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Original Article

Sleep health early in the coronavirus disease 2019 (COVID-19) outbreak in the United States: integrating longitudinal, cross-sectional, and retrospective recall data

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ABSTRACT

Background: The outbreak of coronavirus disease 2019 (COVID-19) caused substantial changes in lifestyle, responsibilities, and stressors. Such dramatic societal changes might cause overall sleep health to decrease (stress view), to remain unchanged (resilience view), or even to improve (reduced work/schedule burden view).

Methods: We addressed this question using longitudinal, cross-sectional, and retrospective recall methodologies in 699 American adult participants in late March 2020, two weeks following the enactment of social distancing and shelter-in-place policies in the United States.

Results: Relative to baseline data from mid February 2020, cross-sectional and longitudinal analyses demonstrated that average sleep quality was unchanged, or even improved, early in the pandemic. However, there were clear individual differences: approximately 25% of participants reported that their sleep quality had worsened, which was explained by stress vulnerability, caregiving, adverse life impact, shift work, and presence of COVID-19 symptoms.

Conclusions: Therefore, the COVID-19 pandemic has detrimentally impacted some individuals' sleep health while paradoxically benefited other individuals' sleep health by reducing rigid work/school schedules such as early morning commitments.

1. Introduction

In December 2019, an outbreak of coronavirus disease 2019 (COVID-19) was reported in Wuhan, China [1]. By March 11, 2020, the outbreak had spread to over 100 countries and was classified as a pandemic by the World Health Organization [2]. The United States (U.S.) was the most severely impacted country, with more than two million confirmed cases and over 110,000 deaths in the first three months [3].

Because the coronavirus can be transmitted from person to person even when the carrier is asymptomatic, physical/social distancing is required to limit the spread of the disease [4]. To encourage social distancing, the U.S. White House declared a national emergency on March 13, prompting widespread closings of schools and businesses [5]. By March 24, shelter-in-place (or stay-at-home) policies were ordered for 175 million Americans (Fig. 1; [6]). These policies dramatically changed residents' lifestyles, work commitments, social opportunities, and caregiver responsibilities. For many individuals, the pandemic led to financial stress, food insecurity, and fear of becoming ill or transmitting the virus to others [7].

The present work investigated how COVID-19 impacted the sleep health of Americans during the first couple weeks of the pandemic declaration (Fig. 1). This question has translational health implications: Poorer sleep quality is associated with increased susceptibility to viral infections [8], reduced efficacy of vaccinations [9], and worsened mental health [10]. When people are sleep deprived, they show greater anxiety/stress reactivity [11], greater tendencies to blame and punish others for mistakes [12], poorer job performance [13], and lower cognitive functioning [14].

In addition to translational implications, the COVID-19 social isolation policies provide an opportunity to test how one's environment influences sleep patterns. If poor sleep health is primarily driven by stress, then the COVID-19 pandemic should be linked to poorer sleep quality due to increased financial, food, and health

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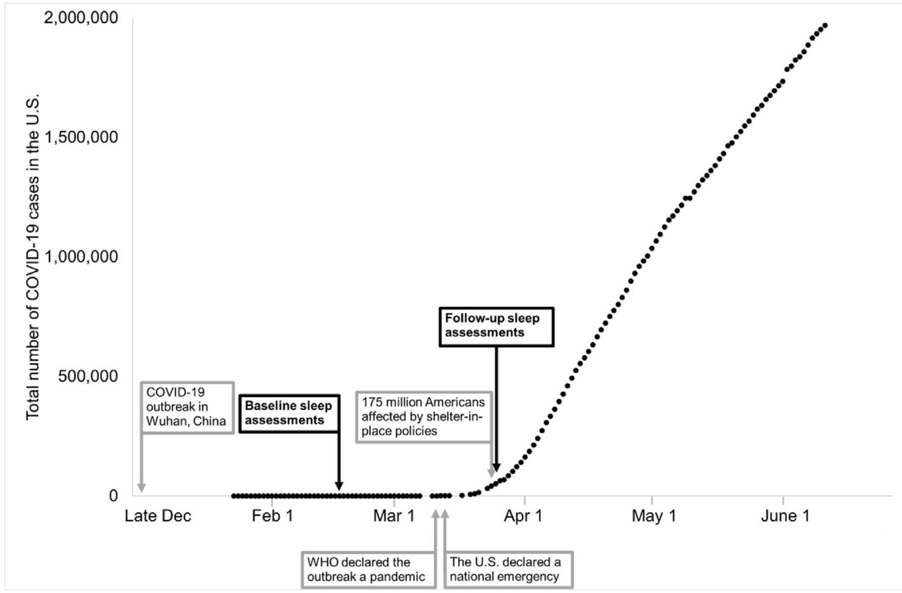

Fig. 1. Timeline of coronavirus disease 2019 pandemic in the United States, indicating that data collection occurred during the early, escalation phase and following approximately two weeks of social distancing policies. Data source for confirmed cases: [3]). WHO = The World Health Organization.

stressors that cause pre-bed cognitive arousal [15]. Alternatively, if poor sleep health is primarily driven by demanding work/school obligations, then the COVID-19 pandemic should be linked to better sleep quality due to reduced early morning requirements, lessened time-sensitive work/school demands, and simplified to-do lists [16,17]. It is also possible, of course, that people will show resilience in their overall sleep quality to the COVID-19 pandemic [18].

2. Methods

2.1. Participants

Participants ($N = 699$, $M_{age} = 38.04$, $SD_{age} = 11.65$, 44.78% female) consisted of two samples of adults who were living in the United States (Table 1). Both groups of participants completed all assessments online via the Amazon Mechanical Turk website.

The first group included 199 adults who completed a sleep survey in mid-February,[1] that is, prior to the implementation of quarantine policies in the U.S (Fig. 1). We hereafter refer to this group as baseline data. We invited these baseline participants to complete the survey again in late-March, after approximately two weeks of quarantine/social distancing due to COVID-19 being declared a national emergency (longitudinal data). Two participants indicated at baseline that they did not want to complete a follow-up study, 111 individuals did not respond, and 86 participants completed the follow-up survey (43.22%). This subsample was generalizable to the overall sample in showing similar global sleep quality scores [t (184) = 0.002, $p > 0.99$, $d < 0.01$], gender [$\chi(1) = 0.16$, $p = 0.686$, $\varphi = 0.03$], race/ethnicity [$\chi(1) = 0.84$, $p = 0.359$, $\varphi = 0.07$], chronotype [t (197) = 0.22, $p = 0.823$, $d = 0.03$], and baseline employment status [$\chi(1) = 1.84$, $p = 0.174$, $\varphi = 0.10$]. The only difference was that the follow-up subsample was slightly older ($M = 38.23$, $SD = 12.91$) than the subsample that did not complete the follow-up [$M = 34.22$, $SD = 8.76$; t (197) = 2.61, $p = 0.010$, $d = 0.35$]. Among the 86 participants who completed the longitudinal assessments, employment status did not change from baseline to follow-up (McNemar test: $p = 0.500$).

The second group of 500 participants only completed the sleep survey during the quarantine period (Table 1). The sample size of this second group was determined by an a priori power analysis which indicated that $n = 500$ provided 0.90 power for two-tailed tests with alpha = 0.05 to detect small-medium sized cross-sectional effects ($d = 0.30$) and small-medium sized ($r = 0.15$) correlations between sleep patterns and COVID-19-related factors (eg, stress, adverse life impact, geographical location).

Inclusion criteria were being 18 years or older and living in the United States. This study was approved by the Baylor University Institutional Review Board and all participants provided written informed consent prior to participation. This study was registered on Open Science Framework prior to data collection (https://osf.io/exkcq). Study materials and de-identified data are also publicly available (https://osf.io/ey3fz).

2.2. Procedure

The procedure timeline relative to the COVID-19 pandemic spread is illustrated in Fig. 1. Baseline-phase data collection occurred on February 17, 2020. At baseline, there had been 0 deaths and only 15 confirmed cases in the U.S [19]. There were no business or school closings and the national leading experts (eg, Anthony Fauci) had not advised lifestyle changes in response to COVID-19 [20]. In addition, at the time of baseline assessment, no formal concerns were expressed by the U.S. White House or local governments [20]. The baseline survey assessed demographic information, global sleep quality, vulnerability to stress-related sleep disturbance, sleepiness, intraindividual variability in sleep,[2]

[1] The baseline data collection in February was conducted with the intention of studying sleep health in relation to music habits (see Ref. [21]), but because assessing sleep patterns in mid-February served as an ideal pre-quarantine baseline, we recruited these participants to repeat the sleep survey during the quarantine period so that the study would include both cross-sectional and longitudinal data.

[2] At both time points we included a measure of intraindividual variability in sleep that we recently developed, but because we have yet to validate this scale the data will not be included in the current report.

Table 1
Participant characteristics.

	n = 199 before quarantine	n = 86 before and during quarantine		n = 500 new participants during quarantine
		Before quarantine	During quarantine	
Age	35.95 (10.91), Range: 20-74	38.23 (12.91), Range: 22-74		38.87 (11.84), Range: 18-69
Gender (Female)	87 (43.72%)	39 (45.35%)		226 (45.20%)
Race (Caucasian)	151 (75.88%)	68 (79.07%)		359 (71.80%)
Employed	180 (90.45%)	75 (87.21%)		448 (89.60%)
Shift worker	66 (33.17%)	25 (29.07%)	21 (24.42%)	115 (23.00%)
Chronotype (Morning)	108 (54.27%)	45 (52.33%)	40 (46.51%)	289 (57.80%)
Overall health (1–5 scale, lower = poorer)	3.65 (0.88), Range: 1-5	3.62 (0.96), Range: 1-5	3.56 (0.93), Range: 1-5	3.66 (0.90), Range: 1-5
Coffee (cups consumed today)	1.55 (1.59), Range: 0-8	1.13 (1.47), Range: 0-8	1.23 (1.37), Range: 0-5	1.42 (1.55), Range: 0-9
Local government issued shelter-in-place/stay-at-home orders	NA[a]	NA[a]	51 (59.30%)	356 (71.20%)
Had symptoms of COVID-19 in past two weeks	NA[a]	NA[a]	2 (2.33%)	35 (7.00%)
Tested positive for COVID-19	NA[a]	NA[a]	1 (1.16%)	20 (4.00%)
Number of COVID-19 cases in the participants' state as of March 24				
>10,000	NA[a]	NA[a]	7 (8.14%)	32 (6.40%)
1001–10,000	NA[a]	NA[a]	33 (38.37%)	236 (47.20%)
501-1000	NA[a]	NA[a]	24 (27.91%)	81 (16.20%)
≤500	NA[a]	NA[a]	21 (24.42%)	150 (30%)

Data presented as mean (standard deviation), range or n (%).
[a] COVID-19 related data are not available from baseline participants.

chronotype, overall health, and music listening habits[1] (music data are reported elsewhere [21]).

Quarantine-phase data collection occurred from March 25 through March 27, 2020, which was approximately two weeks after the U.S. declared a national emergency and social distancing/quarantine policies began. At least one week before the March 25 assessment, 41 states had mandated state-wide school closures, and many schools in the remaining nine states had closed voluntarily (a similar pattern existed for non-essential businesses, eg, there were local school closures before statewide school closures in Texas [22]). We launched the survey at approximately 2:30pm CDT, which was the same time of day as the baseline survey. Data collection concluded at 4:40pm CDT on March 27, 2020. The questions included in the survey were the same as at baseline, but we replaced the questions on music listening with questions regarding COVID-19-related stressors/experiences as well as retrospective recall questions on sleep patterns prior to (versus during) the COVID-19 quarantine.

2.3. Materials

The primary sleep measure was the Pittsburgh Sleep Quality Index (PSQI [23]). The PSQI is a 9-item questionnaire assessing sleep habits and sleep difficulties over the past month. The questionnaire yields a widely-used global sleep quality index in which higher scores indicate worse sleep quality (primary dependent variable). To better capture the COVID-19 quarantine time interval, we modified the PSQI to refer to sleep over the past two weeks.

Vulnerability to stress-related sleep disturbance was measured by the Ford Insomnia Response to Stress Test (FIRST [24]). The FIRST has participants rate the likelihood of experiencing difficulty sleeping in nine stressful situations on a 4-point scale from “Not likely” to “Very likely” (eg, “How likely are you to have difficulty sleeping after a stressful experience during the day?”). Total FIRST scores range from 9 to 36 and higher scores indicate greater vulnerability to sleep disturbances in stressful situations.

Daytime sleepiness was measured by the Stanford Sleepiness Scale (SSS [25]). Participants rated how sleepy they felt at the moment from 1 (“Feeling active, vital, alert, or wide awake”) to 7 (“No longer fighting sleep, sleep onset soon; having dream-like thoughts”). Participants additionally reported their coffee consumption (number of cups that day), chronotype (from “definitely morning” to “definitely evening”), and their overall health (5-point scale ranging from “Poor” to “Excellent”).

In addition to the aforementioned questionnaires, during the quarantine phase, we additionally had participants attempt to retrospectively recall how they slept before the COVID-19 pandemic relative to how they were sleeping currently. Participants were asked to estimate their bedtime, risetime, sleep duration, sleep onset latency, and the number of nighttime awakenings for before and during the quarantine.

To examine moderators of sleep health during the quarantine phase, we asked questions that focused on COVID-19 experiences. Participants indicated whether their local government had issued shelter-in-place orders (or stay-at-home orders), whether they or people around them had shown symptoms of COVID-19 or been tested positive for COVID-19, and whether their caregiver or work responsibilities had changed during the COVID-19 quarantine. Moreover, participants rated the extent to which they agreed or disagreed with ten statements related to COVID-19 and reported whether they experienced changes in how well-rested they have felt during the quarantine on a 7-point Likert scale. These statements can be seen in Table S1. We analyzed participants' responses on these statements by conducting factor analysis with Varimax rotation to reduce the number of dimensions. Factor analysis revealed that the ten statements loaded onto three factors that we labeled “adverse life impact,” “worry/stress,” and “pro-actions.” We summed the scores on the items in each dimension to constitute a dimensional score. Last, participants completed a free response question in which they were invited to comment on how the quarantine/social distancing had affected them (responses are available at https://osf.io/ey3fz). At both baseline and quarantine phases, participants reported standard demographic (eg, age, gender, race/ethnicity) and work information (employed, shift-work). At the quarantine phase, we also had participants report their geographical location. By doing so, we were able to match participants’ location to the number of confirmed COVID-19 cases in their state of residence as of midnight March 24, 2020. The geographical distributions of participants and COVID-19 cases at the time of data collection are displayed in Figure S1 (Johns

Hopkins University [26]). Note that the number of confirmed cases may be inconsistent with daily data reported by the WHO, because the Johns Hopkins database extracted state-level data from multiple publicly available sources and updated the results in real time [27].

2.4. Statistical analysis

Participants who met any of the following criteria did not pass data quality control: (1) reported impossible values (eg, sleeping for 25 h/day); (2) responded to free response questions in an identical manner as other participants (suggesting a bot); or (3) demographic information at follow-up did not match demographic information at baseline. Of 791 survey responses, 699 passed data quality control and were included in analyses (Fig. 2).

Study hypotheses, study design, power analyses, and dependent variables were pre-registered to Open Science Framework. We used SPSS (version 26) to conduct all statistical analyses. All tests were two-tailed and results were considered significant if $p \le 0.05$. Effect sizes were estimated using Cohen's d (for t-tests), φ (for chi-square tests), and correlation coefficients (for Pearson's correlation analyses).

For the cross-sectional analyses, we used independent-samples t-tests to compare the sleep measures across participants who completed the study in mid February (baseline) and participants who only completed the study in late March (quarantine phase). We then supplemented the t-tests with independent samples Bayesian analyses. For the longitudinal analyses, we used paired-sample t-tests to assess changes in sleep measures in participants who completed the survey both in mid-February and late-March, supplementing these t-tests with related-samples Bayesian analyses.

3. Results

3.1. Group differences in demographic variables

We first examined whether there were demographic differences between participants at the baseline assessment ($n = 199$) and participants who only completed the quarantine assessment ($n = 500$; Table 1). The groups were similar in proportion of females [$\chi(1) = 0.13$, $p = 0.722$, $\varphi = 0.01$], race/ethnicity [$\chi(1) = 1.20$, $p = 0.273$, $\varphi = 0.04$], proportion of employed participants [$\chi(1) = 0.04$, $p = 0.844$, $\varphi = 0.01$], and proportion of participants living in a state with more than 1000 confirmed COVID-19 cases [$\chi(1) = 1.29$, $p = 0.256$, $\varphi = 0.05$]. Relative to baseline participants, quarantine-phase participants were 2.92 years older [$t(696) = 3.00$, $p = 0.003$. $d = 0.25$]; however, because chronological age was not related to the primary sleep measure (PSQI), $r(577) = 0.004$, $p = 0.914$, it will not be discussed further (see Figure S2 for age distribution and PSQI-age scatterplot).

The only other demographic difference across the two groups was that the quarantine phase included fewer shift workers than the baseline phase [$\chi(1) = 7.67$, $p = 0.006$, $\varphi = 0.11$]. One possible explanation for this change was that shift workers were more likely than non-shift workers to be classified as essential workers during the pandemic, meaning they were probably less available for study participation. Shift work is known to influence sleep quality, and was associated with worse PSQI sleep quality in the current study (Fig. 3a); therefore, we will address the influence of shift work below using sensitivity analyses. In addition, 7.68% of participants reported having symptoms or testing positive for COVID-19, which was associated with considerably worse sleep quality (Fig. 3b). We accounted for this potential confound to the cross-sectional and longitudinal comparisons via sensitivity analyses (see also, study on frontline healthcare workers [28,29]).

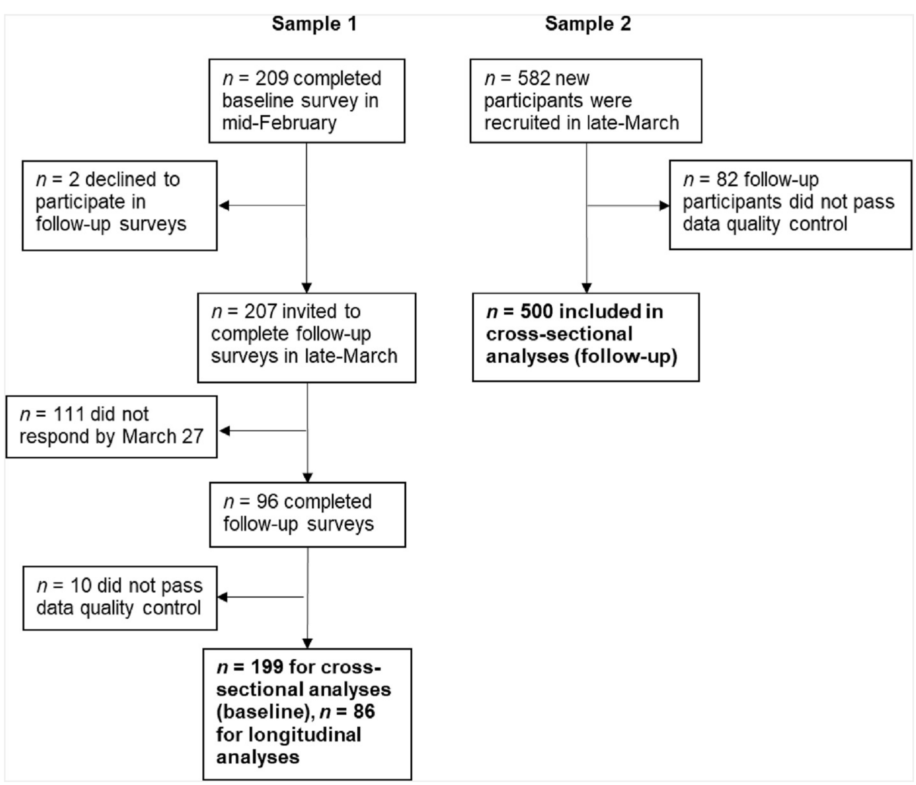

Fig. 2. Data collection procedures. Sample 1 completed assessments in mid-February prior to widespread COVID-19 concerns in the United States and again in late-March, approximately two weeks into social distancing, shelter-in-place, and other "quarantine" policies. Sample 2 only completed assessments in late-March.

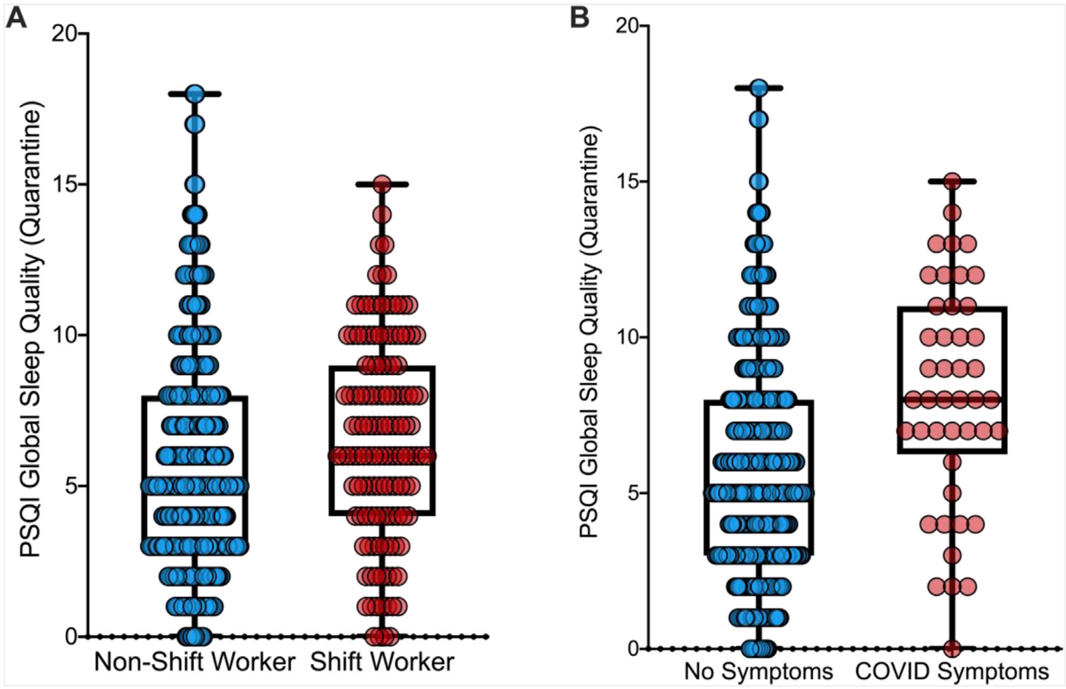

Fig. 3. Box and whisker plots illustrating that the primary dependent measure—PSQI global sleep quality score—was significantly worse/higher in shift workers (A), $t\,(578) = 2.272$, $p = 0.023$, and significantly worse/higher in individuals who tested positive or showed symptoms of COVID-19 (B), $t\,(578) = 4.314$, $p < 0.001$.

3.2. Cross-sectional differences in the primary and secondary sleep measures

Table 2 shows the cross-sectional comparison between participants who only completed the survey during the quarantine ($n = 500$) and participants who completed the baseline survey ($n = 199$). The two groups slept very similarly, as measured by the primary dependent measure (PSQI global sleep quality: $t\,(678) = 1.51$, $p = 0.130$, $d = 0.13$], and the secondary measures (FIRST: $t\,(697) = 1.25$, $p = 0.211$, $d = 0.11$; SSS: $t\,(697) = 1.24$, $p = 0.216$, $d = 0.10$]. Bayes Factor (BF) analyses indicated moderate to strong evidence for the null hypothesis for PSQI scores ($BF_{10} = 0.21$), FIRST scores ($BF_{10} = 0.14$), and SSS scores ($BF_{10} = 0.14$). Sensitivity analyses that excluded shift workers and participants who tested positive or reported symptoms of COVID-19 (Fig. 3; [30,31]) showed a nominal, though nonsignificant, leaning toward improved sleep quality during the pandemic (Table 2). This was an interesting initial finding, running counter to the notion that stress-induced heightened arousal globally worsened sleep quality during the COVID-19 pandemic.

3.3. Longitudinal changes in the primary and secondary sleep measures

We next repeated the sleep measure analyses using participants who completed both the baseline and quarantine phase assessments. The data are presented in Table 3. This longitudinal analysis converged with the cross-sectional findings in showing no significant changes in the primary dependent measure (PSQI global score: $t\,(82) = 1.88$, $p = 0.064$, $d = 0.21$, $BF_{10} = 0.48$] or the secondary dependent measures (FIRST scores: $t\,(85) = 0.68$, $p = 0.497$, $d = 0.07$, $BF_{10} = 0.11$; SSS scores: $t\,(85) = 0.56$, $p = 0.577$, $d = 0.06$, $BF_{10} = 0.10$]. As we initially observed with the cross-sectional data (Table 2), the longitudinal data showed nominal improvements in sleep quality during the quarantine period (Table 3). For example, it can be seen from Fig. 4a that 47% of participants had improved PSQI scores from baseline to quarantine, a significantly larger proportion than the 29% of participants who had worsened PSQI scores, $\chi(1) = 5.76$, $p = 0.016$.

The sensitivity analyses on non-shiftworkers without COVID-19 positive tests (or symptoms) provided additional evidence for these sleep improvements. Participants' PSQI sleep quality scores improved significantly from the baseline to the quarantine phase [Table 3; $t\,(50) = 2.61$, $p = 0.012$, $d = 0.37$, $BF_{10} = 2.53$]. Given the significant overall effect, we more closely examined why PSQI scores were improving, with the data detailed in Table S2. During the quarantine phase, participants showed increased sleep duration [$t\,(51) = 2.08$, $p = 0.043$, $d = 0.29$] with delayed bedtimes [$t\,(51) = 2.36$, $p = 0.022$, $d = 0.33$], delayed risetimes [$t\,(50) = 2.30$, $p = 0.026$, $d = 0.32$], and fewer sleep disturbances [$t\,(50) = 2.71$, $p = 0.009$, $d = 0.38$].

3.4. Retrospective recall of sleep prior to the current quarantine phase

The cross-sectional and longitudinal evidence has thus far indicated that, for many U.S. adults, sleep quality was not changed early in the COVID-19 pandemic; notably, when excluding shiftworkers and symptomatic individuals, longitudinal analyses indicated that sleep quality improved early in the pandemic in U.S. adults. At the end of the survey, we asked participants to retrospectively recall how they thought they slept before the pandemic (in comparison to their current sleep). Those reports are provided in Table 4. When asked to retrospectively recall their sleep, participants estimated that they had slept much better prior to the COVID-19 quarantine, including greater ease falling asleep (sleep onset latency; $t\,(574) = 5.83$, $p < 0.001$, $d = 0.24$, $BF_{10} > 10.00$], fewer awakenings in the middle of the night [$t\,(574) = 6.56$, $p < 0.001$, $d = 0.27$, $BF_{10} > 10.00$], earlier bedtimes [$t\,(428) = 3.91$, $p < 0.001$, $d = 0.19$, $BF_{10} > 10.00$], later wake times [$t\,(434) = 6.76$, $p < 0.001$, $d = 0.32$, $BF_{10} > 10.00$], and feeling more rested [$t\,(580) = 8.30$, $p < 0.001$, $d = 0.34$, $BF_{10} > 10.00$; no changes to sleep duration, $t\,(568) = 1.84$, $p = 0.066$, $d = 0.08$, $BF_{10} = 0.18$].

Table 2
Cross-sectional comparisons of sleep patterns before and during the COVID-19 quarantine.

	Before quarantine	During quarantine	Comparisons
All Participants	$n = 199$	$n = 500$	
PSQI (global sleep quality)	6.45 (3.59), Range: 0-16	5.99 (3.43), Range: 0-18	$t\,(678) = 1.51$, $p = 0.130$, $d = 0.13$, $BF_{10} = 0.21$
FIRST (sleep vulnerability to stress)	20.65 (7.32), Range: 9-35	19.92 (6.72), Range: 9-36	$t\,(697) = 1.25$, $p = 0.211$, $d = 0.11$, $BF_{10} = 0.14$
SSS (daytime sleepiness)	2.26 (1.53), Range: 1-7	2.12 (1.29), Range: 1-7	$t\,(697) = 1.24$, $p = 0.216$, $d = 0.10$, $BF_{10} = 0.14$
Sensitivity Analyses	$n = 133$	$n = 362$	
PSQI (global sleep quality)	6.05 (3.62), Range: 0-16	5.70 (3.37), Range: 0-18	$t\,(486) = 0.99$, $p = 0.325$, $d = 0.10$, $BF_{10} = 0.13$
FIRST (sleep vulnerability to stress)	19.86 (7.06), Range: 9-35	19.51 (6.60), Range: 9-36	$t\,(493) = 0.53$, $p = 0.599$, $d = 0.05$, $BF_{10} = 0.09$
SSS (daytime sleepiness)	2.08 (1.32), Range: 1-6	2.02 (1.21), Range: 1-6	$t\,(493) = 0.50$, $p = 0.614$, $d = 0.05$, $BF_{10} = 0.09$

Data presented as mean (standard deviation), range.
Note: Higher scores represent worse sleep outcomes for PSQI, FIRST, and SSS.
Abbreviations: BF_{10} = Bayes Factor: Alternative versus null hypothesis; FIRST = Ford Insomnia Response to Stress Test; PSQI = Pittsburgh Sleep Quality Index; SSS = Stanford Sleepiness Scale.
Sensitivity analyses excluded shift-workers and participants who reported symptoms or positive tests of COVID-19.

Table 3
Longitudinal analyses of sleep patterns at baseline and during the COVID-19 quarantine.

	Before quarantine	Before quarantine	During quarantine	Longitudinal Changes ($n = 86$)
All Participants	$n = 199$	$n = 86$	$n = 86$	
PSQI (global sleep quality)	6.45 (3.59), Range: 0-16	6.45 (3.84), Range: 0-16	5.93 (3.88), Range: 0-17	$t\,(82) = 1.88$, $p = 0.064$, $d = 0.21$, $BF_{10} = 0.48$
FIRST (sleep vulnerability to stress)	20.65 (7.32), Range: 9-35	18.72 (7.38), Range: 9-34	19.02 (7.65), Range: 9-34	$t\,(85) = 0.68$, $p = 0.497$, $d = 0.07$, $BF_{10} = 0.11$
SSS (daytime sleepiness)	2.26 (1.53), Range: 1-7	2.13 (1.37), Range: 1-7	2.21 (1.29), Range: 1-6	$t\,(85) = 0.56$, $p = 0.577$, $d = 0.06$, $BF_{10} = 0.10$
Sensitivity Analyses		$n = 52$	$n = 52$	$n = 52$
PSQI (global sleep quality)	–	6.63 (4.03), Range: 0-16	5.77 (3.79), Range: 0-17	$t\,(50) = 2.61$, $p = 0.012$, $d = 0.37$, $BF_{10} = 2.53$*
FIRST (sleep vulnerability to stress)	–	19.12 (7.63), Range: 9-34	19.33 (7.85), Range: 9-34	$t\,(51) = 0.36$, $p = 0.718$, $d = 0.05$, $BF_{10} = 0.12$
SSS (daytime sleepiness)	–	2.15 (1.19), Range: 1-5	2.15 (1.13), Range: 1-5	$t\,(51) < 0.001$, $p > 0.999$, $d = 0$, $BF_{10} = 0.11$

Data presented as mean (standard deviation), range.
*$p \leq 0.05$.
Note: Higher scores represent worse sleep outcomes for PSQI, FIRST, and SSS.
Abbreviations: BF_{10} = Bayes Factor: Alternative versus null hypothesis; FIRST = Ford Insomnia Response to Stress Test; PSQI = Pittsburgh Sleep Quality Index; SSS = Stanford Sleepiness Scale.
Sensitivity analyses excluded shift-workers and participants who reported symptoms or positive tests of COVID-19.

One interpretation of the retrospective recall data is that they indicate rosy retrospection (ie, remembering the past as being more positive than it actually was) and/or an expectancy effect such that when COVID-19-related changes are queried participants are biased toward negative responses [32,33]. Such psychological reporting tendencies have previously been noted when sleep was measured during wartime [34]. This explanation was supported in the longitudinal sample (shiftworkers, symptomatic individuals excluded); they showed "rosier" remembering of their pre-quarantine sleep when using their actual values at baseline for comparison. For example, at baseline these participants estimated that they slept 6.70 h/night ($SD = 1.15$), but during the follow-up they retrospectively recalled their pre-quarantine sleep duration to be better than that ($M = 6.95$ h, $SD = 1.04$ h), $t\,(48) = 2.68$, $p = 0.010$, $d = 0.38$, $BF_{10} = 2.96$ (Figure S3). Furthermore, at baseline, these participants stated it took them 29.79 min to fall asleep ($SD = 34.10$), but during the follow-up they retrospectively recalled their pre-quarantine sleep latency to be 23% better than that ($M = 22.96$ min, $SD = 22.44$ min), $t\,(50) = 1.72$, $p = 0.092$, $d = 0.24$, $BF_{10} = 0.45$. Participants' bedtime [$t\,(48) = 0.67$, $p = 0.509$, $d = 0.09$, $BF_{10} = 0.14$] and risetime [$t\,(49) = 0.62$, $p = 0.540$, $d = 0.09$, $BF_{10} = 0.13$] estimates did match the values they reported at baseline, providing greater confidence in participants' reports of circadian delays during the COVID-19 pandemic.

3.5. Moderators of sleep quality during the quarantine phase

Fig. 4 indicates that there was individual-level variability in changes to sleep during the pandemic. To understand the sources of this variability in change, we controlled for baseline PSQI global scores and tested whether quarantine PSQI global scores were related to demographic, psychological, or quarantine-related social factors. Changes in sleep quality were not significantly related to demographic factors [age: $r_p\,(80) = 0.10$, $p = 0.354$; gender: $r_p\,(80) = -0.16$, $p = 0.164$; race/ethnicity: $r_p\,(80) = 0.10$, $p = 0.362$], chronotype [$r_p = 0.09$, $p = 0.432$], caregiving responsibilities [$r_p\,(78) = -0.13$, $p = 0.261$], work responsibilities [$r_p\,(79) = 0.12$, $p = 0.292$], shelter-in-place orders [$r_p\,(79) = 0.10$, $p = 0.373$], the number of confirmed COVID-19 cases in participants' state of residence [$r_p\,(79) = -0.21$, $p = 0.060$], or COVID-19 psychological factors [adverse life impact: $r_p\,(78) = 0.08$, $p = 0.494$; worry/stress: $r_p\,(78) = 0.21$, $p = 0.067$; pro-actions: $r_p\,(79) = -0.03$, $p = 0.775$]. Similar results were observed when we restricted the sample to non-shiftworkers without COVID-19 symptoms ($rs \leq 0.25$, $ps > 0.05$).

Nevertheless, Fig. 5 illustrates that participants who reported greater sleep vulnerability to stress at baseline were significantly more likely to show worsening PSQI global scores at quarantine, even when controlling for baseline PSQI scores, $r_p\,(80) = 0.27$, $p = 0.017$. This overall association was driven by driven by three component scores: worsening subjective sleep quality [$r_p\,(80) = 0.36$, $p = 0.001$], worsening daytime functioning [$r_p\,(80) = 0.34$, $p = 0.002$], and worsening sleep disturbances [$r_p\,(80) = 0.42$, $p < 0.001$]. Because sleep disturbances showed a particularly strong association with sleep vulnerability to stress, and because sleep disturbances showed significant longitudinal changes in sensitivity analyses (Table S3), we further analyzed whether worse sleep disturbance scores during the quarantine phase (after controlling for baseline PSQI sleep disturbance) were associated with COVID-19 psychological factors. Fig. 6 shows that

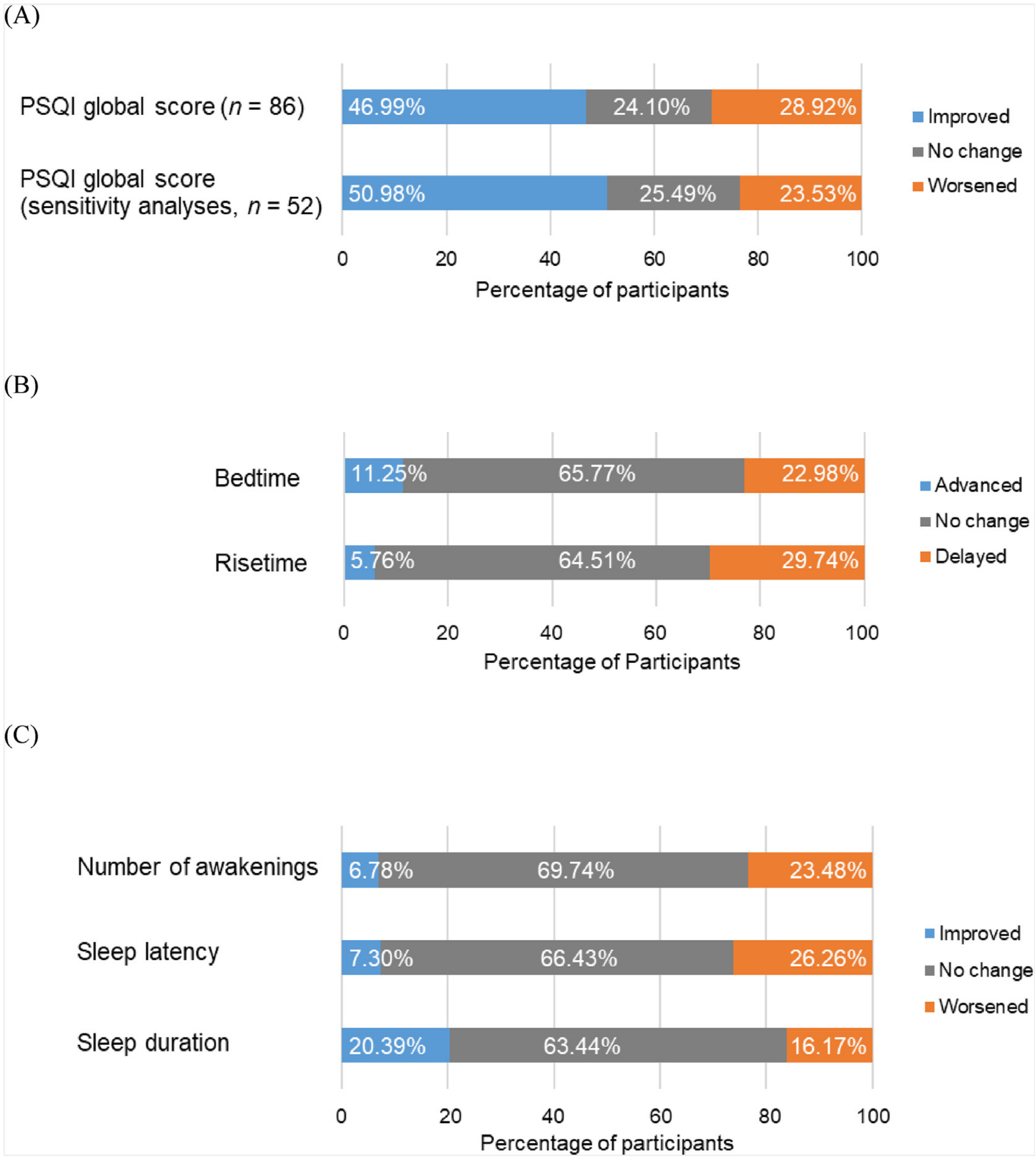

Fig. 4. Individual variability in whether sleep patterns reported on Pittsburgh Sleep Quality Index at two occasions (A; sample 1) and retrospective recall of sleep patterns at follow-up (B, C; sample 1 and sample 2, $n = 586$) improved or worsened as a function of the COVID-19 pandemic.

Table 4
Retrospective recall of sleep patterns before and during quarantine.

	$n = 586$ participants who completed follow-up assessments		
	Before quarantine	During quarantine	Comparisons
Bedtime[a]	10:59pm (109.63 min), Range: 4:00pm-9:30am	11:13pm (126.94 min), Range: 4:00pm-11:00am	t (428) = 3.91, $p < 0.001$, $d = 0.19$, $BF_{10} > 10.00$**
Risetime[a]	6:50am (108.54 min), Range: 12:00am-6:15pm	7:14am (118.66 min), Range: 12:00am-6:15pm	t (434) = 6.76, $p < 0.001$, $d = 0.32$, $BF_{10} > 10.00$**
Sleep duration (h)	7.07 (1.40), Range: 1-15	7.15 (1.47), Range: 1-15	t (568) = 1.84, $p = 0.066$, $d = 0.08$, $BF_{10} = 0.18$
Sleep latency (min)	21.47 (20.83), Range: 0-180	24.14 (23.15), Range: 0-180	t (574) = 5.83, $p < 0.001$, $d = 0.24$, $BF_{10} > 10.00$**
Number of awakenings	1.37 (1.54), Range: 0-10	1.70 (1.77), Range: 0-15	t (574) = 6.56, $p < 0.001$, $d = 0.27$, $BF_{10} > 10.00$**

Data presented as mean (standard deviation), range.
**$p \leq 0.01$.
Abbreviation: BF_{10} = Bayes Factor: Alternative versus null hypothesis.
[a] To reduce the impact of extreme values, shift workers were excluded from analyses of bedtime and risetime.

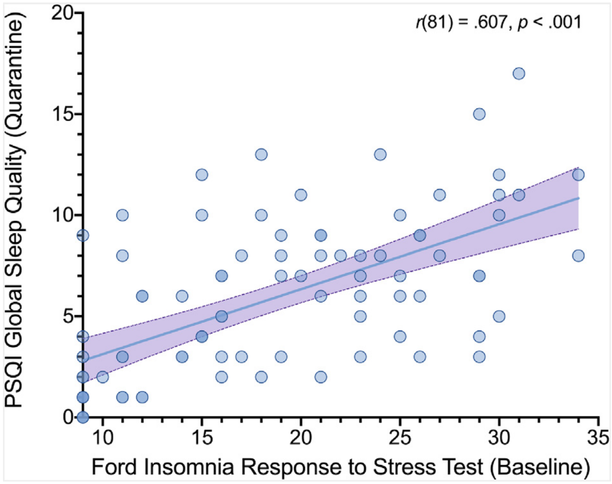

Fig. 5. Scatterplot to illustrate the longitudinal association between baseline-phase stress vulnerability (FIRST scores) and quarantine-phase sleep quality (PSQI scores). Upper and lower bounds represent the 95% confidence interval. Regression-based analyses demonstrate that this relationship is retained after controlling for baseline PSQI scores [r_p (80) = 0.27, $p = 0.017$]. Higher scores represent worse sleep quality and greater vulnerability to stress.

greater COVID-19 adverse life impact (r_p (46) = 0.30, $p = 0.040$) and greater COVID-19 worry/stress (r_p (47) = 0.43, $p = 0.002$) were significantly associated with a longitudinal worsening of PSQI sleep disturbances (other factors: $rs \leq 0.24$, $ps > 0.10$). Thus, there is a group of stress-vulnerable and life-impacted individuals who are particularly susceptible to sleep loss in the current pandemic.

Next, we tested whether participants' retrospective recall estimates of their sleep changes were moderated by the same factors (see Table S3 for nonsignificant associations). After adjusting for pre-quarantine estimates, individuals with greater vulnerability to stress (FIRST scores) perceived greater sleep latencies [r_p (572) = 0.17, $p < 0.001$] and more awakenings during the quarantine [r_p (572) = 0.27, $p < 0.001$]. Increased caregiving responsibilities were also associated with perceptions of greater difficulty falling asleep [r_p (570) = 0.12, $p = 0.005$] and more awakenings during the night [r_p (570) = 0.15, $p < 0.001$], after adjusting for pre-quarantine estimates. The number of confirmed COVID-19 cases in the participant's state was only predictive of a greater delay in bedtimes [r_p (426) = 0.16, $p = 0.001$], whereas COVID-19 psychological factors (adverse life impact and worry/stress) were significantly associated with difficulty falling asleep [r_p (564) = 0.15, $p < 0.001$; r_p (566) = 0.16, $p < 0.001$], awakenings during the night [r_p (564) = 0.18, $p < 0.001$; r_p (566) = 0.21, $p < 0.001$], and circadian delays [r_p (427) = 0.13, $p = 0.009$; r_p (427) = 0.14, $p = 0.005$].

4. Discussion

Despite the myriad of COVID-19-related changes to stressors, work, and lifestyles, cross-sectional analyses indicated that U.S. participants, in general, showed resilience in their overall sleep health. Though sleep quality undoubtedly worsened in some individuals during the pandemic, the longitudinal analyses indicated that, on average, sleep health actually improved in non-shiftworkers. We will discuss each of these findings in turn.

4.1. Some individuals experienced or perceived worsening sleep

The current study coincidentally had an optimal control (baseline) group for this online study as we had surveyed sleep health using an online sample one month prior to the U.S. outbreak of COVID-19 infections and associated policies.[1] The sleep data in the baseline group closely matched the sleep data we observed in another online sample taken years prior to the COVID-19 pandemic (mean PSQI = 6.60 in Ref. [35]). If we had not included this baseline group, but instead relied solely on retrospective recall data, then we would have (erroneously) concluded that most Americans' sleep during the pandemic was far worse than it was prior to the pandemic.

In times of stress, recall biases can emerge [33], particularly when people are expecting negative outcomes [32,34]. The increased fear during the COVID-19 pandemic [36] may bias people toward recalling only poor nights of sleep, or viewing one's pre-pandemic health as more positive than it actually was [37]. We observed some evidence of rosy retrospection in our data (Figure S3). Though the collective data do not point to an overall worsening of worsening of sleep quality during the pandemic, the longitudinal analyses did indicate that approximately ¼ of participants' PSQI scores worsened. Sleep quality was more likely to worsen if an individual had pre-existing vulnerability to stressors, if their caregiving responsibilities had increased, and if their life had

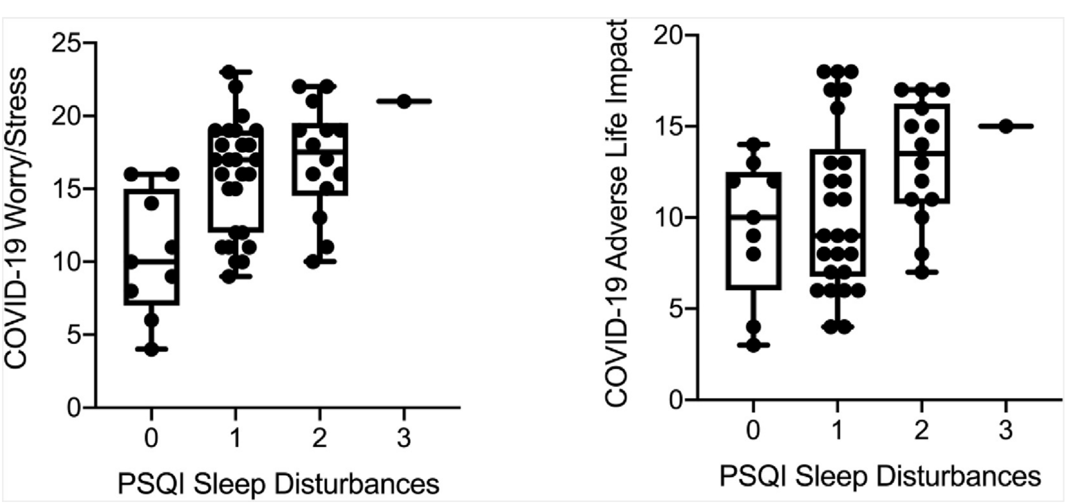

Fig. 6. Greater levels of COVID-19 worry/stress and adverse life impact were associated with greater levels of quarantine PSQI sleep disturbances (even when controlling for baseline sleep disturbance component scores).

been adversely impacted by COVID-19 (including becoming infected). Special attention should be paid to improving the sleep health of these at-risk individuals because sleep quality underlies cognitive, mental, and physical health, including the likelihood of resisting viral infections [8,9].

4.2. Societal resilience

The mental health and sleep health of frontline responders has been severely affected by COVID-19 [28,29]. However, the current study indicates that the general public has remained resilient to the chronic threat of viral infection and upheaval of their daily lifestyles. Though surprising, this is not the first study to document that sleep can adapt well in dangerous environments. During World War II, sleep health was generally preserved in London residents during the 8-month “London Blitz” bombing campaign [18]. Furthermore, during the Gulf War, individuals living in areas under missile attacks did not show objective sleep quality declines, despite phone survey respondents issuing subjective sleep complaints [34]. While imminent threat and constant vigilance undoubtedly worsen sleep [28,29,38], in general, the current findings of resilience to the pandemic are consistent with the theory that sleep is homeostatically regulated ([39]; see also [40], for conceptual application to insomnia).

4.3. Mechanisms of sleep improvement during the pandemic

Unlike the Gulf War environment, the COVID-19 pandemic required social distancing, school closures, and working from homes. Under these conditions, approximately 50% of U.S. adult participants showed improvements to their global sleep quality in longitudinal analyses (25% were unchanged; see also [41]). The improvements were strikingly evident when the analyses excluded shiftworkers and people who had tested positive or showed symptoms of COVID-19 (both of which were independently associated with worse sleep quality, Fig. 3). These findings highlight the negative impact that morning commitments, urgency of work/school demands, and extensive to-do lists can have on society's sleep health [17,41,42].

4.4. Limitations and conclusions

Limitations of the current study include a non-random sample of Americans, attrition, and reliance on surveys rather than actigraphy. Nevertheless, the current work demonstrates that individuals who are not sick, are not working night shifts, and are not frontline responders may actually experience improvements to their sleep quality as a result of shelter-in-place and social distancing policies. The lesson, therefore, is that when the nation returns “to normal” (post-pandemic), maintaining flexibility in school/work schedules will be critical to preserving or enhancing the sleep health of the public.

Author statement

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Conflict of interest

The authors do not have any conflict of interest to report.

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Conflict of interest

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sleep.2020.06.032.

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