*
Fixed effects									
Intercept	2.13	1.55 to 2.71	<**.001**	2.25	1.65 to 2.85	<**.001**	2.22	1.63 to 2.80	<**.001**
Study day (0 = First day)	−0.05	−0.08 to −0.03	<**.001**	−0.06	−0.09 to −0.03	<**.001**	−0.06	−0.09 to −0.04	<**.001**
Age (centered)	−0.00	−0.01 to 0.01	.539	−0.01	−0.02 to 0.00	.184	−0.01	−0.01 to 0.00	.204
Gender (ref = Men)	0.37	−0.03 to 0.77	.068	0.33	−0.09 to 0.74	.120	0.29	−0.12 to 0.70	.162
Race (ref = Non-White)	−0.14	−0.58 to 0.30	.520	−0.16	−0.62 to 0.30	.496	−0.11	−0.56 to 0.34	.631
Chronic condition status (ref = No)	0.80	0.49 to 1.12	<**.001**	0.84	0.52-1.17	<**.001**	0.81	0.49 to 1.13	<**.001**
Education status (ref = some college or less)	−0.29	−0.57 to −0.01	**.043**	−0.36	−0.64 to −0.07	**.016**	−0.32	−0.60 to −0.03	**.029**
Weekday (ref = Yes)	−0.02	−0.11 to 0.06	.588	−0.02	−0.11 to 0.07	.634	−0.04	−0.13 to 0.04	.317
Month of data collection (ref = March)	0.19	0.02 to 0.37	**.028**	0.17	−0.01 to 0.35	.069	0.17	−0.01 to 0.34	.064
Depressive symptoms (CES-D; centered)	0.02	−0.00 to 0.05	.057	0.05	0.02-0.07	<**.001**	0.03	0.01-0.06	**.007**
Prior-day physical symptoms	−0.01	−0.05 to 0.03	.714	0.00	−0.04 to 0.04	.996	−0.00	−0.04 to 0.04	.926
COVID-19 threat	0.15	−0.12 to 0.43	.277	0.19	−0.10 to 0.48	.193	0.20	−0.09 to 0.48	.178
Sleep quality (BP)	−0.34	−0.42 to −0.27	<**.001**						
Sleep quality (WP)	−0.07	−0.09 to −0.05	<**.001**						
Sleep quality (BP) x COVID-19 threat	−0.10	−0.21 to 0.01	.085						
Sleep quality (WP) x COVID-19 threat	0.03	−0.00 to 0.07	.077						
Sleep duration (BP)				−0.24	−0.38 to −0.11	**.001**			
Sleep duration (WP)				−0.09	−0.13 to −0.06	<**.001**			
Sleep duration (BP) x COVID-19 threat				0.09	−0.12 to 0.30	.398			
Sleep duration (WP) x COVID-19 threat				0.09	0.03 to 0.16	**.003**			
Sleep efficiency (BP)							−0.06	−0.08 to −0.04	<**.001**
Sleep efficiency (WP)							−0.01	−0.01 to −0.00	<**.001**
Sleep efficiency (BP) x COVID-19 threat							−0.01	−0.03 to 0.01	.376
Sleep efficiency (WP) x COVID-19 threat							0.01	0.00 to 0.02	**.011**
Random effects	Variance [95%CI]			Variance [95%CI]			Variance [95%CI]		
Residual variance	1.13 [1.06 to 1.20]			1.10 [1.03 to 1.17]			1.11 [1.04 to 1.18]		
Intercept	3.96 [3.6 to 4.32]			4.24 [3.82 to 4.62]			4.10 [3.68 to 4.47]		
Prior-day physical symptoms	0.06 [0.04 to 0.08]			0.06 [0.04 to 0.08]			0.05 [0.03 to 0.08]		
Sleep measure (WP)	0.01 [0.00 to 0.02]			0.03 [0.01 to 0.05]			0.00 [0.0001 to 0.001]		

Note: BP, between-person, grand-mean-centered; WP, within-person, person-mean-centered; CES-D, Center for Epidemiological Studies Depression Scale.
Bolded values refer to effects that are significant at $p < .05$.

Daily well-being as predictors of sleep quality, duration, and efficiency

Sleep quality

Supplementary Table S4 presents the results of models for daily physical symptoms, NA, and stressor occurrence as predictors of sleep quality. The between-person associations were similar to those in the previous sets of models, such that people with higher physical symptoms, NA, and stressor occurrence tended to have relatively lower average sleep quality. At the within-person level, there were no main effects nor moderation by COVID-19 threat for daily experiences as predictors of same-night sleep quality.

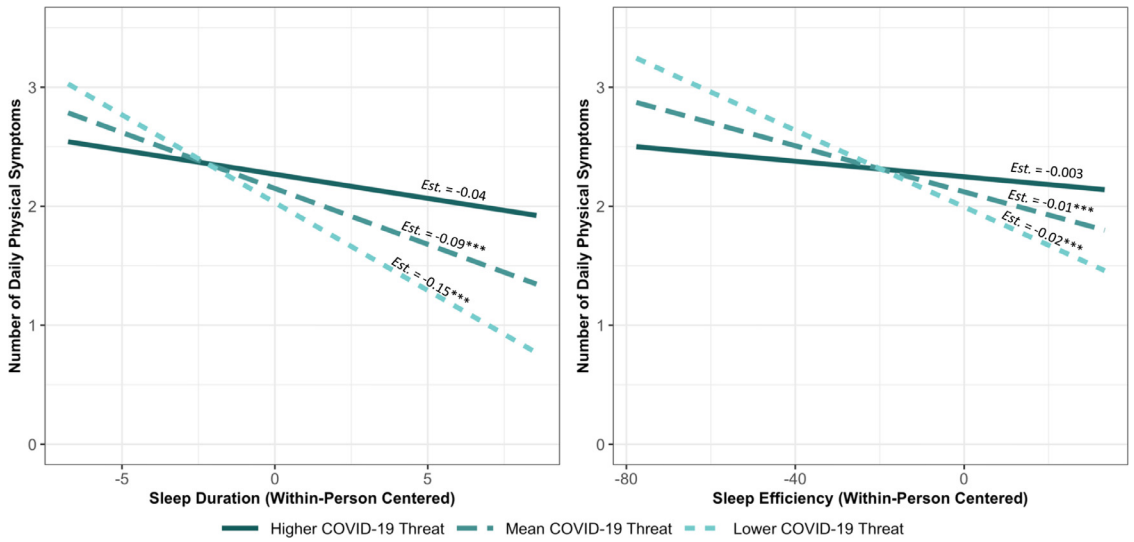

Fig. 1. Individual differences in COVID-19 threat moderated the within-person associations of sleep duration (left) and sleep efficiency (right) with next-day physical symptoms, Note. People with lower-to-moderate COVID-19 threat showed a significant association between longer sleep duration (left panel) or higher sleep efficiency (right panel) and fewer next-day physical symptoms, whereas sleep duration and efficiency were not associated with next-day physical symptoms among people with higher COVID-19 threat. The Johnson-Neyman intervals indicated that sleep duration and efficiency were significantly associated with next-day physical symptoms among participants who scored below 2.9 and 2.7 on the COVID-19 threat measure (1-4 scale), respectively.

Table 3
Multilevel model results for sleep quality, duration, and efficiency predicting next-day negative affect

	Sleep quality model			Sleep duration model			Sleep efficiency model		
Predictors	Est.	95% CI	*p*	Est.	95% CI	*p*	Est.	95% CI	*p*
Fixed effects									
Intercept	31.28	27.36 to 35.19	**<.001**	32.04	27.94 to 36.13	**<.001**	32.09	28.03 to 36.16	**<.001**
Study day (0 = First day)	−0.71	−0.97 to −0.44	**<.001**	−0.82	−1.09 to −0.54	**<.001**	−0.83	−1.10 to −0.56	**<.001**
Age (centered)	0.01	−0.05 to 0.06	.841	−0.02	−0.08 to 0.05	.636	−0.01	−0.07 to 0.05	.704
Gender (ref = Men)	−1.62	−4.29 to 1.05	.233	−2.03	−4.83 to 0.77	.155	−2.33	−5.11 to 0.45	.100
Race (ref = Non-White)	−0.96	−3.92 to 1.99	.523	−1.11	−4.21 to 1.99	.484	−0.81	−3.89 to 2.26	.603
Chronic condition status (ref = No)	0.11	−1.99 to 2.22	.915	0.36	−1.86 to 2.57	.753	0.09	−2.11 to 2.29	.937
Education status (ref = some college or less)	−1.68	−3.55 to 0.18	.077	−1.80	−3.75 to 0.16	.072	−1.80	−3.74 to 0.14	.069
Weekday (ref = Yes)	−1.88	−2.77 to −0.99	**<.001**	−1.73	−2.66 to −0.80	**<.001**	−1.82	−2.75 to −0.90	**<.001**
Month of data collection (ref = March)	−0.28	−1.42 to 0.87	.637	−0.34	−1.55 to 0.86	.578	−0.29	−1.49 to 0.90	.632
Depressive symptoms (CES-D; centered)	0.71	0.54 to 0.87	**<.001**	0.92	0.75 to 1.09	**<.001**	0.85	0.68 to 1.02	**<.001**
Prior-day negative affect	−0.09	−0.13 to −0.05	**<.001**	−0.09	−0.13 to −0.05	**<.001**	−0.09	−0.13 to −0.05	**<.001**
COVID-19 threat	2.58	0.72 to 4.43	**.006**	2.57	0.60 to 4.53	**.010**	2.66	0.71 to 4.62	**.008**
Sleep quality (BP)	−2.68	−3.19 to −2.17	**<.001**						
Sleep quality (WP)	−0.36	−0.59 to −0.12	**.003**						
Sleep quality (BP) x COVID-19 threat	−0.02	−0.76 to 0.73	.967						
Sleep quality (WP) x COVID-19 threat	−0.27	−0.66 to 0.12	.179						
Sleep duration (BP)				−1.56	−2.50 to −0.62	**.001**			
Sleep duration (WP)				−0.34	−0.73 to 0.06	.092			
Sleep duration (BP) x COVID-19 threat				1.28	−0.13 to 2.69	.075			
Sleep duration (WP) x COVID-19 threat				0.40	−0.24 to 1.05	.223			
Sleep efficiency (BP)							−0.32	−0.44 to −0.20	**<.001**
Sleep efficiency (WP)							−0.03	−0.08 to 0.02	.201
Sleep efficiency (BP) x COVID-19 threat							0.11	−0.05 to 0.28	.189
Sleep efficiency (WP) x COVID threat							0.04	−0.04 to 0.11	.335
Random effects	Variance [95%CI]			Variance [95%CI]			Variance [95%CI]		
Residual variance	126.61 [126.19 to 128.34]			129.19 [128.52 to 131.11]			133.48 [125.98 to 141.17]		
Intercept	151.42 [148.86 to 151.53]			167.89 [164.60 to 168.15]			162.58 [143.16 to 179.60]		
Prior-day negative affect	0.04 [0.02 to 0.06]			0.05 [0.03 to 0.07]			0.05 [0.03 to 0.07]		
Sleep measure (WP)	1.65 [1.49 to 1.68]			2.98 [2.86 to 3.09]			—		

Note: BP, between-person, grand-mean-centered; WP, within-person, person-mean-centered; CES-D, Center for Epidemiological Studies Depression Scale.
Random effect of within-person sleep efficiency was removed due to convergence problems.
Bolded values refer to effects that are significant at $p < .05$.

Table 4
Multilevel model results for sleep quality, duration, and efficiency predicting odds of stressor occurrence the next-day

	Sleep quality model			Sleep duration model			Sleep efficiency model		
Predictors	OR	95% CI	*p*	OR	95% CI	*p*	OR	95% CI	*p*
Fixed effects									
Intercept	2.05	1.25 to 3.34	**.004**	2.09	1.27 to 3.44	**.004**	2.08	1.27 to 3.43	**.004**
Study day (0 = First day)	0.93	0.89 to 0.98	**.008**	0.92	0.88 to 0.97	**.003**	0.92	0.88 to 0.97	**.003**
Age (centered)	1.00	1.00 to 1.01	.189	1.00	1.00 to 1.01	.292	1.00	1.00 to 1.01	.283
Gender (ref = Men)	1.04	0.75 to 1.43	.831	0.96	0.69 to 1.33	.812	0.95	0.69 to 1.31	.749
Race (ref = Non-White)	0.80	0.56 to 1.14	.220	0.85	0.59 to 1.23	.393	0.87	0.60 to 1.25	.445
Chronic condition status (ref = No)	0.93	0.72 to 1.20	.585	0.95	0.73 to 1.23	.712	0.94	0.73 to 1.22	.666
Education status (ref = some college or less)	1.26	1.01 to 1.58	**.043**	1.23	0.98 to 1.54	.079	1.23	0.98 to 1.55	.073
Weekday (ref = Yes)	0.53	0.44 to 0.63	**<.001**	0.54	0.45 to 0.64	**<.001**	0.53	0.44 to 0.63	**<.001**
Month of data collection (ref = March)	1.01	0.88 to 1.16	.875	1.01	0.88 to 1.16	.906	1.01	0.89 to 1.14	.895
Depressive symptoms (CES-D; centered)	1.01	1.00 to 1.03	.127	1.03	1.01 to 1.05	**.003**	1.02	1.00 to 1.04	**.025**
Prior-day stressor occurrence	1.01	1.00 to 1.03	.142	1.03	1.01 to 1.05	**.004**	1.02	1.00 to 1.04	**.029**
COVID-19 threat	1.33	1.06 to 1.66	**.013**	1.36	1.08 to 1.71	**.009**	1.35	1.07 to 1.70	**.012**
Sleep quality (BP)	0.84	0.79 to 0.89	**<.001**						
Sleep quality (WP)	0.94	0.91 to 0.98	**.006**						
Sleep quality (BP) x COVID-19 threat	1.10	1.00 to 1.21	**.045**						
Sleep quality (WP) x COVID-19 threat	1.01	0.94 to 1.08	.852						
Sleep duration (BP)				0.89	0.79 to 0.99	**.037**			
Sleep duration (WP)				0.94	0.88 to 1.01	.076			
Sleep duration (BP) x COVID-19 threat				1.07	0.90 to 1.26	.457			
Sleep duration (WP) x COVID-19 threat				1.15	1.03 to 1.29	**.015**			
Sleep efficiency (BP)							0.97	0.96 to 0.98	**<.001**
Sleep efficiency (WP)							1.00	0.99 to 1.01	.512
Sleep efficiency (BP) x COVID-19 threat							1.00	0.97 to 1.02	.652
Sleep efficiency (WP) x COVID-19 threat							1.01	0.99 to 1.02	.219
Random effects	Variance [95%CI]			Variance [95%CI]			Variance [95%CI]		
Intercept	1.16 [0.67 to 1.17]			1.22 [0.95 to 1.57]			1.19 [0.68 to 1.21]		

Note: BP, between-person; grand-mean-centered; WP, within-person; person-mean-centered; CES-D, Center for Epidemiological Studies Depression Scale.
Random effects for within-person sleep measures and prior-day stressors were removed due to convergence problems.
Bolded values refer to effects that are significant at $p < .05$.

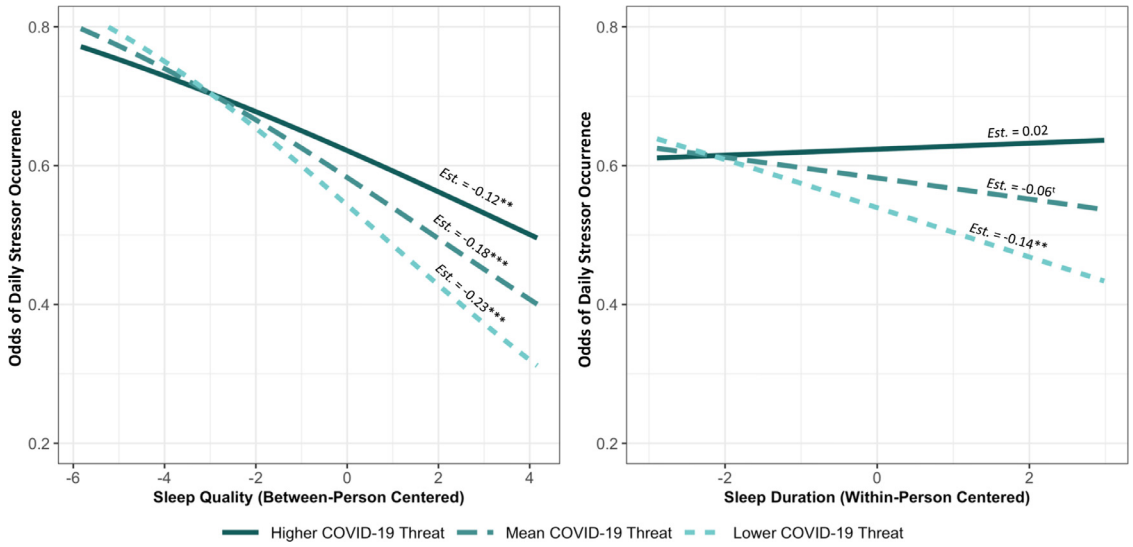

Fig. 2. Individual differences in COVID-19 threat moderated the between-person association of sleep quality (left) and within-person association of sleep duration with odds of daily stressor occurrence (right), Note. On the left, person-mean sleep quality was significantly associated with odds of stressor occurrence at all levels of COVID-19 threat, although the association is weaker among people with higher levels of COVID-19 threat. On the right, people with lower-to-moderate COVID-19 threat showed a significant association between longer-than-usual sleep duration and lower odds of stressor occurrence the next day, whereas sleep duration was not associated with next-day stressor occurrence among people with higher COVID-19 threat. The Johnson-Neyman interval indicated that within-person sleep duration was significantly associated with daily stressor occurrence among participants who scored 2.4 or below on the COVID-19 threat measure (1-4 scale).

Sleep duration

People who reported more physical symptoms, higher NA, and more frequent daily stressors tended to have shorter average sleep duration across the week (Supplementary Table S5). A significant interaction was observed for between-person physical symptoms and COVID-19 threat, such that higher average physical symptoms was associated with shorter average sleep duration only among individuals with low (simple slope: Est = −0.10, SE = 0.02, $p < .001$) to moderate (simple slope: Est = −0.07, SE = 0.02, $p < .001$) COVID-19 threat, but not among people with higher COVID-19 threat (simple slope: Est = −0.03, SE = 0.02, $p = .08$). At the within-person level, daily stressor occurrence (but not NA or physical symptoms) predicted shorter-than-usual sleep duration.

Sleep efficiency

At the between-person level, physical symptoms, NA, and stressor occurrence were inversely associated with average sleep efficiency (Supplementary Table S6). However, daily well-being did not predict same-night sleep efficiency at the within-person level, and there were not significant interactions for COVID-19 threat by daily well-being variables (either between- or within-persons).

Discussion

The current study examined between- and within-person associations of sleep quality, duration, and efficiency with daily physical symptoms, NA, and stressor occurrence during the COVID-19 pandemic in Canada and the United States. On average (ie, between-persons), people with better, longer, and more efficient sleep had more favorable well-being—specifically, fewer physical symptoms, lower NA, and lower odds of encountering daily stressors—across the study week. Within-persons, following nights when sleep quality was better than one's usual level, physical symptoms, NA, and the odds of stressor occurrence were lower on the following day. Nights with longer-than-usual sleep duration and higher-than-usual sleep efficiency were also linked with fewer next-day physical symptoms, but not with NA or stressor occurrence. For the reversed direction of association, stressor occurrence predicted shorter-than-usual sleep that night, but no other links between daily well-being and subsequent sleep were observed. Furthermore, in an exploratory analysis, individual differences in COVID-19 threat ratings moderated the link between sleep and next-day experiences, such that people with greater COVID-19 threat showed a weakened (or blunted) protective benefit of sleep on next-day physical symptoms and stressor occurrence, compared to people with lower COVID-19 threat. Taken together, these findings demonstrate the importance of sleep quality, duration, and efficiency for promoting better well-being in the context of COVID-19 as well as highlight the potential blunting effects of heightened threat appraisals.

Our between-person results revealed that participants who had obtained more adequate sleep (ie, higher quality, longer duration, more efficient) experienced fewer physical symptoms, lower negative affect, and less-frequent stressors across the study week, compared to participants with relatively poorer quality, shorter, or less efficient sleep. These findings support and extend previous research conducted both before[10] and during the pandemic,[28] suggesting that sleep remained an important correlate of health and well-being despite the severe disruptions to daily life.

Building on previous daily diary studies of sleep,[10,11,13] we found that self-reported sleep predicted well-being outcomes in daily life. The current study extends prior research due to our consideration of multiple measures of sleep and stress-relevant daily well-being, and importantly, our study was focused on daily life in the context of major stress. These results underscore the contributions of sleep in the midst of severe life disruption and uncertainty during the pandemic. For example, a 10-point increase in sleep quality (on a 0-100 scale) was associated with a 6% decrease in the odds of experiencing a stressor on the next day. These day-to-day benefits from sleep could potentially mitigate exposure and subjective responses to both minor and major forms of pandemic-related stressors,[8,9] and these effects may accumulate over time to decrease risks for long-term chronic health conditions. For the opposite direction of association, we found less support for daily experiences predicting same-night sleep, such that only stressor occurrence (but not NA or physical symptoms) predicted shorter sleep duration. Although this pattern of findings was in line with previous daily diary studies (in which

nightly sleep was more consistently associated with next-day psychosocial experiences than vice versa[11,13,29]), it is possible that our evening surveys were not fine-grained enough to capture very minor stressors or short-lived negative emotions that may have occurred earlier in the day. Based on the present findings, it appears that sleep may be most consequential for next-day health. Overall, the current study contributes to the growing literature demonstrating the strong links among sleep, daily health and well-being at both the person-level (between-persons) as well as the daily-level (within-persons).[16,28,30]

Sleep may be linked to emotions and stress through alterations in emotion regulation, in which poor sleep quality and/or short sleep duration could reduce one's ability to effectively manage negative emotions and emotion-eliciting situations.[31] For example, previous studies have shown that shorter-than-usual sleep duration or poorer-than-usual sleep quality predict greater exposure to next-day stressors,[10,12] more negative appraisals,[12] heightened emotional reactivity to those stressors,[13,32] and slower emotional recovery.[33] It should be considered that sleep quality may also be a proxy for same-day psychological distress given that the 2 variables have been shown to be highly correlated,[34] although further research using inferred and objective measures of sleep quality is needed to address this. Multiple nights of partial sleep deprivation (eg, restricted to 4-6 hours) can reduce one's ability to engage in effective coping strategies, by increasing risk-taking and diminishing one's tendency to reflect on impulsive actions,[35,36] as well as engaging in health risk behaviors such as the consumption of unhealthy foods.[37] Future research could disentangle whether various aspects of nightly sleep influence perceptions of experiences (eg, negative appraisals) or behaviors (eg, hostile actions) that provoke the occurrence of stressors.

We found that higher COVID-19 threat exhibited a blunting effect,[19] such that only individuals who reported lower-to-moderate levels of COVID-19 threat showed associations between sleep duration and efficiency with next-day physical symptoms and stressor occurrence. Similarly, at the between-person level, people with fewer daily physical symptoms tended to sleep longer on average, but only if they had lower-to-moderate levels of COVID-19 threat. One possible explanation is that the COVID-19 pandemic encompassed multiple potent elements of stress, including uncontrollability,[38] prolonged duration,[39] and threat of bodily harm to self and close others.[40] The stress caused by the pandemic also extended to many important life domains (eg, finances, basic resources, safety, health[9,16]) and was compounded by the uncertainty of changing government regulations,[6] consequently hindering coping efforts and making pandemic-related stress more salient in daily life. Thus, although better overall sleep—as well as night-to-night improvements—were beneficial for daily physical symptoms and stress exposure (possibly via situation selection or appraisals[31]) among individuals with lower COVID-19 threat, sleep did not confer as much protective effects for participants with more severe threat appraisals during the pandemic. These results also add to the previous literature on major stressors (eg, natural disasters) and sleep difficulties by demonstrating that individual differences in major stress could weaken the link between nightly sleep and daily well-being.[41-43]

Implications

Given the large body of evidence linking shorter or poorer quality sleep to acute and longer-term health risks[44] and greater stress,[13] it is critical that individuals strive to prioritize sleep during periods of major stress. Although our study was observational and did not allow for causal conclusions, our results revealed associations of better, longer, and more efficient sleep with better health and psychological functioning on a day-to-day basis. However, because these sleep-related benefits were diminished at higher levels of COVID-19 threat, exposure and responses to major stressors should be addressed first and foremost. For example, other research using data from the current sample showed that experiencing more daily positive events,[8] volunteering, and providing and receiving social support[23] were associated with improved same-day affective well-being. In addition, a recent study of college students showed that the transition to remote learning resulted in initial improvements in stress and sleep, but greater stressor exposure was nonetheless linked to poorer same-night sleep quality.[28] In the context of the pandemic (and beyond), interventions that aim to improve sleep could provide personalized recommendations for sleep practices,[45] taking into account the concurrent need to cope with major life stressors. Additionally, structural and policy-level changes that address stressors exacerbated by the pandemic (such as improving access to healthcare, housing, childcare, and financial support) could help alleviate burdens associated with major life stressors and, in turn, may contribute to downstream improvements in sleep, health, and well-being.[10,14]

Limitations

The findings of this study should be considered in light of at least several limitations. First, although we used the well-validated and standardized Consensus Sleep Diary,[21] self-report measures are nonetheless susceptible to recall biases. Second, because this study was launched with the goal of examining psychological adjustment during COVID-19, we did not have any data on participants' daily lives or sleep measures prior to the pandemic. This limits our ability to draw inferences on whether the observed associations between sleep and daily experiences (and the moderating role of broader contextual stress) are specific to the COVID-19 pandemic, or whether these findings are representative of sleep and daily well-being phenomena in general. Lastly, the sample was disproportionately composed of participants who identified as White and women, and many had a university degree. Given that racial/ethnic minorities and people with lower socioeconomic status were disproportionately affected by COVID-19,[46] our findings may not extend to under-represented and under-resourced populations that were under the greatest degree of burden due to COVID-19.

Conclusion

In summary, based on a one-week snapshot of daily life during the COVID-19 pandemic, better quality, longer-than-usual, and more efficient sleep were associated with fewer physical symptoms, lower negative affect, and lower odds of experiencing a stressor the next day. Higher ratings of COVID-19 threat to important life domains exhibited a blunting effect, such that people who reported higher pandemic threat did not show the typical benefits of longer and more efficient sleep on next-day physical symptoms, nor an association between longer-than-usual sleep and lower odds of next-day stressors. The current study extends prior research by suggesting that the oft-observed links between sleep and next-day well-being may be attenuated or eliminated under conditions of major life stress. As we reflect on the stress and uncertainty associated with the pandemic, it remains imperative to improve and maintain optimal sleep behaviors, while also supporting individuals and groups at greatest risk for psychological distress.

Declaration of conflict of interest

Dr Slavish reports industry grant funding from Canopy Growth Corporation that is outside the scope of the current work. The other authors have no conflicts of interest to report.

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Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.sleh.2021.09.007.

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