Supplemental Information: Sleep in University Students Prior to and During COVID-19 Stay-at-Home Orders

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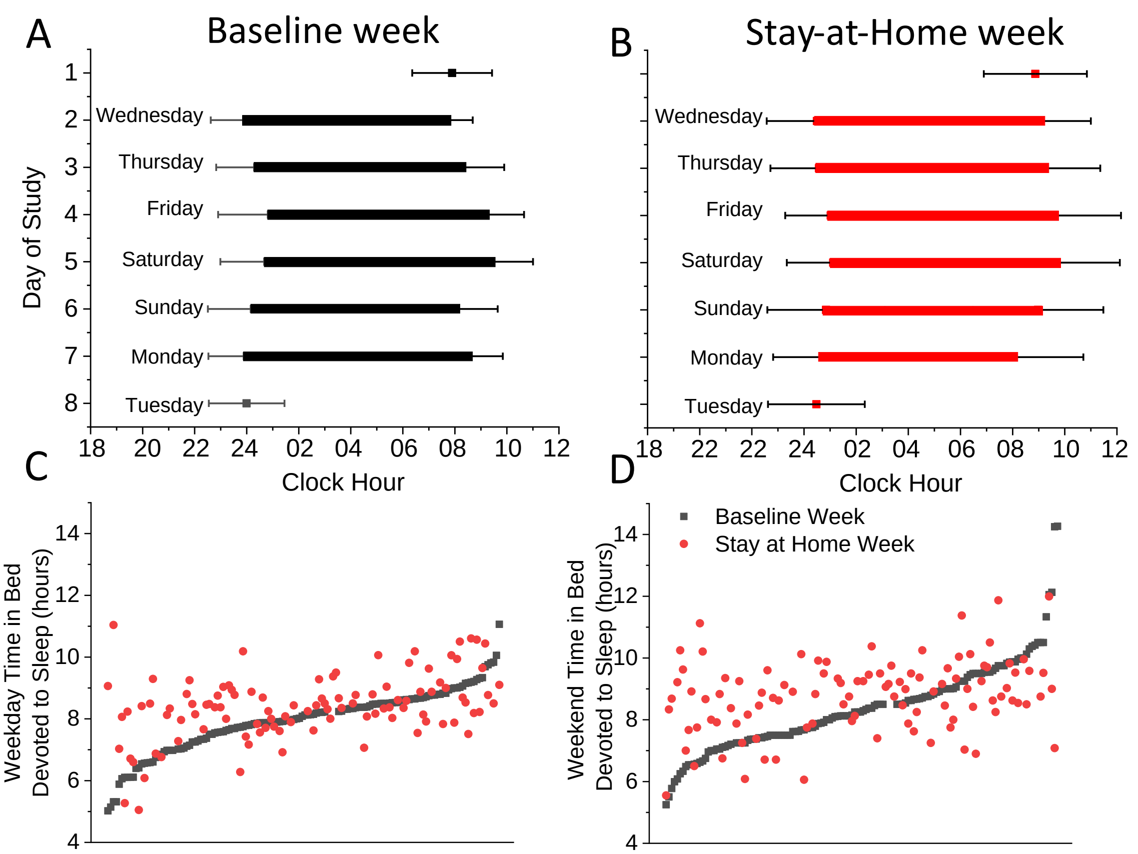

Figure S1. Daily TIB devoted to sleep and Individual Differences. During Stay-at-Home, people had longer TIB and later sleep midpoints (A and B, see main text for details). Tuesday TIB could not be examined as we did not assess waketime on Wednesday. Percentage of students that reported 7h or more TIB per night was higher for Stay-at-Home on the weekend (87%, 93%) and on Wednesday (77%, 92%), Thursday (75%, 86%), Friday (76%, 89%), Saturday (81%, 87%), Sunday (69%, 83%), but was less on Monday (80%, 70%) (all McNemar's χ^2, $p<0.001$). Individual differences show a large range of TIB on the weekdays (C) and weekend (D). Further, participants with shorter TIB devoted to sleep at baseline during the weekdays and weekend tended to increase their TIB during Stay-at-Home; whereas participants with longer TIB at baseline during the weekdays tended to either increase or decrease their TIB during Stay-at-Home and during the weekend tended to decrease their TIB during Stay-at-Home. While some people reduced their TIB during Stay-at-Home, the overwhelming majority still maintained 7h or more of TIB (i.e., of those that reported 7h or more TIB at baseline only ~2%

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on weekdays and ~6% on weekends reported less that 7h TIB during Stay-at-Home). Black bars represent reported sleep times for baseline week and red bars reported sleep times for Stay-at-Home week (A and B). Black squares show data for the baseline week and red circles for the Stay-at-Home week for individual participants in each column for weekday TIB devoted to sleep and weekend TIB devoted to sleep (C and D). Data in C and D are ranked from shortest to longest TIB devoted to sleep at baseline for weekdays and weekends respectively and thus the participant with the shortest TIB on the weekday is not necessarily the participant with the shortest TIB on the weekend at baseline.

Change in Sleep Behaviors (Stay-at-Home Week minus Baseline Week)	**Factor 1**	**Factor 2**	**Factor 3**
Weekday Time in Bed Devoted to Sleep (Δ h)	0.00	-0.12	**0.81**
Weekend Time in Bed Devoted to Sleep (Δ h)	0.07	0.13	**0.72**
Weekday Sleep Midpoint (Δ h)	**0.94**	0.10	0.08
Weekend Sleep Midpoint (Δ h)	**0.76**	0.46	0.14
Waketime (Δ h)	**0.84**	0.06	0.50
Bedtime (Δ h)	**0.90**	0.19	-0.33
Waketime Regularity (Δ SD)	-0.03	**0.82**	0.02
Bedtime Regularity (Δ SD)	0.32	**0.67**	-0.06
Sleep Midpoint Regularity (Δ SD)	0.23	**0.90**	0.05

Δ=change

	Factor 1	**Factor 2**	**Factor 3**
Eigenvalue	3.1	2.2	1.6
% Total Variance	34.8	24.6	17.4

Table S1 - Exploratory factor analyses

Exploratory factor analyses show three separate dimensions of sleep health during the public health Stay-at-Home order: TIB devoted to sleep, sleep regularity, and sleep timing. Specifically, exploratory factor analysis of the change in sleep behaviors during Stay-at-Home shows sleep behaviors have a simple-to-understand factor structure with high loadings of sleep behaviors on a particular factor (in red bolded text) and negligible loadings on other factors (in black text): Factor 1—sleep timing, Factor 2—sleep time regularity, Factor 3—time in bed devoted to sleep.

SUPPLEMENTAL EXPERIMENTAL PROCEDURES

Of the 139 students, 98 were female and 6 did not report their sex. Baseline data collection was planned and conducted as part of a university class project, but not initially designed as a control condition for Stay-at-Home data collection. Written informed consent/IRB waiver was obtained. We took the opportunity to re-collect the same data during Stay-at-Home orders to describe changes in sleep behaviors in the student population tested. Thus, there is selection bias as we did not randomly sample our participants from the student population. Outcomes were analyzed with mixed-model ANOVA with subject as a random factor and week (baseline versus Stay-at-Home) and sex as fixed factors. Sex was not significant and removed from the models. Change in sleep behaviors were analyzed with exploratory factor analysis, limited to factors with eigenvalues greater than one (Varimax rotation, normalized). McNemar's chi-square was used to test for a within-subject's analysis of participants obtaining 7h or more time in bed devoted to sleep (TIB) per night. Pearson correlations were performed between TIB at baseline and the change in TIB devoted to sleep between baseline and Stay-at-Home. Sensitivity analysis removed participants who moved to another time zone and results were the same. One hundred students had complete sleep log data on both visits and these participants contributed to the factor analyses and percent of people obtaining 7h or more time in bed devoted to sleep. Findings were similar if all participants were included in these analyses. Extreme outliers—three times the interquartile range—were identified for the waketime regularity variable and these participants were removed from the ANOVA analyses. Statistical analyses were conducted with Statistica 13 (StatSoft Inc.). Data reported are mean ± standard deviation.

We did not collect other relevant variables that may contribute to changes in sleep behaviors such as changes in people living in the home, extent of social isolation, being single or living with a partner/parents, changes in commute time to school and work demands, changes in napping or daytime sleepiness, changes in light exposure and physical activity, changes in electronic device and social media use, changes in caffeine and alcohol consumption, changes in stress and anxiety, and health status/exposure to COVID-19. The data presented in the paper are observational, the results are descriptive, and as noted, several relevant variables were not collected; thus, causal inferences should be made with caution. Further, the population of university students in Boulder Colorado, USA are not necessarily representative of the general student population nor the general population. For example, findings from prior studies show that the percentage of college students reporting less than 7h sleep per night was ~29% [S1], a higher percentage than found in our sample, and that average sleep per night based on actigraphy was ~6.8h per night[S2]. Further, according to public health databases, Boulder Colorado is ranked as one of the healthiest cities in the USA. With regards to sleep health specifically, data from the "500 Cities Project: Local Data for Better Health" [S3] a collaboration between the Centers for Disease Control (CDC), the Robert Wood John Foundation and the CDC Foundation, show that of the top 500 populated cities in the USA, Boulder Colorado has the lowest percentage of adults that obtain less than 7h sleep per night, at 24.5%. Thus, that we find improvements in TIB in this already healthy sleep population suggests it may be possible to achieve even larger percent increases of TIB devoted to sleep in other student and in other adult populations that have a higher prevalence of insufficient sleep duration.

Our findings also indicate lower levels of social jetlag in the student population studied here compared to findings from other studies. For example, ~one-third adults show 2h or more of social jetlag and ~69% 1h or more of social jetlag [S4] We find that during baseline, ~16% and ~44% of our study participants showed 2h or more and 1h or more of social jetlag, respectively; whereas during Stay-at-Home, ~7% and ~29% of our study participants showed 2h or more and 1h or more of social jetlag, respectively. Thus, the percentage of those with social jetlag for these cutoffs was significantly reduced during Stay-at-Home (McNemar's $\chi 2$, 2h $p<0.0001$, 1h $p<0.01$). We did not assess circadian phase or any questionnaire data to estimate chronotype. We provide however an analysis of sleep midpoint on weekends as a proxy for chronotype and show that sleep midpoint is correlated for baseline and Stay-at-Home weeks ($r=0.60$, $p<0.001$) such that those with later sleep midpoints at baseline still had later midpoints during Stay-at-Home; but there was no association between sleep midpoint and the change in sleep midpoint ($r=-.14$, $p=0.16$) suggesting that chronotype at baseline does not determine how much sleep midpoint changes under these unique circumstances.

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AUTHOR CONTRIBUTIONS

K.P.W., S.B.L., L.C., S.M.L., H.O.D. designed the experiment; K.P.W., S.B.L., and S.M.L. collected data; all authors analyzed data/contributed to data analysis discussions and edited the paper; K.P.W. wrote the manuscript.

DECLARATION OF INTERESTS

S.K.L, D.W., L.C. S.M.L., and H.O.D. declare no competing interests. C.V., reports during the conduct of the study receiving research support from the NIH, was a scientific advisory board member of Circadian Light Therapy Inc. and Chronsulting, and served as a paid consultant to the US Department of Energy outside the submitted work. C.M.D. reports receiving research support from the NIH outside the submitted work. K.P.W. reports during the conduct of the study being a board member of the Sleep Research Society; and receiving research support from the NIH, the Office of Naval Research, the PAC-12 conference outside the submitted work.

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