



Sleep during “lockdown” highlighted the need to rethink the concept of weekend catch-up sleep

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Received: 30 May 2021 / Revised: 24 August 2021 / Accepted: 9 September 2021
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Abstract

Purpose Many people believe in their ability to sleep for longer time on weekends to make up for sleep lost due to early wakeups on weekdays. This widely held belief was not supported by the simulations of rise- and bedtimes on weekdays and weekends with a sleep–wake regulating model. The simulations suggested the inability to extend sleep on any of two weekend nights and they predicted identical weekend sleep durations for weeks with relatively earlier and relatively later weekday risetimes. By April 2020, about half of the world’s population was under some form of “lockdown” due to the COVID-19 pandemic. This “lockdown” provided a new opportunity to demonstrate the predictive power of the sleep–wake regulating models. Therefore, the purpose of this report was to support the prediction of identity of weekend sleep durations after weeks with earlier and later weekday wakeups.

Methods Weekend and weekday rise- and bedtimes before and during “lockdown” for 31 samples were taken from recent journal publications. Time in bed on weekends and 12 other measures of sleep duration and timing were calculated and simulated.

Results For only one of 13 measures, weekend time in bed, statistical analysis did not yield a statistically significant difference between the estimates obtained before and during “lockdown”. The model-based simulations pointed to the 0.3-h delay of the sleep–wake cycle in response to the 1-h delay of weekday risetime during “lockdown”.

Conclusion The model-based prediction was confirmed, thus, highlighting again the necessity to rethink the concept of weekend catch-up sleep.

Keywords Sleep–wake regulation · Two-process model · Simulation · Sleep duration · Sleep timing

Introduction

Many people believe in their ability to partly recover their sleep missed during weekdays by sleeping ad lib during the following weekend. It is possible to test this widely held belief by simulating sleep times with a sleep–wake regulating model. Such models (e.g., [1]) postulate that, during daytime wakefulness, sleep pressure exhibits a reversed exponential buildup to reach its upper threshold in the late evening and to switch thereafter to an exponential decay of sleep pressure after the transition from wakefulness to

habitual sleep. A buildup of sleep pressure beyond its everyday upper threshold occurs during a voluntary extension of wakefulness to night hours. This additional buildup is usually viewed as a process of accumulation of “sleep debt” that is “paid” back during the following recovery sleep of longer duration and intensity [1]. The intuitive view of the wake-sleep alternations on weekdays and weekends might be associated with the alternation of a reduced weekday sleep and a lengthened weekend sleep with such a process of accumulation of “sleep debt” and its “payment”, respectively. However, the results of simulation of weekday and weekend bed- and risetimes [2] with a sleep–wake regulating model [3] has indicated that, irrespective of whether sleep was terminated spontaneously (on a weekend night) or somewhat earlier (on a weekday night), each of the everyday switches of the level of sleep pressure from its buildup to its decay occurred exactly at the model-predicted upper threshold, not above this threshold (Fig. 1A and C). This implies that

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Fig. 1 Model-based simulations and bed- and risetimes on weekdays and weekends. **A** Simulations of 10 sleep–wake cycles Before and During “lockdown” (see the list of parameters of the model in Table S1, middle and right columns, respectively). Phases of the sleep–wake regulating process were simulated as alternations between exponential buildups and decays of SWA (an index of sleep pressure) that is additionally modulated by sine-form function with 24-h period (see Methods and Supplementary2_Simulation). UT and LT: The highest buildup and the lowest decay of sleep pressure, respectively; **B** and **C** Night subintervals of simulations (A), either the interval of one night, between Saturday and Sunday (Sa-Su), or the intervals for weekend and weekday nights, between Saturday and Sunday (Sa-Su) and between Wednesday and Thursday (We-Th), respectively (the simulation of sleep Before “lockdown”). Data on bed- and risetimes before and during “lockdown” were taken from Table 1

“sleep debt” cannot be accumulated during weekdays, and if it cannot be accumulated during weekdays, there is nothing to be “paid” back during weekend nights. Therefore, the widely held belief in human ability to catch up on sleep over such weekend nights has not been validated by the model-based simulations [2, 4, 5].

By April 2020, due to the COVID-19 pandemic about half of the world’s population was under some form of “lockdown” [6]. People were asked or ordered by their governments to stay at home. This “lockdown” provided a new opportunity to demonstrate the predictive power of a sleep–wake regulating model by supporting the simulation results suggesting the inability to make up for sleep lost on weekdays by sleeping for longer time on weekends.

The following response of sleep to “lockdown” can be expected from the results of previous simulations of sleep times [2, 4, 5]. Due to a failure to accumulate “sleep debt” during weekdays, a shift from an earlier risetimes before “lockdown” to a later weekday risetimes during “lockdown” must lead to an increase of weekday sleep duration during “lockdown”. Despite this decrease of weekday sleep loss, a weekend sleep duration during “lockdown” cannot be reduced. In other words, when people wake up later on weekdays during “lockdown”, they sleep longer on these days, but this elongation of weekday sleep cannot lead to the reduction of weekend sleep duration during “lockdown”. Therefore, a weekend sleep duration before and during “lockdown” must be found to be practically identical (Fig. 1B).

In different countries around the world, the estimates of weekday and weekend sleep times prior to and during “lockdown” were collected and published for more than 30 samples ([7–22]; see Supplementary1_31samples). This dataset allowed the testing of model’s prediction of the failure of weekend sleep duration to become shorter in response to later weekday wakeups and longer weekday sleep duration during “lockdown”.

Consequently, the purpose of the present report was to test the model-based prediction that a weekday sleep

duration before and during “lockdown” was practically identical. The tested hypothesis was the following: Despite a significantly increased weekday sleep duration during “lockdown”, the weekend sleep duration during this “lockdown” did not become, in turn, significantly shorter compared to the weekend sleep duration before “lockdown”.

Methods

Data on rise- and bedtime on weekdays and weekends before and during “lockdown” were collected from a number of journal papers [7–22]. In Supplementary1_31samples, these 31 samples are listed with some other details (e.g., mean age, method of data collection, etc.).

Using the Statistical Package for the Social Sciences (SPSS₂₃, IBM, Armonk, NY, USA), paired t-test was employed to compare the estimates of sleep times before and during “lockdown”. The list of such estimates (Table 1) includes an additional measure named “sleep loss” whose calculation is explained in Supplementary2_Simulation.

In order to explain the difference in sleep times before and during “lockdown” in terms of the sleep–wake regulating model, the rise- and bedtimes were simulated (Fig. 1). The previously proposed variant of two-process model of sleep–wake regulation [3] was used for these simulations. If $t1$ and $t2$ are the initial times for the buildup and decay phases (rise- and bedtime, respectively) of the 24-h sleep–wake cycle, the sleep–wake regulating process $X(t)$ can be simulated using the following equations:

$$X(t) = [X_u + C(t)] - \{ [X_u + C(t)] - X_b \} * e^{-(t-t1)/[Tb-k * C(t)]} \quad (1a)$$

$$X(t) = [X_l + C(t)] - \{ X_d - [X_l + C(t)] \} * e^{-(t-t2)/[Td-k * C(t)]} \quad (1b)$$

where

$$C(t) = A * \sin(2\pi * t/\tau + \varphi_0) \quad (2)$$

is a periodic function with a period τ assigned to 24 h [3].

To perform the present simulations, the slightly modified initial parameters of the model [3] were utilized (Table S1 and Fig. 1). The estimates of rise- and bedtimes on weekends were taken from Table 1 as initial times ($t1$ and $t2$). For the sake of simplicity and clarity, these sleep times were rounded off to obtain 8.3 h and 24.0 h for $t1$ and $t2$, respectively, and to obtain 7.5 h for risetime on weekdays in the simulation of samples with late weekday risetime. Correspondingly, another simulation, for early weekday risetime, was performed with 8.5 h and 23.5 for $t1$ and $t2$, respectively, and 6.9 h and 7.9 h for weekday risetime before and during lockdown, respectively (see Table S1). Thus, the duration of

Table 1 Comparison of sleep times before and during “lockdown”

Paired samples	Before “lockdown”		During “lockdown”		Before-During difference		
	Mean	SEM	Mean	SEM	Mean	SEM	t_{30}
Sleep time							
Bedtime:							
Weekday	23.403	0.179	23.930	0.160	-0.527	0.071	-7.423***
Weekend	24.060	0.158	24.350	0.167	-0.290	0.058	-4.989***
Weekly averaged	23.591	0.170	24.050	0.161	-0.459	0.060	-7.649***
Risetime:							
Weekday	6.955	0.121	7.802	0.174	-0.848	0.120	-7.055***
Weekend	8.390	0.158	8.656	0.177	-0.266	0.072	-3.692**
Weekly averaged	7.364	0.119	8.046	0.171	-0.682	0.095	-7.144***
Time in Bed:							
Weekday	7.552	0.150	7.871	0.185	-0.319	0.055	-5.787***
Weekend	8.329	0.182	8.305	0.173	0.024	0.039	0.617
Weekly averaged	7.773	0.157	7.995	0.181	-0.222	0.042	-5.340***
Difference:							
Bedtime	0.656	0.070	0.420	0.044	0.236	0.069	3.445**
Risetime	1.434	0.129	0.854	0.084	0.581	0.115	5.047***
Time in Bed	0.777	0.071	0.433	0.046	0.345	0.065	5.323***
Sleep Loss, %	8.403	0.664	5.009	0.491	3.394	0.606	5.605***

Mean and SEM: On the left, Mean is a sample-averaged value and SEM is Standard Error of this Mean. On the right, Mean is the difference between sample-averaged values (Before-During difference) and SEM is Standard Error of this Mean difference; t_{30} : Paired Student's t-test for equality of mean values obtained for 31 pairs of samples Before and During “lockdown”; * $p < 0.05$, ** $p < 0.01$ or =0.001, *** $p < 0.001$. Calculation of Sleep Loss is explained in details in Supplementary2_Simulation

weekend sleep was the same, 8.3 h in both conditions, and the difference in weekday risetime was equal to 1 h.

Because the parameters of the applied model (see Supplementary2_Simulation) were initially derived from the simulations of other samples [3], Table S1 of Supplementary2_Simulation provides the comparison between the initially derived and present study parameters.

Results

Mean age obtained by averaging over 31 samples was 32.5 years with standard deviation of 15.8 years. The results of comparison of sleep times before and during “lockdown” supported the prediction that the weekend time in bed was not significantly altered during “lockdown” (Table 1). In contrast to this estimate, a before-during difference was found to be significant at $p \leq 0.001$ for any of 12 other estimates (Table 1). As predicted, a statistically significant increase in weekday time in bed was observed in response to the 1-h delay in weekday risetime during “lockdown” (Table 1). Therefore, the statistical analysis of sleep times indicated that the weekend time in bed did not become shorter during “lockdown” despite the increase of weekday time in bed during “lockdown” caused by the delay of weekday wakeups.

The increase in weekday sleep was smaller than the 1-h before-during difference in weekday risetimes. As it is illustrated in Fig. 1B and C, the 1-h delay of weekday risetime during “lockdown” (Table 1) can be partly explained by a delay of circadian phase during “lockdown” (Fig. 1B). Namely, approximately 30% of this 1-h difference between weekday risetimes before and during “lockdown” might be accounted by the delay of the sleep-wake cycle during “lockdown”. Therefore, the only difference between simulations of weekend sleep-wake cycles before and during “lockdown” was the 0.3-h delay of the cycle during “lockdown” relative to the cycle before “lockdown” (Fig. 1B). Approximately identical delays were observed for weekend bed- and risetimes. Therefore, the time in bed on weekends was not affected by “lockdown”.

Both before and during “lockdown”, the inability to catch up on sleep lost during 5 weekdays led to a reduction of weekly averaged time in bed compared to weekend time in bed (Table 1). As expected, such a reduction before “lockdown” was larger than before “lockdown” (Table 1). The model-based estimates of weekday sleep loss (see Supplementary2_Simulation for details) suggested only 5% reduction of weekday sleep during “lockdown” that was approximately 3% smaller compared to the estimate of sleep loss for weekday sleep before “lockdown” (Table 1).

Discussion

The ability to reveal novel insights into human sleep–wake behavior that is not simply intuitive is an important measure of the usefulness of sleep–wake cycle modeling for sleep science. The new challenge of “lockdown” during the COVID-19 pandemic provided the opportunity to demonstrate the predictive power of the models of sleep–wake regulation by testing the prediction that the weekend sleep duration would not be significantly altered during “lockdown”. Such a prediction fully disagrees with the widely held belief in human ability to make up missed weekday sleep by increasing sleep duration on weekend nights. Previous simulations [2, 4, 5] and the present model-based simulations (Fig. 1) did not support the concept of catching up on missed weekday sleep during the following weekend. Since early weekday wakeups did not lead to an additional buildup of sleep pressure (i.e., the accumulation of “sleep debt”), weekend sleep remained unaffected by the delay of weekday wakeups, a cause of the increase of weekday sleep duration. In the present study, model-based comparison of risetimes and bedtimes before and during “lockdown” suggested that the human body has no way to deal with weekday sleep loss. Irrespective of whether or not this loss was larger or smaller (i.e., before and larger during “lockdown”), people were incapable of sleeping for longer periods of time on weekends before “lockdown”. Their relatively long weekend sleep before “lockdown” cannot be regarded as an extended sleep. This was an adequate sleep whose duration was unaffected by earlier weekday wakeups.

The present analysis of sleep times before and during “lockdown” has highlighted the need to rethink the widely held view that people can catch up on sleep over the weekend nights. The simulations and the statistical analysis of the empirical dataset indicated that the weekend sleep duration remains approximately the same after a shorter and a longer weekday sleep reported before and during “lockdown”.

The results suggesting a failure to accumulate “sleep debt” in response to 1-h earlier weekday risetimes are in agreement with some other recently reported findings. Approximately the same 1-h difference was found between weekday risetimes of people living in close proximity one to another on two opposing sides of a border between two time zones. The results of comparison of employed people living on the late sunset side of a time zone border with employed people living in neighboring US counties on the opposite side of the border indicated that they slept, on average, 19 fewer minutes [23]. A reduced sleep duration at the late sunset side of a time zone was also reported for children and school students [24]. The example of

comparison of sleep durations of an individual in two conditions with approximately 1-h difference in wakeups was provided by Garefelt et al. [25]. The authors found that although after retirement sleep duration increases by 21 min, the changes in duration and timing of sleep were driven by weekday sleep, whereas weekend sleep stayed about the same. Such reports provide further evidence for the plausibility of considering the weekend sleep as an adequate, not extended sleep.

Since getting enough sleep is essential for maintaining optimal health and well-being, its reduction due to the 1-h earlier weekday wakeups before “lockdown” might be associated with negative consequences for health and performance. Therefore, in the light of the present results, it comes as no surprise that Depner et al. [26] failed to prevent a metabolic dysregulation associated with recurrent insufficient sleep by allowing a weekend recovery sleep. It would be of practical importance to estimate sleep curtailment caused by early weekday risetimes. The present results have indicated that sleep loss cannot be excluded even during “lockdown” and that the 1-h delay of weekday risetime during “lockdown” cannot lead to a drastic reduction of sleep loss.

There are several limitations of the methods of estimation of the relationship between weekday sleep curtailment and weekend sleep duration used in this study. The sleep measures did not include any markers of sleep intensity that can be, for instance, assessed by calculating an SWA index (Fig. 1). Objective methods (i.e., actigraphy) were applied for measuring sleep in only a small fraction of the analyzed samples (see Supplementary1_31samples). Furthermore, bedtimes and risetimes rather than sleep onsets and offsets were used for testing the prediction of the model-based simulations. There are several major reasons to rely on these simple estimates of sleep times. First, the authors of most of publications do not give sleep latencies in addition to risetimes and bedtimes. Second, it is hard to imagine the way by which these sleep latencies might be self-measured. Third, when a difference between two reports of weekend times in bed was calculated, this was made by subtracting one latency from another. In the case of the existence of a small (i.e., few minutes) difference between sleep latencies self-assessed before and during “lockdown”, this small difference cannot significantly challenge the present results including the result suggesting similarity of weekend sleep times before and during “lockdown”.

There are also several limitations of using this particular dataset collected during the natural “lockdown” experiment for testing the prediction of the model. The number of published samples was not big enough to perform multiple tests of the model’s prediction, and to confirm this result by several separate examinations for subsets of data representing two genders and several distinct age groups. Although the difference in intrinsic desire for sleep might underlie some of

the observed male–female differences in sleep duration [27], much of the gap between men and women was explained by gendered time tradeoffs and by work and family responsibilities [28]. This gender gap might be further increased in the condition of “lockdown” in some of age groups. Therefore, a possibility of significant difference between genders and between ages in the responsiveness of weekend sleep duration to “lockdown” might not be excluded. Furthermore, sleep of the same duration can be more or less restorative depending upon mood state and level of stress. The adverse effects of “lockdown” on mood and sleep were emphasized in numerous recent publications [29–44]. It is not excluded that stressful situations caused by “lockdown” resulted in a longer but less restorative sleep.

Conclusions

Analysis of sleep during “lockdown” has highlighted the need to rethink the concept of weekend catch-up sleep. The belief in human ability to accumulate “sleep debt” over weekdays and to recover from weekday sleep loss at weekend nights was supported neither by the statistical comparison of the bedtimes and risetimes reported before and during “lockdown”, nor by the model-based simulations of these times. The present and previous results allow the conclusion that people fail to sleep for longer on weekend to make up for weekday sleep loss and that their weekend sleep is not extended sleep.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s11325-021-02492-z>.

Author contribution AAP is the only author.

Funding The author was supported by the Russian Foundation for Basic Research (grant numbers 19-013–00424).

Data availability Data are included as one of Supplementary files.

Code availability Formula and parameters for data simulations are included in the text of method section and in one of supplementary files.

Declarations

Ethics approval and consent to participate Sleep times analyzed in the present report were collected from the published studies that have been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for studies involving humans. Individual data were not used, only group-averaged values from previous publications.

Consent for publication N/A

Conflict of interest The author declares no competing interests.

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