Insomnia, Poor Sleep Quality and Sleep Duration, and Risk for COVID-19 Infection and Hospitalization

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ABSTRACT

BACKGROUND: Medical comorbidities increase the risk of severe acute COVID-19 illness. Although sleep problems are common after COVID-19 infection, it is unclear whether insomnia, poor sleep quality, and extremely long or short sleep increase risk of developing COVID-19 infection or hospitalization.

METHODS: The study used a cross-sectional survey of a diverse sample of 19,926 US adults.

RESULTS: COVID-19 infection and hospitalization prevalence rates were 40.1% and 2.9%, respectively. Insomnia and poor sleep quality were reported in 19.8% and 40.1%, respectively. In logistic regression models adjusted for comorbid medical conditions and sleep duration but excluding participants who reported COVID-19-associated sleep problems, poor sleep quality, but not insomnia, was associated with COVID-19 infection (adjusted odds ratio [aOR] 1.16; 95% CI, 1.07-1.26) and COVID-19 hospitalization (aOR 1.50; 95% CI, 1.18-1.91). In comparison with habitual sleep duration of 7-8 hours, sleep durations <7 hours (aOR 1.14; 95% CI, 1.06-1.23) and sleep duration of 12 hours (aOR 1.61; 95% CI, 1.12-2.31) were associated with increased odds of COVID-19 infection. Overall, the relationship between COVID-19 infection and hours of sleep followed a quadratic (U-shaped) pattern. No association between sleep duration and COVID-19 hospitalization was observed.

CONCLUSION: In a general population sample, poor sleep quality and extremes of sleep duration are associated with greater odds of having had a COVID-19 infection; poor sleep quality was associated with an increased requirement of hospitalization for severe COVID-19 illness. These observations suggest that inclusion of healthy sleep practices in public health messaging may reduce the impact of the COVID-19 pandemic.

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KEYWORDS: COVID-19; Epidemiology; Hospitalization; Infection; Insomnia; Poor sleep quality; Sleep duration

INTRODUCTION

As of March 2, 2023, the mortality estimates from COVID-19 worldwide and in the United States are 6,874,788 and 1,121,280, respectively.[1] Despite the introduction of effective vaccines, treatments and other mitigation strategies, disease burden remains high.[1]

Early in the pandemic it was established that older individuals and those with several common medical conditions are at greater jeopardy for COVID-19-related hospitalization and death.[2,3] These risk factors garnered considerable attention and shaped initial public health messaging. However, with the exception of several studies implicating obstructive sleep apnea to higher rates of COVID-19 infection,[4-6] morbidity,[7] and mortality,[8] there have been relatively few investigations of dysfunctional sleep as a potential risk for developing COVID-19.[9-12]

Both short and long sleep duration have been implicated as causal factors in the development of a number of medical conditions, including cardiovascular disease and diabetes.[13-15] Importantly, insufficient sleep has been demonstrated to blunt the immune response to vaccination[16-18] and increase the risk of developing rhinovirus virus infection.[19] Insomnia and poor sleep quality also have been linked to greater rates of cardiovascular disease,[20] diabetes,[21] and early mortality.[22]

Sleep problems are commonly reported symptoms among individuals with post-acute sequelae of COVID-19 (PASC; also called Post-COVID Condition [PCC] and "long COVID").[23] However, it remains unclear whether poor sleep is a risk factor for COVID-19 infection. This study aimed to evaluate whether individuals with self-reported insomnia, poor sleep quality, or either short or long sleep duration have differential risk of COVID-19 outcomes (infection, hospitalization). To accomplish this, we used data from the first 4 2022 waves of the COVID-19 Outbreak Public Evaluation (COPE) Initiative (http://www.thecopeinitiative.org/), a program focused on collecting and disseminating data on public attitudes, behaviors, and beliefs related to the COVID-19 pandemic, as well as on mental and behavioral health during the pandemic from large-scale, demographically representative samples of US adults.

METHODS

Study Design and Participants

From March 10 to August 18, 2022, the COPE Initiative administered 4 successive waves of public health surveillance surveys. Each wave consisted of more than 5000 unique participants recruited by Qualtrics, LLC (Provo, Utah, and Seattle, Wash) using demographic quota sampling to approximate population estimates for age, sex, race, and ethnicity based on the 2020 US census. The study was approved by the Monash University Human Research Ethics Committee (Study #24036).

CLINICAL SIGNIFICANCE

- Insomnia or poor-quality sleep may be risk factors for developing COVID-19 infection.
- Poor sleep quality may be a risk factor for COVID-19 hospitalization.
- Short sleep duration and very long sleep duration may increase the risk for COVID-19 infection.

Survey Items

Participants self-reported demographic, anthropometric, and socioeconomic information including age, race, ethnicity, sex, height and weight, education level, employment status, and household income. As detailed in the Appendix (available online), they reported information on several current and past medical conditions including insomnia.

The following 2 questions pertaining to sleep quality were asked of the participants:

1. "Thinking about the past month, to what extent has poor sleep troubled you in general?" Possible responses were "Not at all," "A little," "Somewhat," "Much," and "Very Much."
2. From the Pittsburgh Sleep Quality Index,[24] "During the past month, how would you rate your sleep quality overall?" Possible responses were "Very good," "Fairly good," "Fairly bad," and "Very bad."

Participants were considered to have "Poor Sleep Quality" if they endorsed currently having insomnia or being troubled by poor sleep ("Much" or "Very Much") or rating their sleep quality as "Fairly Bad" or "Very Bad."

Circadian preference was ascertained by asking participants a single question from the Horne & Östberg Morningness-Eveningness questionnaire[25] (for details, see the Appendix). Sleep duration was assessed using a question from the Pittsburgh Sleep Quality Index:[24] Responses were rounded to the nearest hour; those <3 hours or >12 hours were excluded as improbable estimates (n = 987). In addition, sleep duration was stratified as short sleep (≤6 hours), normal (7-8 hours), and long sleep (≥9 hours).

To ascertain whether sleep difficulties developed as a result of COVID-19 infection, participants were asked "Have you experienced "Difficulties with sleep (eg, trouble falling/staying asleep, restlessness, nightmares)" after your COVID-19 diagnosis?" Possible responses were "I experienced this symptom with COVID infection" and "I am also experiencing this symptom now." The latter response was used to classify participants as currently experiencing insomnia or poor sleep quality as a result of COVID-19 infection.

Each survey (for details, see the Appendix) contained identical items related to COVID-19 infection status (eg, self-reported positive test, clinical diagnosis, loss of smell/taste), COVID-19-related hospitalization, and the number of COVID-19 vaccinations participants had obtained.

Statistical Analyses

Summary data for continuous or ordinal variables are reported as their respective means and standard deviations and for categorical variables as their percentages. After preliminary analyses, we defined a positive history of COVID-19 infection as an affirmative response to having tested positive for COVID-19, loss of taste or smell, or a clinical diagnosis of COVID-19. Participants were considered to have insomnia if they endorsed currently having the condition. Number of COVID-19 vaccinations was utilized as an ordinal variable and also dichotomized as Boosted (>2 vaccinations) or Not Boosted (≤2 vaccinations). Comorbid medical conditions were defined as currently having the condition whether treated or untreated. The effect of comorbid medical conditions was evaluated by summing the number of conditions reported by the participant (minimum value 0, maximum value 9). Body mass index was calculated using self-reported height and weight as kg/m^2. Socioeconomic covariates were dichotomized as follows: employment (retired vs not retired), education (high school or less vs some college or higher) and income in US dollars to approximate 200% of the 2022 US Poverty Level for a family of 4 (<$50,000 vs ≥$50,000).[26]

Comparisons of continuous or ordinal variables stratified by COVID-19 infection status or history of COVID-19 hospitalization were performed using Student's unpaired t test. Bivariate comparisons of categorical variables stratified by COVID-19 infection or history of COVID-19 hospitalization were completed using χ^2.

Multivariable modeling using logistic regression was utilized to determine whether insomnia, poor sleep quality, and sleep duration were associated with COVID-19 infection and hospitalization. An initial baseline model was constructed entering only either insomnia or poor sleep quality. We then developed increasingly complex models by sequentially including demographic factors, comorbidities, socioeconomic factors, circadian preference, vaccination number, and sleep duration. To separately determine the relationship of sleep duration with COVID-19 infection or hospitalization, models sequentially included demographic factors, comorbidities, and socioeconomic factors using sleep duration as a continuous ordinal variable, as well as stratified into short, normal, and long sleep duration. Inasmuch as COVID-19 infection could result in insomnia and other sleep problems, we repeated the aforementioned analyses after excluding participants who were currently experiencing sleep problems after their COVID-19 infection. Furthermore, we performed sensitivity analyses with stricter (ie, using COVID-19 infection as a positive test only) and broader (ie, our original definition plus presumed positive, but not tested as an indicator of a past COVID-19 infection) definitions.[27]

All analyses were conducted using IBM SPSS version 28 (Armonk, NY). A $P < .05$ was considered statistically significant.

RESULTS

Table 1 shows bivariate associations between COVID-19 infection status, insomnia, sleep duration, and several comorbid medical, demographic, and social characteristics for all 19,926 participants; 40.1% endorsed a previous COVID-19 infection and 59.9% did not. Previously, COVID-19-positive participants more commonly reported insomnia, poor sleep quality, and shorter sleep durations. Longer sleep durations from 10 to 12 hours were marginally more prevalent in this group. Notably, they more commonly reported comorbidities, exhibited morningness, and less commonly received a booster vaccination.

In Table 2 are the unadjusted and adjusted odds ratios for reporting a previous COVID-19 infection in association with insomnia or poor sleep quality. Higher odds of COVID-19 infection were related to both insomnia and poor sleep quality in unadjusted and fully adjusted models. Current sleep problems that occurred after a COVID-19 infection were endorsed by 1788 participants. After full adjustment, their exclusion abolished the association for insomnia, but not for poor sleep quality. Addition of sleep duration to the models marginally attenuated but did not eliminate these associations.

Bivariate associations between COVID-19-related hospitalization, and insomnia, sleep duration, and comorbid medical, demographic, and social characteristics are shown in Table 3. There were 570 (2.9%) participants who reported having had a COVID-19-related hospitalization. They had a greater prevalence rate of insomnia, poor sleep quality, both short and long sleep duration, morningness, and medical comorbidities. Conversely, they had a lower prevalence of receiving a COVID-19 booster vaccination.

As shown in Table 4, odds of COVID-19-related hospitalization increased for both insomnia and poor sleep in both unadjusted and fully adjusted models. After exclusion of participants with current COVID-19-related sleep problems, poor sleep quality remained significant, but insomnia did not. The addition of sleep duration to the models did not alter these observations.

Table 5 depicts the relationship between previous COVID-19 infection and sleep duration. Compared with a reference of 7-8 hours of sleep, decreasing hours of sleep were associated with greater odds of previous COVID-19 infection in both unadjusted and fully adjusted models. With the exception of 3 hours of sleep, exclusion of those with current COVID-19-related sleep problems did not nullify these findings. Increasing sleep duration in a fully adjusted model was associated with higher odds of COVID-19 infection only at 12 hours. This association persisted after exclusion of those with current COVID-19 sleep

Table 1 Associations Between COVID-19 Infection Status, Insomnia, Sleep Duration and Comorbid Medical, Demographic, and Social Characteristics

	n	COVID-19 Negative (n = 11,945)		COVID-19 Positive (n = 7981)		Overall (N = 19.926)	
		Mean	SD	Mean	SD	Mean	SD
Age (y)*	19,917	50.4	18.0	40.2	15.8	46.3	17.9
Body Mass Index (kg/m^2)*	19,683	28.3	7.8	28.7	10.4	28.5	8.9
No. Comorbidities*	19,926	0.8	1.2	1.8	2.4	1.2	1.9
		n	%	n	%	n	%
Sleep duration (hours)*,†	18,939						
3		265	2.3	300	4.1	565	3.0
4		657	5.7	634	8.6	1291	6.8
5		1266	10.9	1016	13.8	2282	12.0
6		2216	19.1	1466	19.9	3682	19.4
7 to 8		5934	51.3	3148	42.8	9082	48.0
9		815	7.0	396	5.4	1211	6.4
10		292	2.5	247	3.4	539	2.8
11		61	0.5	45	0.6	106	0.6
12		72	0.6	109	1.5	181	1.0
Sleep duration (hours)*,†	18,939						
≤6		4404	38.0	3416	46.4	7820	41.3
7-8		5934	51.3	3148	42.8	9082	48.0
≥9		1240	10.7	797	10.8	2037	10.8
Insomnia	19,926						
Not present*		10,112	84.7	5874	73.6	15,986	80.2
Present		1833	15.3	2107	26.4	3940	19.8
Poor sleep quality*	19,926						
Not present		7981	66.8	3964	48.3	11,945	59.9
Present		3853	33.2	4128	51.7	7981	40.1
Sex	19,767						
Male		5781	48.6	3900	49.5	9681	49.0
Female		6107	51.4	3979	50.5	10,086	51.0
Race/ethnicity*	19,926						
White		7870	65.9	4714	59.1	12,584	63.2
Black		1257	10.5	846	10.6	2103	10.6
Hispanic		1497	12.5	1736	21.8	3233	16.2
Other		1321	11.1	685	8..6	2006	10.1
Employment*	19,926						
Retired		3676	30.8	998	12.5	4674	23.5
Not retired		8269	69.2	6983	87.5	15,338	76.6
Education	19,926						
High school or Less		3201	26.8	2152	27.0	5353	26.9
Some college		8744	73.2	5829	73.0	14,573	73.1
Income (yearly)*	19,086						
<$50,000		5445	48.0	3240	41.9	8685	45.5
≥$50,000		5907	52.0	4494	58.1	10,401	54.5
Vaccination*	19,926						
0		2659	22.3	1795	22.5	4454	22.4
1		692	5.8	1272	15.9	1964	9.9
2		3047	25.5	2712	34.0	5759	28.9
3		4385	36.7	1855	23.2	6240	31.3
4		1162	9.7	347	4.3	1509	7.6
Vaccination boosted*	19,926						
No (≤2 vaccina-tions)		6398	53.6	5779	72.4	12,177	61.1
Yes (>2 vaccina-tions)		5547	46.4	2202	27.6	7749	38.9
Morningness/eve-ningness *	19,926						
Morningness		6325	53.0	4706	59.0	11,031	55.4
Eveningness		5620	47.0	3275	41.0	8895	44.6

*$P ≤ .001$, significant differences in means or proportions.
†Participants reporting <3 or >12 hours sleep were excluded (see Methods).

Table 2 Adjusted Odds Ratio (aOR) for Reporting One or More COVID-19 Infections Based on Self-Reported Insomnia or Poor Sleep Quality and Self-Reported Insomnia or Poor Sleep Quality Excluding Cases With Current COVID-19-Related Sleep Problems (PASC)

| | Insomnia | | Insomnia-No PASC | | Poor Sleep Quality | | Poor Sleep Quality-No PASC | |
| | n = 3940 | | n = 3250 | | n = 7981 | | n = 6791 | |
Model	aOR	95% CI	aOR	95% CI	aOR	95% CI	aOR	95% CI
Baseline	1.98	1.84-2.12[¶]	1.69	1.56-1.82[¶]	2.16	2.04-2.29[¶]	1.77	1.66-1.88[¶]
+Demographics*	1.80	1.67-1.94[¶]	1.52	1.40-1.65[¶]	1.86	1.75-1.98[¶]	1.51	1.41-1.61[¶]
+Comorbidities[†]	1.21	1.11-1.31[¶]	1.02	0.93-1.12	1.48	1.38-1.58[¶]	1.20	1.11-1.29[¶]
+Socioeconomic[‡]	1.21	1.12-1.32[¶]	1.02	0.93-1.12	1.51	1.41-1.62[¶]	1.22	1.13-1.31[¶]
+Vaccination[§]	1.20	1.10-1.31[¶]	1.01	0.91-1.11	1.49	1.39-1.59[¶]	1.20	1.11-1.29[¶]
+Sleep Duration[‖]	1.13	1.04-1.24[#]	0.98	0.89-1.08	1.41	1.30-1.51[¶]	1.16	1.07-1.26[¶]

CI = confidence interval; PASC = post-acute sequelae of COVID-19.

COVID-19 Infection: Yes = 7981, No = 11,945.

The baseline model includes only self-reported insomnia or insomnia with poor sleep.

Subsequent models are additive to their immediate predecessor and are adjusted as indicated below (see text for covariate definitions) with the fully adjusted model reflecting demographic, comorbid disease, socioeconomic characteristics and vaccination number.

*Age, sex, race.

[†]Body mass index, # of the following conditions: diabetes, asthma, sickle cell disease, cardiovascular disease, hypertension, cancer, chronic kidney disease, liver disease, chronic obstructive pulmonary disease, morningness/eveningness.

[‡]Education, income, employment.

[§]Number of COVID-19 vaccinations.

[‖]Self-reported sleep duration ($\leq$6, 7-8, $\geq$9 hours).

[¶]$P < .01$.

[#]$P < .001$.

problems. Exploratory analyses using a reference of 7-8 hours of sleep found that the overall relationship between COVID-19 hospitalization and hours of sleep followed a quadratic (U-shaped) pattern.

In Table 6 the association is shown between history of previous COVID-19 infection and hours of sleep duration stratified into short, normal, and long sleep duration. In a fully adjusted model, only short sleep duration was associated with previous COVID-19 infection. This finding persisted after exclusion of participants with current COVID-19 sleep problems.

The relationships between COVID-19-related hospitalization and sleep duration are shown in Supplementary Tables 1 and 2 (available online). There were no consistent associations between COVID-19-related hospitalization and hourly sleep duration (Supplementary Table 1). When stratified into short, normal, and long sleep duration categories (Supplementary Table 2), short, but not long, sleep duration was associated with increased odds of hospitalization after full adjustment and exclusion of participants with current COVID-19-related sleep problems.

Sensitivity analyses using a definition of COVID-19 infection that was stricter (test positive only, either test positive or clinical diagnosis) generally found that associations with insomnia, poor sleep quality (Supplementary Table 3, available online), and sleep duration (Supplementary Tables 4 and 5, available online) were less robust, but qualitatively similar. A more permissive definition that included presumptive COVID-19 infection also resulted in qualitatively similar results (Supplementary Tables 4 and 5).

DISCUSSION

In this study, both insomnia and poor sleep quality were associated with a greater risk of having had a COVID-19 infection. The association was stronger for poor sleep quality than for insomnia. Poor sleep quality, but not insomnia alone, was also linked to greater likelihood of COVID-19-related hospitalization. Furthermore, short sleep duration was related to COVID-19 infection and hospitalization. In contrast, extremely long sleep duration was associated with COVID-19 infection, but not hospitalization. These findings suggest that measures for improving sleep health may help reduce the impact of COVID-19 infection in the general adult population.

We observed that both insomnia and poor sleep quality were related to previous infection with COVID-19 and that poor sleep quality had higher odds for COVID-19-related hospitalization. Scant studies have investigated these relationships. In the UK Biobank, those with a high level of "sleep behavior burden" (ie, sleep duration, sleepiness, insomnia, and chronotype) prior to the COVID-19 pandemic had a greater rate of subsequent COVID-19 test positivity, hospitalization, and death.[12] Similarly, in a study of European and US health care workers, insomnia symptoms and hypnotic use were associated with an 88% greater odds of contracting COVID-19,[11] and a study of elderly adults found sleep disturbances were associated with greater COVID-19-related symptoms.[28] In contrast, survival and logistic regression analyses of the FinnGen and UK Biobank databases did not find associations between insomnia and COVID-19 infection risk.[10] However, Mendelian randomization analyses of combinations of FinnGen, UK

Table 3   Associations Between COVID-19 Hospitalization, Insomnia, Sleep Duration and Co-morbid Medical, Demographic and Social Characteristics

	n	COVID-19 Hospitalization Negative (n = 19,356)		COVID-19 Hospitalization Positive (n = 570)		Overall (n = 19,926)	
		Mean	SD	Mean	SD	Mean	SD
Age (y)*	19,917	46.5	17.9	41.2	15.1	46.3	17.9
Body mass index (kg/m2)	19,683	28.5	8.9	28.9	10.6	28.5	8.9
No. Comorbidities*	19,926	1.1	2.5	2.5	2.7	1.2	1.9
		n	%	n	%	n	%
Sleep duration (hours)*,†	18,939						
3		543	2.9	22	4.2	565	3.0
4		1242	6.7	49	9.5	1291	6.8
5		2202	12.0	80	15.4	2282	12.0
6		3580	19.4	102	19.7	3682	19.4
7 to 8		8879	48.2	203	39.2	9082	48.0
9		1183	6.4	28	5.4	1211	6.4
10		516	2.8	23	4.4	539	2.8
11		101	0.5	5	1.0	106	0.6
12		175	1.0	6	1.2	181	1.0
Sleep duration (hours)*,†	18,939						
≤6		7567	41.1	253	48.8	7820	41.3
7-8		8879	48.2	203	39.2	9082	48.0
≥9		1975	10.7	62	12.0	2037	10.8
Insomnia	19,926						
Not present*		15,614	80.7	372	65.3	15,986	80.2
Present		3742	19.3	198	34.7	3940	19.8
Insomnia/poor sleep*	19,926						
Not present		11,613	60.0	221	38.8	11,945	59.9
Present		7743	40.0	349	61.2	7981	40.1
Sex*	19,767						
Male		9365	48.8	316	55.9	9681	49.0
Female		9837	51.2	249	44.1	10,086	51.0
Race/ethnicity*	19,926						
White		12,238	63.2	346	60.7	12,584	63.2
Black		2027	10.5	76	13.3	2103	10.6
Hispanic		3128	16.2	105	18.4	3233	16.2
Other		1963	10.1	43	7.5	2006	10.1
Employment*	19,926						
Retired		4609	23.8	65	11.4	4674	23.5
Not retired		14,747	76.2	505	88.6	15,338	76.6
Education‡	19,926						
High school or Less		5224	27.0	129	22.6	5353	26.9
Some college		14,132	73.0	441	77.4	14,573	73.1
Income (yearly)*	19,086						
< $50,000		8469	45.7	216	38.5	8685	45.5
≥ $50,000		10,056	54.3	345	61.5	10,401	54.5
Vaccination #*	19,926						
0		4334	22.4	120	21.1	4454	22.4
1		1855	9.6	109	19.1	1964	9.9
2		5568	28.8	191	33.5	5759	28.9
3		6108	31.6	132	23.2	6240	31.3
4		1491	7.7	18	3.2	1509	7.6
Vaccination boosted*	19,926						
No (≤2 vaccinations)		11,757	60.7	420	73.7	12,177	61.1
Yes (>2 vaccinations)		7599	39.3	150	26.3	7749	38.9
Morningness/eveningness*	19,926						
Morningness		10,666	55.1	365	64.0	11,031	55.4
Eveningness		8690	44.9	205	36.0	8895	44.6

*P ≤ .001, significant differences in means or proportions.
†Participants reporting <3 or >12 hours sleep were excluded (see Methods).
‡P ≤ .05, significant differences in means or proportions.

Biobank, and other genome-wide association study cohorts observed causal relationships between insomnia and risks of COVID-19 infection,[29] severity of infection,[10] and hospitalization.[10,29] Our results support the findings from the majority of these initial studies that demonstrated a linkage between insomnia and poor sleep quality, and COVID-19 infection and hospitalization. Adjusting for sleep duration and circadian preference in our analyses extends these observations by making it less likely that these factors entirely explain these associations.

The explanation for the increases in COVID-19 infection and hospitalization related to insomnia or poor sleep quality is unclear. However, insomnia and, most likely, poor sleep quality as well, are associated with elevated stress, with consequent activation of the sympathetic nervous system and elevations in cortisol.[30] This increases release of

Table 4 Adjusted Odds Ratio (aOR) for Reporting One or More COVID-19 Hospitalizations Based on Self-Reported Insomnia or Poor Sleep Quality and Self-Reported Insomnia or Poor Sleep Excluding Cases With Current COVID-19-Related Sleep Problems (PASC)

Model	Insomnia		Insomnia-No PASC		Poor Sleep Quality		Poor Sleep Quality-No PASC	
	n = 3940		n = 3250		n = 7981		n = 6791	
	aOR	95% CI	aOR	95% CI	aOR	95% CI	aOR	95% CI
Baseline	2.22	1.86-2.65[¶]	2.04	1.65-2.52[¶]	2.37	2.00-2.81[¶]	2.16	1.78-2.63[¶]
+Demographics*	2.15	1.79-2.57[¶]	1.97	1.59-2.45[¶]	2.26	1.89-2.69[¶]	2.07	1.70-2.54[¶]
+Comorbidities[†]	1.35	1.10-1.66[#]	1.22	0.95-1.57	1.70	1.41-2.06[¶]	1.57	1.26-1.96[¶]
+Socioeconomic[‡]	1.32	1.07-1.64[#]	1.19	0.92-1.54	1.69	1.39-2.05[¶]	1.55	1.24-1.94[¶]
+Vaccination[§,‖]	1.33	1.06-1.65**	1.18	0.91-1.54	1.49	1.39-1.59[¶]	1.47	1.17-1.86[¶]
+Sleep duration[‖]	1.29	1.03-1.60**	1.17	0.90-1.53	1.41	1.30-1.51[¶]	1.50	1.18-1.91[¶]

CI = confidence interval; PASC = post-acute sequelae of COVID-19.

COVID-19 Hospitalizations: Yes = 570, No = 19,356.

The baseline model includes only self-reported insomnia or insomnia with poor sleep.

Subsequent models are additive to their immediate predecessor and are adjusted as indicated below (see text for covariate definitions) with the fully adjusted model reflecting demographic, comorbid disease, and socioeconomic characteristics.

*Age, sex, race.

[†]Body mass index, # of the following conditions: diabetes, asthma, sickle cell disease, cardiovascular disease, hypertension, cancer, chronic kidney disease, liver disease, chronic obstructive pulmonary disease, morningness/eveningness.

[‡]Education, income, employment.

[§]Number of COVID-19 vaccinations.

[‖]Self-reported sleep duration (≤6, 7-8, ≥9 hours).

[¶]$P < .001$.

[#]$P < .01$.

**$P < .05$.

norepinephrine; it has been suggested that such adrenergic signaling can suppress transcription of antiviral interferon genes, potentially increasing susceptibility to viral infection.[31] Furthermore, increased sympathetic nervous system activity can induce a state of chronic inflammation, leading to a weakened immune response.[32] In support of these possible mechanisms, insomnia severity has been prospectively linked to increased numbers of respiratory infections and changes in neutrophil to lymphocyte ratio.[33]

The other major finding from our study was that extremes of sleep duration were associated with prior COVID-19 infection or hospitalization. The relationship with short sleep duration was stronger than that of long sleep duration. In the few studies that have assessed the relationship between sleep duration and COVID-19, 2 analyses demonstrated that short sleep duration was associated with increase in COVID-19 risk.[9,11] In contradistinction, no relationship was observed in the much larger, previously

Table 5 Adjusted Odds Ratio (aOR) for Reporting One or More COVID-19 Infections Based on Self-Reported Hourly Sleep Duration* and Self-Reported Hourly Sleep Duration* Excluding Cases With Current COVID-19-Related Sleep Problems (PASC)

Sleep Duration, Hours	n	Unadjusted		Fully Adjusted[†]		n	Unadjusted No PASC		Fully Adjusted[†] No PASC	
		aOR	95% CI	aOR	95% CI		aOR	95% CI	aOR	95% CI
3	565	2.13[‡]	1.80-2.52	1.40[‡]	1.15-1.70	457	1.72[‡]	1.42-2.07	1.14	0.92-1.42
4	1291	1.81[‡]	1.61-2.04	1.47[‡]	1.28-1.67	1054	1.50[‡]	1.29-1.67	1.17[§]	1.01-1.36
5	2282	1.51[‡]	1.38-1.66	1.35[‡]	1.22-1.50	1973	1.28[‡]	1.16-1.42	1.15[§]	1.02-1.29
6	3682	1.25[‡]	1.15-1.35	1.22[‡]	1.12-1.33	3341	1.15[‡]	1.05-1.25	1.12[§]	1.02-1.23
7-8	9082	Reference		Reference		8606	Reference		Reference	
9	1211	0.92	0.81-1.04	0.94	0.81-1.08	1135	0.88	0.77-1.01	0.89	0.77-1.04
10	539	1.61[‡]	1.35-1.91	1.17	0.96-1.43	487	1.51[‡]	1.25-1.82	1.10	0.89-1.36
11	106	1.40	0.95-2.05	0.91	0.75-1.43	94	1.28	0.84-1.93	0.84	0.51-1.38
12	181	2.88[‡]	1.13-3.89	1.78[‡]	1.27-2.49	150	2.66[‡]	1.92-3.68	1.61[‖]	1.12-2.31

CI = confidence interval; PASC = post-acute sequelae of COVID-19.

COVID-19 Infection: Yes = 7981, No = 11,945.

*Self-reported sleep duration (3 to 12 hours); Reference is 7-8 hours.

[†]Fully adjusted model includes age, sex, race, body mass index, insomnia, # of comorbidities, Morningness/Eveningness, Education, Income and Employment.

[‡]$P < .001$.

[§]$P < .05$.

[‖]$P < .01$.

Table 6 Adjusted Odds Ratio (aOR) for Reporting One or More COVID-19 Infections Based on Self-Reported Sleep Duration* and Self-Reported Sleep Duration* Excluding Cases With Current COVID-19-Related Sleep Problems (PASC)

Model	≤6 Hours		≥9 Hours		≤6 Hours No PASC		≥9 Hours No PASC	
	aOR	95% CI	aOR	95% CI	aOR	95% CI	aOR	95% CI
Baseline	1.58‖	1.49-1.68	1.31‖	1.19-1.44	1.27‖	1.18-1.35	1.15¶	1.03-1.27
+Demographics†	1.44‖	1.35-1.53	1.08	0.98-1.19	1.17‖	1.09-1.26	0.98	0.88-1.09
+Comorbidities‡	1.28‖	1.20-1.37	1.03	0.93-1.15	1.10¶	1.02-1.18	0.96	0.86-1.08
+Socioeconomic§	1.33‖	1.24-1.43	1.07	0.96-1.19	1.14‖	1.06-1.23	0.99	0.88-1.12

CI = confidence interval; PASC = post-acute sequelae of COVID-19.

COVID-19 Infection: Yes = 7981, No = 11,945.

*Self-reported sleep duration (≤6 [n = 7820], 7-8 [n = 9082], ≥9 hours [n = 2037]); reference is 7-8 hours. The baseline model includes only self-reported insomnia or insomnia with poor sleep. Subsequent models are additive to their immediate predecessor and are adjusted as indicated below (see text for covariate definitions) with the fully adjusted model reflecting demographic, comorbid disease, and socioeconomic characteristics.

†Age, sex, race.

‡Body mass index, insomnia, no. of the following conditions: diabetes, asthma, sickle cell disease, cardiovascular disease, hypertension, cancer, chronic kidney disease, liver disease, chronic obstructive pulmonary disease, morningness/eveningness

§Education, income, employment.

‖$P < .001$.

¶$P < .05$.

cited FinnGen study.[10] To our knowledge, there have not been previous studies demonstrating any associations between long sleep duration and COVID-19 infection. Furthermore, our finding that the association between sleep duration and COVID-19 infection appeared to fit a quadratic (U-shaped) pattern is similar to observations found between sleep duration and other conditions such as cardiovascular disease,[34] diabetes,[15] and cognitive impairment,[35] suggesting that there might be a similar or shared underlying mechanism.

Short sleep duration is associated with an impairment in immune responsiveness[31] and has been associated with increased risk of rhinovirus infection.[19] In addition, a reduction in sleep decreases the antibody response to vaccination.[16,17] These mechanisms could explain the increase in COVID-19 infections observed among participants with short sleep duration. However, the explanation for our observations related to long sleep duration is less obvious. It has been suggested, with little direct evidence, that longer sleep duration may be related to sleep fragmentation or poor sleep quality, sedentary lifestyle, reduced light exposure, and alterations in immunity, as well as undiagnosed comorbid medical conditions (eg, cardiovascular disease, depression).[36,37] We believe the latter is unlikely to explain our finding in that our modeling adjusted for multiple comorbid medical conditions. Nevertheless, additional research is needed to elucidate the mechanisms responsible for the associations between both short and long sleep duration and disease risk.

We observed that participants with a morning chronotype had markedly higher odds of COVID-19 infection and hospitalization. These findings stand in contrast to previous reports where an evening chronotype was associated with hypertension, diabetes, cancer, depression, and an overall worse cardiometabolic profile, which themselves are risk factors for more severe COVID-19 outcomes.[38] These latter associations have been attributed to a greater degree of circadian misalignment experienced by evening chronotypes resulting in dysregulation of a variety of physiologic and metabolic processes.[38] It is unclear why our findings with respect to COVID-19 susceptibility are at variance, but further investigation is warranted.

Although the associations we report are robust, there are nevertheless several limitations that need to be considered. First, our analyses are cross-sectional; causal inferences must be interpreted cautiously. Second, the predictive factors and COVID-19 outcomes were self-reported. However, sensitivity analyses indicated that other definitions of COVID-19 infection yielded qualitatively similar results. Third, insomnia and other sleep problems are common sequelae after COVID-19 infection. In a systematic review of 57 studies that documented short- and long-term sequelae of PASC in 250,351 survivors of COVID-19 infection, 27.0% experienced a sleep disorder.[39] Furthermore, approximately 70% of respondents in an online survey of 3762 individuals with suspected or confirmed COVID-19 reported having insomnia at some point in their illness, with 40% having persistent symptoms 28 months post infection.[23] Therefore, it is possible that COVID-19 infection induced sleep problems rather than vice-versa. However, we believe that this is not the entire explanation for our findings because exclusion of participants who endorsed current COVID-19-related sleep problems did not fundamentally alter our observations.

In conclusion, insomnia, poor sleep quality, and extremes of sleep duration are associated with increased COVID-19 infection and hospitalization. These findings provide evidence that a public health approach encouraging healthy sleep practices will lessen the impact of the COVID-19 pandemic.

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SUPPLEMENTARY DATA

Supplementary data to this article can be found online at https://doi.org/10.1016/j.amjmed.2022.12.015.

APPENDIX

Supplement to Methods

Survey Items. Participants self-reported demographic, anthropometric, and socioeconomic information including age, race, ethnicity, sex, self-reported height and weight, education level, employment status, and household income. In addition, they reported information on several current and past medical conditions including insomnia, as detailed in the Appendix, by answering the question: "Have you ever been diagnosed with any of the following conditions?" In addition to insomnia, opportunity was provided to endorse high blood pressure, cardiovascular disease (eg, heart attack, stroke, angina), gastrointestinal disorder (eg, acid reflux, ulcers, indigestion), cancer, chronic kidney disease, liver disease, sickle cell disease,

Supplementary Table 1 Adjusted Odds Ratio (aOR) for Reporting One or More COVID-19 Hospitalizations Based on Self-Reported Hourly Sleep Duration* and Self-Reported Hourly Sleep Duration* Excluding Cases with Incident Sleep Problems Post COVID Current COVID-19-Related Sleep Problems (PASC)

Sleep Duration, Hours	n	Unadjusted aOR	95% CI	Fully Adjusted† aOR	95% CI	n	Unadjusted No PASC aOR	95% CI	Fully Adjusted† No PASC aOR	95% CI
3	565	1.77‡	1.13-2.78	1.14	0.71-1.81	457	1.88‡	1.12-3.17	1.19	0.69-2.05
4	1291	1.73§	1.26-2.37	1.33	0.95-1.87	1054	1.51‡	1.03-2.25	1.11	0.73-1.70
5	2282	1.59§	1.22-2.07	1.37‡	1.04-1.81	1973	1.35	0.98-1.86	1.17	0.83-1.64
6	3682	1.25	0.98-1.59	1.19	0.93-1.53	3341	1.17	0.89-1.55	1.11	0.83-1.47
7-8	9082	Reference		Reference			Reference		8606	
9	1211	1.04	0.69-1.54	1.07	0.70-1.63	1135	1.17	0.76-1.79	1.21	0.77-1.89
10	539	1.95‖	1.26-3.03	1.49	0.93-2.39	487	2.28§	1.38-3.56	1.73‡	1.05-2.86
11	106	2.17	0.87-5.37	2.21	0.87-5.61	94	2.30	0.84-6.34	2.34	0.83-6.61
12	181	1.50	0.66-3.42	0.76	0.30-1.92	150	1.79	0.73-4.42	0.89	0.32-2.51

CI = confidence interval; PASC = post-acute sequelae of COVID-19.

COVID-19 Infection: Yes = 7981, No = 11,945.

*Self-reported sleep duration (3 to 12 hours); Reference is 7-8 hours

†Fully adjusted model includes age, sex, race, body mass index, insomnia, no. of comorbidities, morningness/eveningness, education, income, and employment.

‡P < .05.

§P < .001.

‖P < .01.

Supplementary Table 2 Adjusted Odds Ratio (aOR) for Reporting One or More COVID-19 Hospitalizations Based on Self-Reported Sleep Duration* and Self-Reported Sleep Duration* Excluding Cases With Current COVID-19-Related Sleep Problems (PASC)

Model	≤6 Hours aOR	95% CI	≥9 Hours aOR	95% CI	≤6 Hours No PASC aOR	95% CI	≥9 Hours No PASC aOR	95% CI
Baseline	1.54‖	1.28-1.85	1.51&	1.16-1.97	1.45‖	1.20-1.74	1.36¶	1.04-1.79
+Demographics†	1.45‖	1.20-1.74	1.36¶	1.04-1.79	1.27¶	1.02-1.58	1.39¶	1.01-1.91
+Comorbidities‡	1.23¶	1.02-1.49	1.03	0.93-1.15	1.12	0.89-1.41	1.32	0.95-1.83
+Socioeconomic§	1.25¶	1.03-1.52	1.33¶	1.00-1.76	1.23¶	1.02-1.49	1.27	0.96-1.68

CI = confidence interval; PASC = post-acute sequelae of COVID-19.

COVID-19 Infection: Yes = 7981, No = 11,945.

*Self-reported sleep duration (≤6 [n = 7820], 7-8 [n = 9082], ≥9 hours [n = 2037]); reference is 7-8 hours. The baseline model includes only self-reported insomnia or insomnia with poor sleep. Subsequent models are additive to their immediate predecessor and are adjusted as indicated below (see text for covariate definitions) with the fully adjusted model reflecting demographic, comorbid disease, socioeconomic characteristics and # of COVID-19 vaccinations.

†Age, Sex, Race

‡Body mass index, insomnia, no. of the following conditions: diabetes, asthma, sickle cell disease, cardiovascular disease, hypertension, cancer, chronic kidney disease, liver disease, chronic obstructive pulmonary disease, morningness/eveningness

§Education, Income, Employment

‖P < .001.

¶P < .05.

Supplementary Table 3 Sensitivity Analyses Showing Adjusted Odds Ratios (aOR) for Reporting One or More COVID-19 Infections Based on Different Definitions of Self-Reported Insomnia or Poor Sleep Quality and Self-Reported Insomnia or Poor Sleep Quality Excluding Cases With Current COVID-19-Related Sleep Problems (PASC)

COVID-19 Infection
Positive Test, Assume Positive, Clinical Diagnosis or Loss of Taste/Smell

	Insomnia		Insomnia-No PASC		Poor Sleep Quality		Poor Sleep Quality-No PASC	
	n = 3563		n = 2944		n = 7425		n = 6238	
Model	aOR	95% CI	aOR	95% CI	aOR	95% CI	aOR	95% CI
Baseline	1.79	1.66-1.92*	1.48	1.37-1.61*	1.98	1.86-2.10*	1.57	1.48-1.68*
Fully adjusted	1.11	1.01-1.20†	0.95	0.87-1.05	1.32	1.23-1.43*	1.08	1.00-1.17†

COVID-19 Infection: Yes = 8238, No = 10,701
  COVID-19 Infection No PASC: Yes = 6636, No = 10,661

Positive Test or Loss of Taste/Smell

Model	aOR	95% CI	aOR	95% CI	aOR	95% CI	aOR	95% CI
Baseline	1.92	1.78-2.07*	1.62	1.49-1.76*	2.14	2.02-2.28*	1.74	1.63-1.86*
Fully adjusted	1.14	1.04-1.25‡	0.99	0.90-1.10	1.42	1.32-1.54*	1.18	1.08-1.28*

COVID-19 Infection: Yes = 7027, No = 11,912
  COVID-19 Infection No PASC: Yes = 5557, No = 11,740

Positive Test Only

Model	aOR	95% CI	aOR	95% CI	aOR	95% CI	aOR	95% CI
Baseline	1.55	1.43-1.67*	1.37	1.25-1.50*	1.76	1.65-1.88*	1.48*	1.37-1.59*
Fully adjusted	1.03	0.94-1.13	0.92	0.83-1.03	1.24	1.14-1.34*	1.05	0.96-1.15

COVID-19 Infection: Yes = 4697, No = 14,242
  COVID-19 Infection No PASC: Yes = 3767, No = 13,530

CI = confidence interval; PASC = post-acute sequelae of COVID-19.
The baseline models include only self-reported insomnia or insomnia with poor sleep.
The fully adjusted models include demographic,§ comorbid disease,‖ socioeconomic characteristics,¶ vaccination number,# and sleep duration.**
  *P < .001.
  †P ≤ .05.
  ‡P ≤ .01.§Age, sex, race.‖Body mass index, # of the following conditions: diabetes, asthma, sickle cell disease, cardiovascular disease, hypertension, cancer, chronic kidney disease, liver disease, chronic obstructive pulmonary disease, morningness/eveningness.¶Education, income, employment.#-
    Number of COVID-19 vaccinations.**Self-reported sleep duration (≤6, 7-8, ≥9 hours).

Supplementary Table 4 Adjusted Odds Ratio (aOR) for Reporting One or More COVID-19 Infections Based on Self-Reported Sleep Duration* and Self-Reported Sleep Duration* Excluding Cases With Current COVID-19-Related Sleep Problems (PASC)

COVID-19 Infection
Positive Test, Assume Positive, Clinical Diagnosis or Loss of Taste/Smell

	≤6 Hours		≥9 Hours		≤6 Hours No PASC		≥9 Hours No PASC	
Model	aOR	95% CI	aOR	95% CI	aOR	95% CI	aOR	95% CI
Baseline	1.45‡	1.36-1.54	1.22‡	1.11-1.34	1.24‡	1.16-1.32	1.14§	1.03-1.27
Fully adjusted†	1.27‡	1.19-1.37	1.06	0.95-1.18	1.11‖	1.03-1.19	1.00	0.80-1.12

COVID-19 Baseline: Pos 8238 Neg 10,701 COVID-19 Adj: Pos 7766 Neg 10,073
  COVID-19 Baseline/No PASC: Pos 6636 Neg 10,661 COVID-19 Adj/No PASC: Pos 6253 Neg 10,033

Positive Test or Loss of Taste/Smell

Model	aOR	95% CI	aOR	95% CI	aOR	95% CI	aOR	95% CI
Baseline	1.47‡	1.38-1.57	1.16‖	1.05-1.28	1.27‡	1.19-1.36	1.09	0.98-1.21
Fully adjusted†	1.30‡	1.21-1.40	1.00	0.87-1.12	1.13‡	1.05-1.22	0.93	0.82-1.05

COVID-19 Baseline: Pos 7027 Neg 11,912 COVID-19 Adj: Pos 6620 Neg 11,219
  COVID-19 Baseline/No PASC: Pos 5557 Nrh 11,740 COVID-19 Adj/No PASC: Pos 5229 Neg 11,057

Positive Test Only

Model	aOR	95% CI	aOR	95% CI	aOR	95% CI	aOR	95% CI
Baseline	1.40‡	1.30-1.50	1.07	0.96-1.20	1.24‡	1.14-1.34	1.03	0.91-1.16
Fully adjusted†	1.25‡	1.16-1.35	0.96	0.85-1.09	1.12‖	1.03-1.22	0.93	0.81-1.06

COVID-19 Baseline: Pos 4697 Neg 14,242 COVID-19 Adj: Pos 4431 Neg 13,408
  COVID-19 Baseline/No PASC: Pos 3767 Neg 13,530 COVID-19 Adj/No PASC: Pos 3543 Neg 12,743

CI = confidence interval; PASC = post-acute sequelae of COVID-19.
  *Self-reported sleep duration (≤6 [n = 7820], 7-8 [n = 9082], ≥9 hours [n = 2037]); reference is 7-8 hours.The baseline model includes only self-reported insomnia or insomnia with poor sleep.Subsequent models are additive to their immediate predecessor and are adjusted as indicated below (see text for covariate definitions) with the fully adjusted model reflecting demographic,¶ comorbid disease,# and socioeconomic characteristics.†
  †Education, income, employment.
  ‡P < .001.
  §P < .05.
  ‖P < .01.¶Age, sex, race.#Body mass index, insomnia, no. of the following conditions: diabetes, asthma, sickle cell disease, cardiovascular disease, hypertension, cancer, chronic kidney disease, liver disease, chronic obstructive pulmonary disease, morningness/eveningness

Supplementary Table 5 Adjusted Odds Ratio (aOR) for Reporting One or More COVID-19 Infections Based on Self-Reported Hourly Sleep Duration* and Self-Reported Hourly Sleep Duration* Excluding Cases With Current COVID-19-Related Sleep Problems (PASC)

| | All Participants | | | | | | PASC-Related Sleep Problems Excluded | | | | | | |
| | Positive Test, Assume Positive or Loss of Taste/Smell | | | Positive Test or Loss of Taste/Smell | | Positive Test Only | | Positive Test, Assume Positive or Loss of Taste/Smell | | | Positive Test or Loss of Taste/Smell | | Positive Test Only | |
Sleep Duration, Hours	n	aOR	95% CI	aOR	95% CI	aOR	95% CI	n	aOR	95% CI	aOR	95% CI	aOR	95% CI
3	537	1.40†	1.15-1.69	1.42†	1.17-1.72	1.06	0.87-1.30	434	1.12	0.91-1.39	1.15	0.92-1.43	0.93	0.74-1.18
4	1222	1.44†	1.27-1.65	1.44†	1.26-1.65	1.31†	1.13-1.50	997	1.12	0.97-1.29	1.15	0.99-1.34	1.12	0.95-1.31
5	2152	1.31‡	1.18-1.46	1.35‡	1.21-1.50	1.28†	1.15-1.43	1854	1.11‡	1.00-1.25	1.13‡	1.01-1.27	1.10	0.97-1.25
6	3480	1.20†	1.10-1.31	1.23‡	1.12-1.34	1.26†	1.14-1.38	3156	1.10‡	1.01-1.21	1.13‡	1.03-1.24	1.17§	1.06-1.29
7-8	8569	Reference		Reference		Reference		8125	Reference		Reference		Reference	
9	1123	0.95	0.83-1.09	0.92	0.79-1.06	0.87	0.74-1.02	1052	0.91	0.79-1.05	0.86	0.74-1.01	0.83‡	0.69-0.98
10	497	1.16	0.96-1.42	1.03	0.84-1.27	1.03	0.83-1.27	449	1.10	0.89-1.35	0.97	0.78-1.21	1.01	0.80-1.27
11	88	1.00	0.63-1.57	0.88	0.55-1.40	0.70	0.41-1.18	78	0.99	0.61-1.60	0.81	0.49-1.35	0.69	0.38-1.24
12	171	1.77†	1.26-2.48	1.61§	1.15-2.25	1.51‡	1.09-2.10	141	1.54‡	1.08-2.22	1.45‡	1.01-2.08	1.59‡	1.10-2.29
COVID-19 Pos	7766			6620		4431		6253			5229		3543	
COVID-19 Neg	10,073			11,219		13,408		10,033			11,057		12,743	

CI = confidence interval; PASC = post-acute sequelae of COVID-19.

Models are adjusted for age, sex, race, body mass index, insomnia, no. of comorbidities, morningness/eveningness, education, income, and employment.

*Self-reported sleep duration (3 to 12 hours); Reference is 7-8 hours.

†P < .001.

‡P ≤ .05.

§P < .01.

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chronic obstructive pulmonary disease, and asthma. Possible responses to each condition were "Never," "Yes I have in the past, but don't have it now," "Yes I have, but I do not regularly take medications or receive treatment," and "Yes I have, and I am regularly taking medications or receiving treatment."

The following 2 questions pertaining to sleep quality were asked of the participants:

1. "Thinking about the past month, to what extent has poor sleep troubled you in general?" Possible responses were "Not at all," "A little," "Somewhat," "Much," and "Very Much."
2. From the Pittsburgh Sleep Quality Index,[24] "During the past month, how would you rate your sleep quality overall?" Possible responses were "Very good," "Fairly good," "Fairly bad," and "Very bad."

Participants were considered to have "Poor Sleep Quality" if they endorsed currently having insomnia or being troubled by poor sleep ("Much" or "Very Much") or rating their sleep quality as "Fairly Bad" or "Very Bad."

Circadian preference was ascertained by asking participants the following question from the Horne & Östberg Morningness-Eveningness questionnaire: "One hears about 'morning' and 'evening' types of people. Which one of these types do you consider yourself to be?" Possible responses were "Definitely a 'morning' type," "Rather more of a 'morning' than an 'evening' type," "Rather more of an 'evening' than a 'morning' type," "Definitely an 'evening' type." Morningness was defined as definitely or rather a "morning" type and Eveningness conversely was defined as definitely or rather an "evening" type.[25]

Sleep duration was assessed with the following question from the Pittsburgh Sleep Quality Index:[24] "During the past month, how many hours of actual sleep did you get at night? (This may be different than the number of hours you spend in bed)." Responses were rounded to the nearest hour; those <3 hours or >12 hours were excluded as improbable estimates (n =987). In addition, sleep duration was stratified as short sleep (≤6 hours), normal (7-8 hours), and long sleep (≥9 hours).

To ascertain whether sleep difficulties developed as a result of COVID-19 infection, participants were asked "Have you experienced 'Difficulties with sleep (eg, trouble falling/staying asleep, restlessness, nightmares)' after your COVID-19 diagnosis?" Possible responses were "I experienced this symptom with COVID infection" and "I am also experiencing this symptom now." The latter response was used to classify participants as currently experiencing insomnia or poor sleep quality as a result of COVID-19 infection.

Each survey contained identical items related to COVID-19 infection status, COVID-19-related hospitalization, and the number of COVID-19 vaccinations participants had obtained. Ascertainment of past COVID-19

infection was obtained using responses from following questions related to COVID-19 testing:

1. "Have you ever tested positive?"
2. "Despite never testing positive, are you confident that you have had COVID-19?"
3. "Despite never testing positive, have you received a clinical diagnosis of COVID-19?"
4. "Have you experienced a problem with decreased sense of smell or taste at any point since January 2020?"

History of hospitalization for COVID-19 was assessed with an affirmative response to the following statement: "I have been hospitalized for symptoms related to COVID-19." COVID-19 vaccination status was ascertained by asking "How many COVID-19 vaccine doses have you received? (If you have had two doses of one brand and one of another, please select three)". Participants were allowed to respond from 0 to 4 vaccine doses.