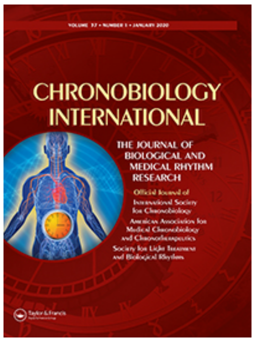

Taylor & Francis
Taylor & Francis Group

Chronobiology International
The Journal of Biological and Medical Rhythm Research

ISSN: 0742-0528 (Print) 1525-6073 (Online) Journal homepage: https://www.tandfonline.com/loi/icbi20

Evening chronotype, late weekend sleep times and social jetlag as possible causes of sleep curtailment after maintaining perennial DST: ain't they as black as they are painted?

Arcady A. Putilov, Mikhail G. Poluektov & Vladimir B. Dorokhov

CHRONOBIOLOGY INTERNATIONAL
2020, VOL. 37, NO. 1, 82–100
https://doi.org/10.1080/07420528.2019.1684937

Taylor & Francis
Taylor & Francis Group

Evening chronotype, late weekend sleep times and social jetlag as possible causes of sleep curtailment after maintaining perennial DST: ain't they as black as they are painted?

Arcady A. Putilov [a], Mikhail G. Poluektov [b], and Vladimir B. Dorokhov [a]

[a]Laboratory of Sleep/Wake Neurobiology, the Institute of Higher Nervous Activity and Neurophysiology of the Russian Academy of Sciences, Moscow, Russia; [b]Department of Nervous Diseases and Neurosurgery, Institute of Clinical Medicine, I.M. Sechenov First MoscowMedical University (Sechenov University)

ABSTRACT

People sleep less in response to setting social clocks earlier relative to the sun clocks. We proposed here a model-based approach for estimating sleep loss as the difference between weekend and weekday risetimes divided on the difference between weekend risetime and weekday bedtime. We compared this approach with a traditional approach to estimating sleep curtailment as the difference in weekly average sleep duration in two conditions. Weekday and weekend sleep times reported for 320 samples provided possibility of testing whether evening types with later weekend sleep times and larger social jetlag differ from morning types with earlier weekend sleep times and smaller social jetlag on amount of sleep lost (1) throughout the week and (2) in response to an advance of weekday wakeups, for instance, after the expected installation of perennial Daylight Saving Time (DST). We found that (1) an amount of sleep lost due to advancing shift of weekday wakeups depends upon neither chronotype nor weekend sleep times nor social jetlag, (2) a very large amount of sleep is usually lost by evening types with later weekend sleep times and larger social jetlag and (3) an essential sleep loss is caused by our usual work/school schedules, even in morning types with early weekend sleep times and small social jetlag. As compared to such permanent sleep losses experienced by any types, an additional loss due to switching from Standard Time (ST) to perennial DST are expected to be relatively small. We also found that the traditional way of calculation of sleep curtailment leads to paradoxical conclusions, such as (1) sleep loss is larger when social jetlag is smaller, not larger, (2) sleep loss is larger when weekend sleep times are earlier, not later, (3) despite 1-h difference between two student samples in weekday wakeups, their sleep losses can be identical.

ARTICLE HISTORY
Received 24 September 2019
Revised 17 October 2019
Accepted 22 October 2019

KEYWORDS
Evening type; morning type; sleep timing; sleep duration; sleep curtailment; sleep-wake regulation; two-process model; simulation

Introduction

People tend to sleep less when social clocks are set earlier relative to the sun clocks. Recently, Giuntella and Mazzonna (2019) demonstrated that employed people living on the late sunset side of a time zone border slept, on average, 19 fewer minutes than employed people living on the opposite side of the border (in neighboring US counties). Health index dropped by 0.3 standard deviations when people were living on the late sunset side of the border compared to the index of people living on the early sunset side (Giuntella and Mazzonna 2019). Gu et al. (2017) reported that risk for total and many specific cancers increased from the east to the west in a time zone and VoPham et al. (2018) found that an increase in longitude moving east to west within a time zone significantly increased the risk of developing hepatocellular carcinoma. Moreover, the results presented online by Jagnani (2019) indicated that, in near equatorial countries, later sunset times are associated with fewer hours of sleep and poorer academic performance.

The occurring twice a year switches between Daylight Saving Time (DST or "summertime") and Standard Time (ST or "wintertime") are expected to be soon ended in the EU and several states of the USA. Would clocks be set in a way that does not make people sleep less year-round? Chronobiologists and sleep researchers are alarming about the negative effects on sleep and health of maintaining perennial DST as compared to the effects from installing

CONTACT Arcady Putilov putilov@ngs.ru 11, Nipkowstr., 12489 Berlin, Germany.
This article has been republished with minor changes. These changes do not impact the academic content of the article.
Supplemental data for this article can be accessed here.

perennial ST with noon occurring when the sun is overhead. Several international chronobiological and sleep societies insisted that, after ending the clock changes twice a year, the best choice for EU, California and any other places around the world would be to set social clocks to year-round ST (EBRS 2019; ESRS 2019; Roenneberg et al. 2019b; Skeldon and Dijk 2019; SRBR 2019; Watson 2019). However, only one-third of several million respondents voted for setting year-round "winter time", whereas more than a half of the respondents voted for constant "summer time" in an EU public international consultation (European Commission 2018).

One of possible explanations of such amazing choice of the majority of respondents (e.g. Roenneberg et al. 2019a) suggests simple misunderstanding around the terms "winter time" and "summer time". They might be associated with a shorter natural daylight interval during "winter time" and a longer daylight interval during "summer time", while, in fact, the switching between DST and ST has nothing to do with the seasonal variation in photoperiod. If this explanation is correct, then one way of challenging the dominated public opinion would be to estimate the amount of sleep that is expected to be lost due to setting social clocks earlier relative to the sun and biological clocks.

Wittmann et al. (2006) introduced the term "social jetlag" to determine a misalignment between social and biological clocks and proposed to quantify it by calculation of a difference between when a person wakes up and goes to sleep on free days and when he/she wakes up and goes to sleep for work/school days. They also suggested that this kind of misalignment would be most pronounced in "late chronotypes" (or, in other terms, E[vening]-types as opposed to M[orning]-types) "who substantially have to readjust their temporal habits to social demands, i.e. having to get up early without being able to advance their circadianly controlled sleep-onset" (Wittmann et al. 2006). In the mentioned above report of Giuntella and Mazzonna (2019), the effects of 1-h difference in sunset time were larger among individuals with early working schedules and children of school age. Therefore, individual chronobiological differences between people as well as the differences in the extent of misalignment between their biological clocks and social clocks would be taken into account in evaluations of sleep curtailment caused by setting social clocks earlier relative to the sun and biological clocks. Individual variation in vulnerability to sleep loss would, in particular, predict that such a setting will be favoring exclusively early chronotypes thus ignoring the negative consequences for sleep and health of late chronotypes.

Here, we suggested that it is necessary to replace a traditional approach to estimation of sleep curtailment from weekday and weekend sleep times in two conditions by a new approach and we illustrated such necessity by comparing the estimates of sleep curtailment in samples with distinct (M- and E-) chronotypes, earlier and later sleep timing on free days; smaller and larger social jetlag; later and earlier weekday wakeups. When the results of applying the traditional and new approaches are compared, what would be the answers to such questions as: Does early chronotype or early weekend sleep times or small social jetlag let people (1) sleep more and (2) lose fewer minutes of sleep after a shift from later to earlier wakeups, in particular, due to the expected installation of perennial DST? The results of applying the two approaches were illustrated by the examination of the following two hypotheses:

E-types (with later sleep timing on free days and larger social jetlag) compared to M-types (with earlier sleep timing on free days and smaller social jetlag)

(1) sleep less throughout a 7-day week consisting of 5 working/school days and 2 free days, and
(2) will lose even more sleep when responding to earlier weekday wakeups, for example, after installation of perennial DST.

Methods

Samples

Bed- and Risetimes on weekdays and weekends (or, in general, free days) were collected form the journal papers. Sleep times for approximately a half of the analyzed here samples were previously used as an input to the model of sleep-wake regulating processes to simulate weekday and weekend time courses of Slow-Wave Activity (SWA), an electroencephalographic marker of these processes (Putilov and Verevkin 2018; Putilov et al. 2019; Figure 1).

Since sleep times dramatically vary with age (i.e. early chronotypes are mostly children and people over 50, while late chronotypes are mostly adolescents and young adults), we enlarged this dataset to 320 samples by searching for the new samples mostly in most recent publications (years 2018 and 2019). Such increase in size of the whole collected dataset provided a possibility of further subdivision of each of eight age subsets into, at least, two smaller subsets differed in either sleep timing or social jetlag or weekday wakeups. The sizes of such age subsets are reported in Supplementary 1 in the first two tables, Tables S1 and S2 (Supplementary Tables and Figures). Moreover, Supplementary 2 contains the list 320 samples with sleep times that were either added more recently for the present analysis or were previously used for simulation (see also this simulation in Supplementary 3).

We applied subdivision of the whole set of samples into two subsets in accord with social jetlag, sleep phase and weekday wakeups. Additionally, we arbitrarily subdivided the whole set of 320 samples in accord with year of publication (earlier than year 2014 or later), even-odd number of a sample (after ranging samples on mean age in a sample), country (Germany or other countries) and availability of data on distinct chronotypes (27 paired samples). Comparison of subsets obtained by such artificial subdivisions allowed the examination of replicability of sleep times calculated by averaging over samples collected without applying such selection criteria as a limited range of mean ages of study participants, sex ratio, employment/student status, years of education, outdoors light exposure, season of data collection, geographic location of the sample relative to the borders of time zone, longitude, latitude and so on.

Subdivision in accord with social jetlag and sleep phase

The major subdivisions of the whole set of samples into two subsets of approximately similar size were performed in accord with smaller or larger social jetlag and in accord with earlier or later sleep phase.

First, we calculated three measures of social jetlag proposed for its quantitative evaluation (Jankowski 2017; Roenneberg et al. 2007; Wittmann et al. 2006). However, the way of this calculation slightly differed from the originally proposed way (see also the limitation paragraph in Discussion). The main difference was in using bed- and risetimes instead of sleep onsets and offsets. Moreover, we need not calculate an absolute difference between weekday and weekend times because, due to averaging within each sample and then over the samples included in a subset, the obtained mean times always indicated a delay rather than advance of sleep timing on weekends. Therefore, we termed such an estimate "timelag" rather than "social jetlag" and calculated this lag as a weekend-weekday difference in either bedtime or risetime or midway from bedtime to risetime (either "bedtime-lag" or "risetime-lag" or "midway time-lag" abbreviated as either "BTL" or "RTL" or "MTL", respectively; Tables 1 and S3).

Second, we utilized three measures for subdividing samples into subsets in accord with sleep phase. Following publications of Roenneberg et al. (2004), Roenneberg et al. (2007), (2019a), we used a measure named "sleep corrected weekend midway time" (MT_{sc}) that is a half of weekly average time in bed (see below) added to weekend bedtime. Again, it differed from the originally proposed "sleep corrected midpoint between sleep onset and offset" due to utilizing for calculations bedtime instead of sleep onset (Tables 1 and S1).

We also suggested another sleep phase measure that we need not calculate because this is risetime on weekends (RT_{we}; Table 1). The reason for considering it as a measure of sleep phase was that, in accord with the simulation prediction, clock hour for wakeups seems to remain stable throughout the week in the case of spontaneous sleep termination, i.e. irrespective of bedtime that was always earlier on weekdays or always later on weekends (Figure 1).

In 26 publications, the estimates of bed- and risetimes were reported separately for 27 samples of M- and E-types. These data (27 of 320 samples) were included in the whole dataset after their averaging over chronotype (Table S4) while the pairs of samples of M- and E-types provided the third subdivision into samples with earlier and later sleep phases named "Type". However, only

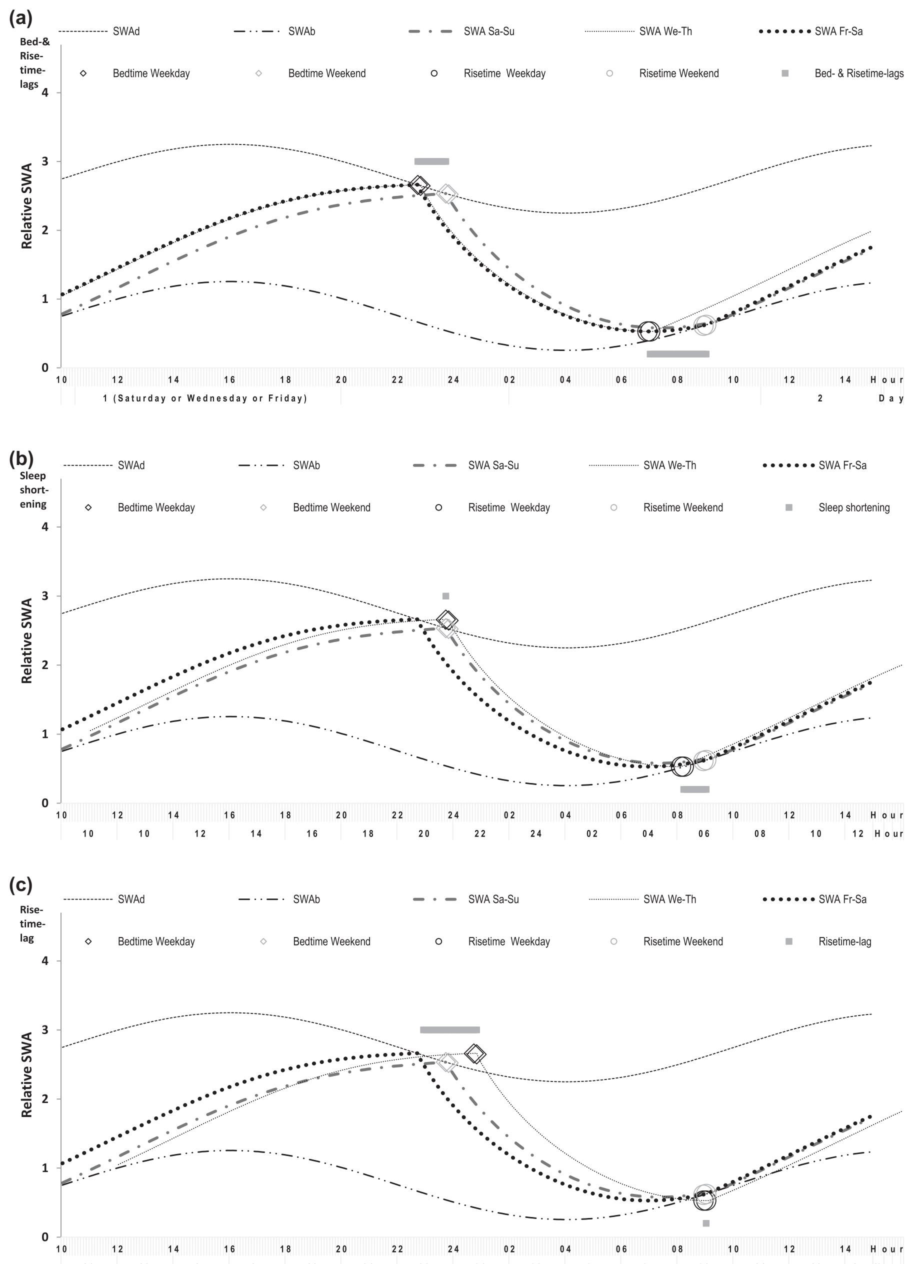

Figure 1. Weekend-weekday difference in sleep timing and duration.

(a) To illustrate the way of calculation of bed- and risetime-lags, bed- and risetimes for two halves of the whole dataset of 320 samples from earlier and later publications (see Table S3, left) are shown along with the time courses of relative value of Slow-Wave Activity (SWA). Previously, these time courses were obtained by simulating three sleep-wake cycles of the week (Saturday-Sunday, Wednesday-Thursday and Friday-Saturday) with a model postulating circadian modulation of SWA (bed- and risetimes obtained by averaging over app. a half of the samples were used as a input; see Putilov and Verevkin 2018; Putilov et al. 2019, and Supplementary 3). The simulation also suggested that weekend risetime predicted the phase of sleep-wake cycle at which sleep was spontaneously terminated irrespective of the days of the week. (b) To illustrate that sleep shortening (weekend-weekday change in time in bed) equaled to the difference between rise- and bedtime-lags, the time course for Wednesday-Thursday and weekday bed- and risetimes were shifted on the interval of bedtime-lag. (c). To illustrate that actual sleep loss due to earlier weekday wakeups equaled to risetime-lag, the time course for Wednesday-Thursday and weekday bed- and risetimes were further shifted on the interval of risetime-lag, i.e. risetime-lag equaled to sleep duration on Friday-Saturday night minus sleep duration on Wednesday-Thursday; this means that the parameters of the homeostatic process are modulated by the circadian clocks in such a way that sleep duration increases with advancing circadian phase at which sleep was spontaneously initiated (see also Figure 2c with empirical data suggesting a very strong correlation between risetime-lag and sleep loss). SWA_b and SWA_b: To illustrate the impact of circadian modulation of sleep homeostasis, the sine-form time courses of the upper and lower limits of normal variation in SWA are shown, i.e. spontaneous initiation of sleep and wake states was predicted to occur at the upper and lower thresholds of the sleep homeostatic process, respectively. Only further prolongation of wake state above the upper threshold would lead to accumulation of sleep debt, but the simulation did not reveal it.

Table 1. Samples sorted into two subsets: weekend and weekday risetimes.

Subdivision		Weekend risetime (RT_{we})					Weekday risetime (RT_{wd})				
two subsets		<9:00		>9:00		p for	<7:00		>7:00		p for
Sleep time		Mean	SEM	Mean	SEM	$F_{1/304}$	Mean	SEM	Mean	SEM	$F_{1/304}$
Bed-time	Weekday	22.71	0.07	23.04	0.06	<0.001	22.63	0.05	23.06	0.06	<0.001
	Weekend	23.43	0.06	24.31	0.06	<0.001	23.67	0.06	24.06	0.06	<0.001
	time-lag	0.72	0.05	1.27	0.05	<0.001	1.03	0.04	0.99	0.05	0.562
Rise-time	Weekday	6.81	0.05	7.18	0.05	<0.001	6.56	0.02	7.42	0.03	<0.001
	weekend	8.24	0.06	9.71	0.05	<0.001	8.65	0.06	9.31	0.07	<0.001
	time-lag	1.43	0.06	2.53	0.05	<0.001	2.09	0.06	1.89	0.07	0.031
Time in bed	Weekday	8.10	0.07	8.15	0.06	0.576	7.92	0.05	8.35	0.06	<0.001
	weekend	8.80	0.06	9.41	0.05	<0.001	8.98	0.04	9.25	0.05	<0.001
	shortening	0.71	0.06	1.26	0.05	<0.001	1.06	0.05	0.90	0.05	0.038
	Average	8.30	0.06	8.51	0.05	0.010	8.22	0.04	8.61	0.05	<0.001
	sleep loss	15.05	0.50	23.57	0.45	<0.001	20.58	0.51	18.24	0.59	0.003
MT_{sc}		3.58	0.05	4.56	0.05	<0.001	3.78	0.05	4.36	0.05	<0.001

Bedtime and risetime: Times to go to bed and to wake up, respectively, clock hours (decimals). Time-lag (TL): Weekend-weekday difference for tise- and bedtimes, hours (Figure 1a); Time in bed: Difference between clock hours for risetime and bedtime, hours; Shortening: Reduction of time in bed calculated as the weekend-weekday difference in time in bed equaled to the difference between rise- and bedtime-lags, hours (Figure 1b); Average: Weekly average time in bed calculated as one-seventh of the sum of time in bed for 5 weekdays and two weekends, hours; Sleep loss: Actual sleep loss calculated by dividing risetime-lag on difference between weekend risetime and weekday bedtime (Figure 1c), in %; SEM: Standard error of mean; Weekend and weekday risetime (RT_{wd} and RT_{wd}): Subdivisions of the whole set of 320 samples into a pair of subsets (either 155 or 176 samples with RT_{wd} or RT_{wd} earlier than either 9:00 or earlier than 7:00, respectively); p for $F_{1/304}$: p value for main effect of factor "Subset" from two-way MANOVAs, the samples were subdivided into eight ages (another factor "Age", see also sample sizes in Table S1 and Figures 3 and S2–S4).

27 paired samples were available for analysis of samples representing this third subdivision into earlier and late sleep phases (Table 2 and S3).

In overall, the six subdivisions allowed the comparison of two subsets of samples differed on three indicators of sleep phase named "Type", "RT_{we}" and "MT_{sc}" and on three measures of social jetlag named "RTL", "MTL" and "BTL" (Tables 1, left, 2, S5 and S6, left).

Subdivision in accord with earlier and later wakeups on weekdays

We also subdivided the whole sample into two subsets in accord with weekday wakeups. If mostly people' biology determines earlier sleep phase and smaller time-lag (six previous subdivisions), earlier weekday risetime (seventh subdivision) is expected to be mostly set by social clocks. Therefore, such a division into early and late risetimes allowed the prediction of possible response to constant DST of people differed in sleep phase and social jetlag. We used this last subdivision, into earlier and later RT_{wd}, for testing whether samples with smaller time-lag and earlier chronotype differed from samples with larger time-lag and later chronotype in responsiveness to earlier wakeups. In particular, such a response is expected after switching from ST to constant DST (the subsets with later and earlier RT_{wd}, respectively). Two subsets of samples with RT_{wd} being earlier and later than 7 a.m. were compared (Table 1, right).

Moreover, we further subdivided each of these two subsets into two smaller subsets with either earlier or later RT_{we}, either smaller or larger RTL and so on (Tables S7–S11). Such four-subset division was applied to all eight ages for comparison of three measures of time-lag (RTL, MTL and BTL; Tables S7–S9). However, a similar comparison of two sleep phase measures (MT_{sc} and RT_{we}; Tables S10 and S11) was limited to three of eight ages due to the absence of either samples with earlier phase (MT_{sc} < 4 a.m.) or samples with later phase (MT_{sc} > 4 a.m.) among samples of five other ages.

Comparison of paired samples

Additionally, several pairs of samples from separate studies allowed the examination of differences in sleep times in two conditions, either with different – earlier and later – weekday wakeups or during DST and ST (Tables S6, S12–S15). Therefore, we compared sleep

Table 2. Samples of distinct chronotypes and samples sorted in two subsets: sleep phase.

Subdivision		Type					Sleep corrected midway time (MT_{sc})				
two subsets		M-type		E-type		*p* for	<4:00		>4:00		*p* for
Sleep time		Mean	SEM	Mean	SEM	$F_{1/19}$	Mean	SEM	Mean	SEM	$F_{1/304}$
Bed-time	Weekday	22.33	0.11	23.34	0.15	<0.001	22.60	0.08	23.15	0.08	<0.001
	weekend	23.28	0.19	24.97	0.14	<0.001	23.18	0.07	24.38	0.07	<0.001
	time-lag	0.94	0.13	1.62	0.13	<0.001	0.57	0.06	1.22	0.05	<0.001
Rise-time	Weekday	6.62	0.13	7.42	0.20	0.002	6.67	0.06	7.19	0.05	<0.001
	weekend	8.25	0.22	10.31	0.20	<0.001	8.27	0.08	9.61	0.08	<0.001
	time-lag	1.62	0.11	2.89	0.19	<0.001	1.59	0.08	2.41	0.08	<0.001
Time in bed	Weekday	8.28	0.14	8.07	0.15	0.050	8.06	0.08	8.03	0.08	0.803
	weekend	8.97	0.16	9.34	0.11	0.016	9.08	0.07	9.22	0.07	0.210
	shortening	0.68	0.13	1.26	0.16	0.002	1.02	0.07	1.18	0.07	0.122
	Average	8.48	0.13	8.43	0.12	0.586	8.36	0.07	8.37	0.07	0.866
	sleep loss	16.15	1.08	25.85	1.60	<0.001	16.35	0.74	22.73	0.70	<0.001
MT_{sc}		3.52	0.19	5.19	0.17	<0.001	3.36	0.06	4.57	0.06	<0.001

Type: 27 pairs of samples were selected as representatives of distinct chronotypes (M[orning]- and E[vening]-types); MT (Midway time): Midpoint of time in bed calculated by adding a half of time in bed to bedtime, clock hours; MT_{sc} (Sleep corrected weekend MT): Weekend bedtime plus a half of average, clock hours; *p* for $F_{1/19}$: *p* value from two-way rANOVAs for main effect of "Chronotype" (27 paired samples of M- and E-types), the samples were distributed into eight ages (another factor "Age", see sample sizes in Table S1); *p* for $F_{1/304}$: *p* value obtained in two-way MANOVAs for main effect of factor "Subset" (165 samples from the whole set of 320 samples with MT_{sc} > 4:00), the samples were distributed into eight age groups (another factor "Age"). See also notes to Table 1 and Figures 3, S3 and S4.

times collected in such studies that can be considered "natural experiments" (see their list in Supplementary references of Supplementary 1).

A similar "natural experiment" was recognized in samples of two ages (16+ vs. 18+) in the collected dataset. Earlier age was mostly represented by high school students with early wakeups due to early school start time while older age was mostly represented by college/university students with much later weekday risetimes (Table S6, right).

Traditional approach to estimation of sleep reduction

A traditional approach to estimating sleep curtailment (e.g. caused by early wakeups) requires the calculation of a pair of weekly average sleep durations (e.g. for two conditions, with earlier and later weekday wakeups) and the following subtraction of one sleep duration from another. In other words, sleep curtailment can be, in particular, traditionally calculated as the difference between sleep durations after later weekday wakeups and sleep duration after earlier weekday wakeups.

To apply this traditional approach, we estimated the differences between rise- and bedtimes ("time in bed") on weekdays and the differences between rise- and bedtimes ("time in bed") on weekends. These times in bed were further used to calculate "weekly average time in bed" or, simply, "average" (in Tables 1–4 and S3–S20) that is one-seventh of the sum of time in bed for 5 weekdays and two weekends. This measure is an analog of weekly average sleep duration in social jetlag studies (e.g. Roenneberg et al. 2019a), but, again, we used for our calculations bed- and risetimes instead of self-reported times of sleep onset and offset.

Although such way of calculation of amount of sleep is very simple, its usefulness for estimation of sleep loss can be questioned by the results of simulation of weekday and weekend sleep times with a sleep-wake regulatory model (Putilov and Verevkin 2018; Putilov et al. 2019; these simulations are described in more details in Supplementary). They, as we expected, confirmed the much earlier published results of simulation of experimental data on circadian variation in sleep duration (Åkerstedt and Gillberg 1981) suggesting the sine-form 24-h modulation of sleep duration. The result explained the paradoxical observations of graduate decreasing rather than increasing in duration of sleep caused by delaying bedtimes due to prolongation of wakefulness into night and early morning hours (Daan et al. 1984; Putilov 1995). Such experimental and modeling results imply that sleep curtailment can be simply calculated as the difference between sleep durations in two conditions only in one case: when in both conditions sleep was initiated at the same circadian phase, but it was not

Table 3. Summary on comparisons of samples sorted into two subsets.

Sleep time	Subdivision subset	Year <2014	Type M-type	RT_{we} <9:00	MT_{sc} <4:00	RTL <2 h	MTL <1.5 h	BTL <1 h	RT_{wd} <7:00
Bed-	Weekday	5↓≈	1↓***	4↓***	2↓***	6↓≈	7 = ≈	8↑*	3↓***
time	weekend	8↓≈	2↓***	3↓***	1↓***	6↓***	4↓***	5↓***	7↓***
	time-lag	7↓≈	6↓***	4↓***	3↓***	5↓***	2↓***	1↓***	8↑≈
	in minutes	−3	−41	−33	−39	−35	−51	−56	2
Rise-	Weekday	5↑≈	2↓**	4↓***	3↓***	7↑*	6↓≈	4↓≈	1↓***
time	weekend	8↓≈	2↓***	1↓***	3↓***	5↓***	4↓***	6↓***	7↓***
	in minutes	−4	−124	−88	−80	−73	−77	−62	−40
	Time-lag	7↓≈	6↓***	3↓***	5↓***	1↓***	2↓***	4↓***	8↑*
	in minutes	−5	−76	−66	−49	−82	−73	−55	12
Time	Weekday	6↑≈	8↑+	5↑≈	3↑≈	7↑*	4↓≈	2↓***	1↓***
in	in minutes	5	13	−3	2	13	−4	−21	−26
bed	Weekend	8↑≈	4↓***	2↓***	7↓≈	1↓***	3↓***	6↓***	5↓***
	in minutes	3	−22	−37	−8	−35	−26	−19	−16
	Shortening	5↓≈	2↓***	3↓***	6↓≈	1↓***	4↓***	7↑≈	8↑*
	in minutes	−2	−35	−33	−10	−47	−22	1	10
	Average	7↑≈	8↑≈	3↓*	5↓≈	6↓≈	4↓+	2↓***	1↓***
	in minutes	4	3	−13	−1	−1	−10	−20	−23
	% to mean	1%	1%	−2%	0%	0%	−2%	−4%	−5%
	Sleep loss	6↓≈	4↓***	3↓***	5↓***	1↓***	2↓***	7↓***	8↑**
	in %	−1%	−10%	−9%	−6%	−11%	−9%	−6%	2%
MT_{sc}		8↓≈	2↓***	3↓***	1↓***	6↓***	4↓***	5↓***	7↓***

Subdivision: The way of subdividing a set of samples into two subsets; Year: Year (of publication), one of the arbitrary divisions into two subsets (see Table S3, left); Subset: One of two subsets with earlier weekend sleep timing (see Tables 1, 2, S5 and S6); ⊠ or ⊠ or =: Value in this subset was either higher or lower or the same as in another subset with later weekend sleep timing; in minutes: This difference between subsets was additionally shown in minutes, (–) indicates earlier risetime on weekends, smaller sleep curtailment due to a smaller bed- and risetime-lags and shortening, and shorter sleep due to shorter weekday, weekend and average time in bed; % to mean: The same difference expressed in percentage to mean average for two subsets; in %: The difference in actual sleep loss measured in percentage, (-) indicates smaller loss; statistical analyses (Tables 1, 2, S3, S5 and S6) yielded main effect of factor "Subset" with levels of significance ≈($p > 0.1$), +($p < 0.1$ or $p = 0.05$), *($p < 0.05$ or $p = 0.01$), **($p < 0.01$), and ***($p < 0.001$); a value in subset was also ranked relative to values obtained by seven other divisions, from the smallest (1) to the largest (8). See also notes to Tables 1 and S3, Figures 3 and S2–S4.

(e.g. in the cases of sleep initiation on either weekdays or weekends either after earlier or after later weekday wakeups).

Estimation of actual sleep loss

Therefore, to take into account the circadian modulation of sleep duration, we proposed another, model-based approach to calculation of sleep curtailment (e.g. sleep loses due to earlier weekday wakeups, including sleep losses cause by observing DST).

Weekend-weekday difference in time in bed was named "sleep shortening" or simply "shortening". It equals to the difference between rise- and bedtime-lags as illustrated in Figure 1b. The simulation (Figures 1c and 2c) prompted a measure of sleep curtailment named "actual sleep loss" or, shortly, "sleep loss" that is calculated as the difference between rise- and bedtime-lags (shortening) expressed in percentage to the difference between weekend risetime (RT_{we}) and weekday bedtime (Tables 1 and S3). In other words, shortening (weekend-weekday difference in time in bed) is expressed in percentage to time in bed expected in the case of naturally occurring sleep on Friday-Saturday night, when bedtime is initiated after the last working/sleep day, earlier than on weekend, to be spontaneously terminated already in the beginning of first free day, later than on weekday (Figure 1c).

To provide direct comparison of difference in the results of using two measures for estimation of sleep curtailment, the difference between two subsets of samples in weekly average time in bed was expressed in percentage to mean value obtained by averaging over these two weekly average times in bed (Tables 3 and S16–S20). The final results of such comparison are given in Table 4.

List of time measures

In overall, the bed- and risetimes for weekdays and weekends were used to calculate the following time measures (Tables 1–3, S3–S20 and Figure 1):

Table 4. Summary on comparisons of weekly average time in bed and actual sleep loss.

Sleep	Subdivision	Type	RT_{we}	MT_{sc}	RTL	MTL	BTL
iime	one subset	M-type	<9:00	<4:00	<2 h	<1.5 h	<1 h
Average	In minutes	3	−13	−1	−1	−10	−20
	% to mean	1%$^{\approx}$	−2%*	0%$^{\approx}$	0%$^{\approx}$	−2%+	−4%***
sleep loss	In %	−10%***	−9%***	−6%***	−11%***	−9%***	−6%***
One subset		RT_{wd} < 7:00		RT_{wd} < 7:00		RT_{wd} < 7:00	
Further subdivision		RTL		MTL		BTL	
Two subsets		<2 h	>2 h	<1.5 h	>1.5 h	<1 h	>1 h
Average	In minutes	−23	−25	−27	−23	−26	−26
	% to mean	−5%***	−5%***	−5%***	−5%***	−5%***	−5%***
sleep loss	In %	2%**	3%**	2%*	1%*	4%***	2%***
One subset		RT_{wd} < 7:00		RT_{wd} < 7:00		RT_{wd}	Age
Further subdivision		RT_{we}		MT_{sc}		<7:00	16+ 18+
Two subsets		<9:00$^{\wedge}$	>9:00$^{\wedge}$	<4:00$^{\wedge}$	>4:00$^{\wedge}$	One subset	16+
Average	In minutes	−31	−34	−20	−37	−23	3
	% to mean	−6%***	−7%***	−4%**	−8%**	−5%***	1%$^{\approx}$
sleep loss	In %	9%***	7%***	7%**	5%**	2%**	8%***
"Natural experiment"		DST vs. ST		School start times		In vs. after school in	
Another sample(s)		Seasonal	Perennial	Later	Holydays	University	College
Sample(s)		DST	DST	Early	Early	School	School
Average	In minutes	−10	−4	−31	−64	−9	1
	% to mean	−2%$^{+}$	−1%	−6%$^{\approx}$	−12%	−2%	0%
sleep loss	In %	0%$^{\approx}$	5%	14%***	17%	5%	10%

Subdivision: Division of samples into two subsets; One subset: One of two subsets with earlier sleep timing (Tables 1, 2, S5 and S6); in minutes and % to mean: The difference between subsets in average measured either in minutes or as percentage to mean average for two subsets; in %: The difference in actual sleep loss measured in percentage, (-) indicates shorter average and smaller sleep loss in one subset; two subsets: Further subdivision into two smaller subsets with RT_{wd} < 7:00 and >7:00; ^: For RT_{we} and MT_{sc}, only three of eight ages were analyzed (see Table S2); Age (16 + and 18+): Two of eight ages, 16.5–18.0 years and 18.5–23.0 years (Tables S6, right, S17 and S20); DST vs. ST: Seasonal and perennial DST vs. ST (Tables S13–S15, S19 and S20); School start times: Early vs. later or vs. holidays (Tables S11, S14, S15, S18 and S20); In vs. after school: Early wakeups when at school age compared to later wakeups in University/College age (Tables S15 and S20); statistical analyses (Tables 1, 2, S4–S10 and S14) yielded main effect of factor "Subset" with levels of significance $^{\approx}$($p > 0.1$), $^{+}$($p < 0.1$ or $p = 0.05$), *($p < 0.05$ or $p = 0.01$), **($p < 0.01$) and ***($p < 0.001$). See also notes to Tables 1 and 3.

Time in bed (TiB), hours, = Risetime (RT), clock hours, – Bedtime (BT), clock hours, + 24 h;

Weekday time in bed (TiB_{wd}), hours, = Weekday risetime (RT_{wd}), clock hours, – Weekday bedtime (BT_{wd}), clock hours, + 24 h;

Weekend time in bed (TiB_{we}), hours, = Weekend risetime (RT_{we}), clock hours, – Weekend bedtime (BT_{we}), clock hours, + 24 h;

Averaged time in bed (Average), hours, = (5 * Weekday time in bed (TiB_{wd}) + 2 * Weekend time in bed (TiB_{we}))/7, hours;

Midway time (MT), clock hours, = Bedtime (BT), clock hours, + (Time in bed (TiB))/2, hours, – 24 h;

Weekday midway time (MT_{wd}), clock hours, = Weekday bedtime (BT_{wd}), clock hours, + (Weekday time in bed (TiB_{wd}))/2, hours, – 24 h;

Weekend midway time (MT_{we}), clock hours, = Weekend bedtime (BT_{we}), clock hours, + (Weekend time in bed (TiB_{we}))/2, hours, – 24 h;

Bedtime-lag (BTL), hours, = Weekend bedtime (BT_{we}), clock hours, – Weekday bedtime (BT_{wd}), clock hours;

Risetime-lag (RTL), hours, = Weekend risetime (RT_{we}), clock hours, – Weekday risetime (RT_{wd}), clock hours;

Midway time-lag (MTL), hours, = Weekend midway time (MT_{we}), clock hours, – Weekday midway time (MT_{wd}), clock hours;

Sleep shortening (Shortening), hours, = Weekend time in bed (TiB_{we}), hours, – Weekday time in bed (TiB_{wd}), hours = Risetime-lag (RTL), hours, – Bedtime-lag (BTL), hours;

Actual sleep loss (Sleep loss), %, = 100* Risetime-lag (RTL), hours,/(Weekend risetime (RT_{we}), clock hours, – Weekday bedtime (BT_{wd}), clock hours, + 24 h);

Difference in sleep loss, %, = Difference in sleep loss in one of two conditions, %, – Difference in sleep loss in another condition, %;

Difference in averaged time in bed, %, = 100 * (Average in one of two conditions, hours, – Average in another condition, hours)/(Average in one of two conditions, hours, + Average in another condition, hours);

Sleep corrected weekend midway time (MT_{sc}), clock hours, = Weekend bedtime (BT_{we}), clock hours, + Average/2, hours.

Statistical analyses

All statistical analyses were performed with the Statistical Package for the Social Sciences ($SPSS_{23}$, IBM, Armonk, NY, USA). The estimates derived from the collected sleep times were related one to another using the Pearson's coefficients of correlation (Figure 2 and Supplementary Figure S1). We performed two-way MANOVAs of 12 (collected and derived) sleep times (Tables 1, 2 and S2–S6) to test, for each of these 12 sleep times, significance of main effect of factor "Subset" (Tables 1, 2 and S2–S6) and its interaction with the second independent factor "Age" (see Results and Figures 3, S2–S4). We also run three-way MANOVAs of these 12 sleep times when each of two subsets was further subdivided into two smaller subsets to test significance of main effects of two "Subset" factors (Tables S7–S11) and interaction between them (see Results and Figure 4). For paired samples (e.g. M- and E-types), two-way repeated measure ANOVAs (rANOVAs) were performed. The second factor was "Age" (Table 2). Paired t-test was employed for paired samples from "natural experiments" (Tables S12, S13, S15) in statistical analysis of data from several such pairs of samples of separate "natural experiments" (Table S14).

Results

Replicability of the results of collection of sleep times

Comparison of subsets obtained by applying any of arbitrary ways of subdivision of the whole set of 320 samples into two subsets suggested high replicability of the results of such approach to sleep times collection (Supplementary Tables S3 and S4). For example, when we used the year of publication (before 2014 or later) for such an arbitrary subdivision of the whole set of samples into two halves, none of 12 analyzed sleep times significantly differed in two halves as indicated by nonsignificant main effects of factor "Subset" in two-way MANOVAs (Supplementary Table S3, left). The largest of these differences between these two halves was 7 min (weekend bedtime) and the smallest was 1 min (weekday risetime).

Figure 1 illustrates the simulated curves consisting of the points divided by the smallest intervals of 6 min length each. Therefore, we only way to show the pairs of subset-averaged sleep times (weekday and weekend bed- and risetimes) obtained from earlier and later publications was to assign any of them to the neighboring points divided by such a 6-min interval. Figure 1 also suggested that the fit between empirical sleep times and their model-based simulation remained excellent despite using the newly obtained results of averaging bed- and risetimes with doubled number of samples as compared to the number of previously simulated samples.

Relating sleep curtailment to later sleep phase and larger time-lag

Our proposed measure of sleep curtailment, actual sleep loss, was introduced here to account for a profound circadian modulation of sleep duration. Figure 1 illustrates that, due to such circadian modulation of the parameters of homeostatic sleep regulation, sleep duration was longer when sleep was initiated earlier in the evening to becoming shorter and shorter with sleep being initiated later and later. Because the simulation predicted that, in overall, the sleep-wake cycle remained to be entrained by the circadian clocks throughout the week, sleep, even when it was initiated at weekday bedtime (earlier), was expected to be spontaneously terminated at the same circadian clock time as sleep initiated at weekend bedtime (later). This mechanism of entrainment provided stability to the phase of sleep-wake cycle to allow it to remain in synch with the circadian clocks

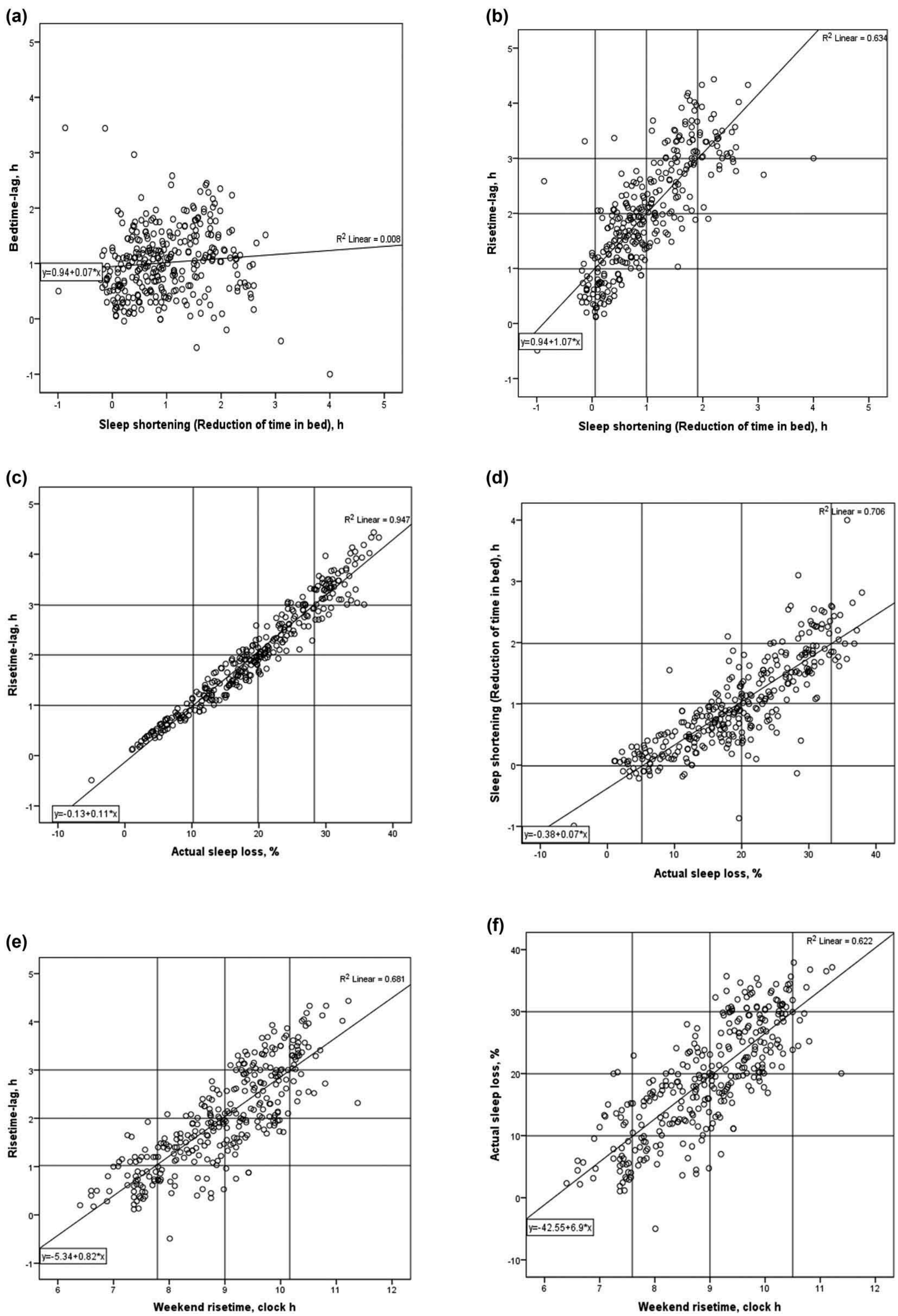

Figure 2. Predictors of risetime lag, sleep shortening and sleep loss.

Lines illustrate linear relationships. (a) and (b) Bed- and risetime-lags (weekend-weekday difference in red- and risetime, respectively) vs. Sleep shortening (weekend-weekday difference in time in bed) equaled to the difference between rise- and bedtime-lags (a and b, respectively). (c) and (d) Risetime-lags and sleep shortening vs. actual sleep loss (risetime-lag expressed as percentage to the difference between weekend risetime and weekday bedtime, (c) and (d), respectively). (e) and (f) Risetime-lags and actual sleep loss vs. weekend risetime (e and f, respectively).

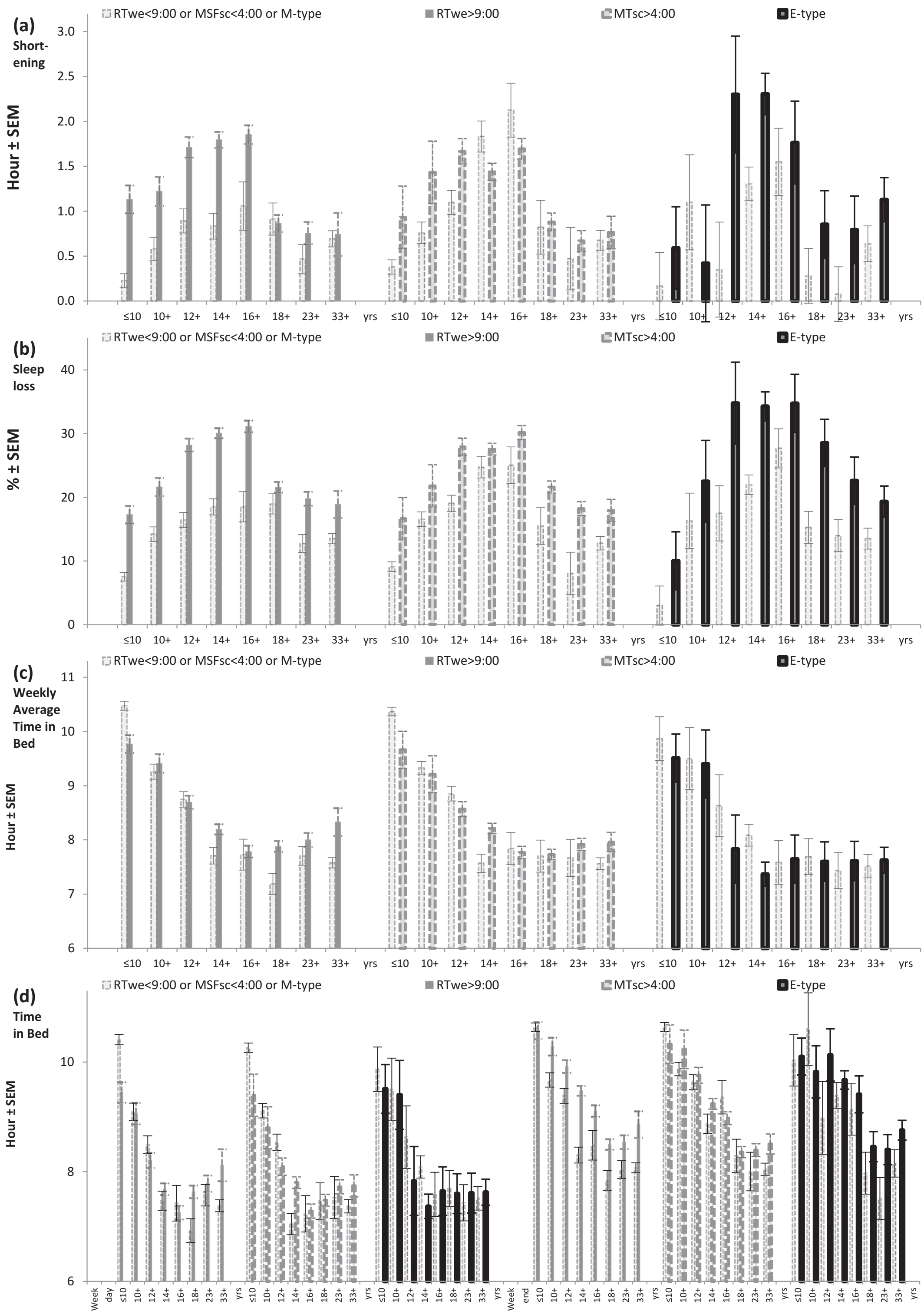

Figure 3. Sleep loss and time in bed in two-subset divisions in accord with sleep phase.

(a) Shortening: Sleep shortening calculated as the weekend-weekday difference in time in bed equaled to the difference between rise- and bedtime-lags (Figure 1b). (b) Sleep loss: Actual sleep loss (Figure 1c) calculated by dividing risetime-lag*100 on the difference between weekend risetime and weekday bedtime, in %. (c) Weekly average time in bed calculated as one-seventh of the sum of times in bed for 5 weekdays and two weekends. (d) Time in bed on weekdays and weekends (left and right, respectively). Two subdivisions of the whole set of 320 samples into two subsets, either with different RT_{we} (weekend risetime) or with different MT_{sc} (sleep corrected weekend midway time), and 27 paired samples representing two distinct chronotypes (M- and E-types). See also notes in Table 1, sizes of subsets in Table S1 and see mean (averaged over eight ages) sleep times in Tables 1, left, and 2.

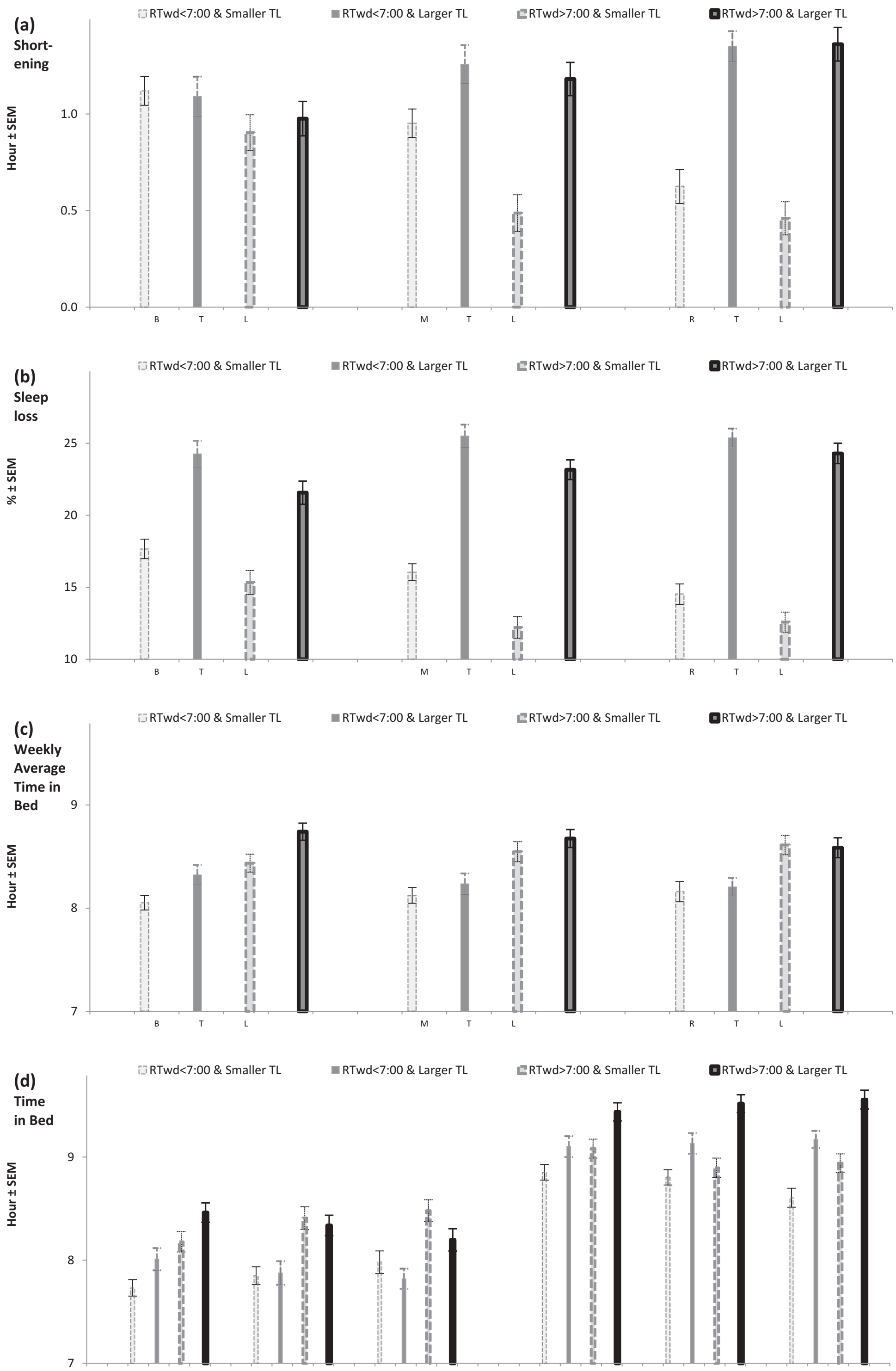

Figure 4. Sleep loss and time in bed in four-subset divisions in accord with time-lag.

(a)–(d) Sleep shortening; actual sleep loss; weekly average time in bed; weekday and weekend time in bed (the same variables as in Figure 3) in samples sorted into four subsets, with the first division in accord with weekday risetime (<7:00>) and the second division in accord with time lags (either 1 h < BTL > 1 h or 1.5 h < MTL > 1.5 h or 2 h < RTL > 2 h). See also sizes of subsets in Table S2 and sleep times in Tables S7–S9.

throughout the week despite the termination of sleep on weekdays prior to its expected spontaneous termination. Ideally, a long spontaneously terminated sleep might be observed only at one of seven nights, between the last working/school day (Friday) and the first free day (Saturday) in the condition when bedtime and risetime are determined exclusively by internal sleep-wake regulating mechanism (e.g. when people do not delay voluntarily their bedtime in the Friday evening). Because sleep in the previous nights was terminated earlier (weekday wakeups), sleep curtailment equals to the difference between weekend and weekday wakeups, that is risetime-lag (Figure 1c), and when this lag is expressed as percentage to total time in bed predicted for Friday-Saturday night, that is the difference between weekday bedtime and weekend risetime, this estimate reveals the amount of actually lost sleep (Tables 1–4, S3–S20).

Figure 2 illustrates the strength of relationships between time-lags, sleep phase and such an actual sleep loss. In particular, the correlation analysis suggested that sleep shortening (reduction of time in bed on weekdays) was unrelated to bedtime-lag but, in contrast, it was very closely related to risetime-lag. This risetime-lag, in turn, demonstrated almost functional relationship with actual sleep loss in accord with the prediction of the model (Figure 2c). For example, when a risetime-lag was small, e.g. just 1 h, this lag suggested a relatively small sleep curtailment, but, nevertheless, even such a 1-h risetime-lag corresponded to, at least, 10% weekday sleep loss. When risetime-lag was large, e.g. 2 h, weekday sleep loss was doubled (i.e. as many as 20% of expected time in bed was lost on weekdays).

Moreover, significant but less strong relationship with sleep loss was shown by such sleep phase measure as risetime on weekends, RT_{we} (Figure 2f). When, on average, wakeup occurred at 9 a.m., the same 20% of expected time in bed was lost, and when risetime was set at 10:30, this resulted in almost 30% sleep loss. In overall, the estimates of actual sleep loss suggested dramatic increasing in sleep loss with delaying sleep phase on free days and, consequently, with increasing time-lag (social jetlag).

Table 3 summaries the differences between pairs of subsets representing earlier and later sleep phases as indicated by Type, RT_{we} and MT_{sc} and smaller and larger social jetlag as estimated with such measures as RTL, MTL and BTL. Additionally, Figure 3 and Supplementary Figures S1–S4 illustrate the relationships of such division with age. The results fully confirmed the results of correlation analysis indicating (1) a profound loss of sleep even in people of M-type characterized by advanced weekend sleep timing and small social jetlag and (2) a dramatic increase in sleep loss in people of E-type with delayed sleep timing on weekend and large social jetlag. Depending upon measure, the difference between subsets in actual sleep loss varied from 6% to 11% ($p < 0.001$ for any of six comparisons).

For example, M-type was associated with losing, on average, 16% of time in bed whereas E-type was associated with loosing 10% more time (Tables 1 and 3). This implies that more than a quarter, 26%, of sleep was lost by people of late types (Table 1). The loss was even higher for some of ages, for instance, approximately a third of total sleep duration in late adolescence (Figure 3).

Time in bed in relation to later sleep phase and larger time-lag

However, a different and, to our mind, much less realistic picture was painted when sleep curtailment was measured in the traditional way, as the difference in time in bed between subsets with different Type, RT_{we}, MT_{sc}, RTL, MTL and BTL (Table 3 and Figures 3, S1–S4). The difference between subsets was mostly nonsignificant. When it was, sometimes, significant, it indicated a shorter sleep in subsets representing early chronotype (or weekend sleep times) and smaller time-lag, e.g. in the case of early RT_{we} and smaller BTL (Tables 1, 3 and S5, and Figures 3 and S2).

Even more, weekday time in bed was also found to be significantly shorter in the subset with smaller BTL despite earlier sleep phase (Table 3). Figures 3 and S1–S4 illustrate statistically significant interaction of weekday time in bed with age. This interaction suggested that, when the difference between subsets was nonsignificant, it can be explained by a linear relationship between age and weekday time in bed. Interaction term in the results of MANOVAs gave $F_{7/304} = 5.4$, $p < 0.001$,

$F_{7/304} = 3.4$, $p < 0.001$, $F_{7/304} = 2.9$, $p < 0.01$, $F_{7/304} = 2.9$, $p < 0.01$ and $F_{7/304} = 4.3$, $p < 0.001$ for interaction of RT_{wd} with RT_{we}, MT_{sc}, RTL, MTL and BTL, respectively (e.g. Figures 3, S2 and S4), and interaction term in the results of rANOVA yielded $F_{7/19} = 3.2$, $p = 0.02$ for interaction of RT_{wd} with Type. For instance, Figure S1 shows that weekday time in bed in M-types (with later weekend sleep times and larger social jetlag) was longer only in younger ages to become shorter in older ages.

Thus, these results suggested that, compared to people with earlier sleep phase and smaller time-lag, people with later sleep phase and larger time-lag did not spend in bed, in overall, less time than the opposing types, even on weekdays (Table 3). As for weekly average time in bed (Tables 3 and 4), they tended to stay in bed even longer, namely, longer on 13, 10 and 20 min as indicated by the estimates of RT_{we}, MTL and BTL, respectively ($p < 0.001$ for all).

Time in bed and actual sleep loss in relation to early wakeups

The estimates of actual sleep loss and weekly average time in bed were in a better agreement in the results of comparison of two subsets with earlier and later RT_{wd}. They indicated that earlier weekday wakeups significantly increased sleep loss and significantly decreased time in bed (Tables 1, 3 and 4).

However, such an increase in sleep loss due to earlier rather than later weekday wakeups was found to be relatively small (2%) in comparison with the described above sleep losses caused by early weekday wakeups per se that reached 15–16% in samples with earlier sleep phase and 23–24% in samples with later sleep phase (Type, RT_{we} and MT_{sc}). Similarly, in samples with smaller and larger time-lags such a sleep loss reached 14–17% and 23–25%, respectively (RTL, MTL and BTL). Moreover, an increase in sleep loss due to earlier rather than later weekday wakeups was rather small when compared to the difference between the subsets of these samples obtained by the division in accord with their earlier-later sleep phase and smaller-larger time-lag (6–10% and 6–11%, respectively).

In contrast, weekly average time in bed demonstrated a relatively large significant reduction (23 min or 5%) compared to the described above difference either between earlier and later sleep phases or between smaller and larger time-lags. They were mostly nonsignificant and, when significant, suggested the opposite direction compared to the direction of reduction of weekly average time in bed with up to 13 min shorter time in bed in samples with earlier phase and up to 20 min smaller time-lag in samples with smaller time-lag (Tables 3 and 4).

None of three-way MANOVAs revealed significant interaction between two factors “Subset” when further division of two subsets of RT_{wd} (before and after 7 a.m.) into two smaller subsets was performed to differential samples on sleep phase and time-lag, (RT_{wd} vs. RT_{we}, MT_{sc} and vs. RTL, MTL, BTL, respectively). Figure 4 illustrates these results indicating that earlier wakeups produced identical effects on samples characterized either by earlier and later sleep phases or by smaller and large time-lags (Tables S4, S7–S11, S16 and S17). Such results, in particular, suggested that none of two chronotypes benefited more from later wakeups and any chronotype suffered from sleep curtailment caused by shifting wakeups on an earlier clock hour. The results were similar when the difference between types was measured either as actual sleep loss or as reduction of weekly average time in bed (Tables S4, S10, S11 and S17).

Time in bed and actual sleep loss in “natural experiments”

Sleep times in samples of school age students provided possibility to compare the effects of earlier wakeups, either by comparing with sleep times of later ages when weekday risetimes significantly delayed (Lund et al. 2010; Urner et al. 2009) or by comparing with holidays (Warner et al. 2008) and delayed school start times (Arrona-Palacios and Díaz-Morales 2018; Arrona-Palacios et al. 2015; Boergers et al. 2014; Brandalize et al. 2011; Carissimi et al. 2016; Lima et al. 2002; Peixoto et al. 2009; Perkinson-Gloor et al. 2013). In overall, they confirmed the results of comparison of the impact of early and late RT_{wd} on actual sleep loss and weekly average time in bed (Table 4).

However, the attending school in early hours was associated with larger and significant sleep loss whereas the reduction of time in bed was much smaller (Tables 4, S6, right, S12, S14, S15, S17, right, S18 and S20). Moreover, it was not noted in any of pairs of samples/subsets and, most importantly, it was always found to be nonsignificant (Tables 4, S6, right, S14, S17, right, S18 and S20).

Thus, the results of these "natural experiments" revealed significant actual loss of sleep but did not provide evidence for significant decrease in weekly average time in bed in students of school age as compared to the students of older age and students of the same age attending school in later hours.

Six studies provided possibility of comparison of seasonally of sleep times under observing DST and ST (Friborg et al. 2012; Johnsen et al. 2013; Lo et al. 2014; Lowden et al. 2018; Miller et al. 2010; Shochat et al. 2019). In overall, this dataset does not support the expectation of a significant sleep loss and a significant reduction of weekly average time in bed due to the observing DST (Tables S13, S14, S19 and S20). It only allows the conclusion that the effects of DST seemed to be weaker than the effects of early school start times (Table 4).

The only "natural experiment" allowing the direct comparison of samples collected during perennial DST and perennial ST was provided in a study of school students in northern regions of Russia (Borisenkov et al. 2016). Our estimates suggested that weekly average time in bed was nonsignificantly reduced under DST (only by 1%). Actual sleep loss was larger, 5%, but not as large as the permanent sleep curtailment caused, presumably, by early school times, either 36% or 31% during perennial DST and perennial ST, respectively (Tables 4, S15, S19 and S20).

Discussion

We tested here the hypotheses that, throughout a 7-day week consisting of 5 working/school days and 2 free days, E-types (with later sleep timing on free days and larger social jetlag) (1) sleep less than M-types (with earlier sleep timing on free days and smaller social jetlag) and (2) are expected to additionally lose more sleep in response to earlier weekday wakeups, in particular, when observing perennial DST. The answers mostly disagreed one with another when provided by applying the traditional and presented here approaches to estimation of sleep curtailment (by calculating the difference in weekly average time in bed and as the difference between weekend and weekday risetimes divided on the difference between weekend risetime and weekday bedtime).

First, no evidence for significant positive association of the amount of sleep loss with E-type, late sleep timing on free days and larger social jetlag was provided by the results of applying the traditional approach to measurement of sleep curtailment. Instead, a significant positive association with M-type and larger social jetlag was shown for some of six sleep phase and time-lag measures. Do these results of answering to the question of whether E-types sleep less than M-types allow the conclusion that any concerns about vulnerability of E-type (or late sleep timing or large social jetlag) to sleep curtailment and health problems would be ill-advised? The answer seems to be no after applying the proposed here approach to quantification of actual sleep losses. These estimates suggested that, irrespective of whether we are M- or E-types, our usual work/school schedules might be harming our sleep and health. Besides, E-types seem to be more than M-types vulnerable to such effects. They have a higher percentage of lost sleep due to a larger weekend-weekday difference in sleep times. For example, empirical results supported the model prediction that actual sleep loss doubles, from 10% to 20%, due to an increase of the weekend-weekday risetime difference (risetime-lag) from 1 to 2 h (Figure 2c).

Second, the answer to the question of whether M-types compared to E-types expected to lose fewer minutes of sleep when responding to earlier weekday wakeups appeared to be less dependent upon the applied approach to measurement of sleep curtailment. However, this answer was no when it was provided by implication of any approach. The results of our analysis suggested that such responses were fully identical in samples of either M- or E-chronotypes, with either earlier or later weekend sleep times, and with either smaller or larger time-lag. Therefore, neither chronotype nor sleep timing on free days nor social jetlag would influence the amount of sleep lost due to a shift from later to earlier wakeups, in particular, when ST would be ended for establishing year-round DST.

The comparison of two conditions of “natural experiments” provided further evidence for the difference between two approaches to calculation of sleep curtailment. Some of these results based on traditional approach were again found to be rather paradoxical.

For instance, at school age a time-lag was found to be very large due to early school start times but it became significantly smaller either after shifting school start time on later hours or after leaving school in a later age. Despite this, evidence for significant sleep curtailment was not provided by comparing weekly average time in bed reported by students of school age with weekly average time in bed reported by university/college students or by comparing time in bed before and after a shift of school start time on later hours. Similar results were provided by the comparison of samples from two neighboring ages, 16+ and 18+. Such lack of evidence for sleep curtailment contradicted to the general concern about the epidemic of sleep deprivation among adolescents (i.e. when schedules maintained during the school year are resulted in insufficient and ill-timed sleep). For instance, this epidemic was recognized in many postindustrial societies with different cultural traditions (see Carskadon 2011; Gradisar et al. 2011; Hagenauer et al. 2009). However, when actual sleep loss was estimated in accord with the proposed here approach, the general results of such “natural experiments” pointed at an extremely large sleep curtailment. It is important to emphasize that only the model-based simulation allowed the introduction of this estimate capable to uncover the dramatic permanent sleep curtailment caused by early school times (e.g. it might exceed one third of the total weekday night sleep duration expected in the case of its spontaneous rather than forced termination).

Results on the estimates obtained in “natural experiments” under seasonal switching between DST and ST did not yield a significant curtailment of sleep. Such results were obtained irrespective of the method of calculation of sleep curtailment and it was not a surprise. Such studies cannot separate two opposing effects observed under DST. The first is an increase in actual sleep loss due to earlier wakeups in summer and the second is a seasonal reduction of sleep duration in this season. Such reduction was, for instance, demonstrated in a current study of population in Japan that does not observe DST (Hashizaki et al. 2018). It is important to note that, even when researchers are sampling sleep times under exactly the same photoperiods (e.g. only in certain days of spring and fall), these sleep times remains to be incomparable due to the difference in aftereffects of exposure to short and long photoperiods in the previous winter and summer months, respectively.

Only two samples that were collected in northern regions of Russia allowed the direct comparison of perennial DST with the following perennial ST. The comparison did not reveal an essential reduction of weekly average time in bed. Although it yielded 5% sleep loss, such a loss was relatively small compared to loss caused by early school start times in both conditions. In general, the changes in social clocks in Russia during the last 10 years can be considered a “natural experiment”. However, its results seem to be also inconclusive. Perennial DST was introduced by a Russian president (Medvedev) in March 2011 to be observed until October 2014 when another president from this tandem (Putin) introduced perennial ST. Therefore, if someone would suggest that there was any misunderstanding around the terms “winter time” and “summer time” in Russian population, there was enough time to feel the difference, both before and after October 2014. Meanwhile, as soon as in summer 2015, several regional parliaments adopted the lows suggesting the return of their regions back to perennial DST (i.e. by adding one to the current number of their time zones). In the last 4 years (2015–2018), 11 regional parliaments, including the parliament of Novosibirsk region, voted for such a return, and it seems that this process will be continued in the nearest future. Paradoxically, currently in Moscow and Novosibirsk that are the first and third largest cities of Russia located at similar latitudes (55.7°N and 55.0°N), sunrise and sunset on March 15 occur at 6:45 and 18:31 and at 7:44 and 19:30, respectively.

Let us imagine that the difference in weekly average time in bed was accurately estimated during winter months with ST and during summer months with DST by those millions of respondents from an EU public international consultation who voted for year-round "winter time" (European Commission 2018). In overall, the result of such estimates would be misguided. They would fail to reveal (1) any consistent difference between DST and ST due to seasonal shortening of sleep duration in summer; (2) a large amount of sleep lost due to usual work/school schedules during both DST and ST; (3) a large difference between M- and E-types in this permanent sleep loss. Further, the comparisons that traditionally rely on calculation of weekly average time in bed would lead them to the conclusion that sleep lost by E-types with later weekend risetimes and larger bedtime-lag during the week is larger than that lost by M-types with earlier weekend risetimes and smaller bedtime-lag. Finally, let us imagine that they carefully read the paper of Borisenkov et al. (2016) with the only published results of direct comparison of sleep times under year-round DST and year-round ST. They can see in this paper's table that the estimates of weekly average sleep duration were identical for samples collected under perennial DST and perennial ST.

If someone would ask a lay person about his/her personal experience, he/she would confirm that runs short of sleep during the week due to extended wakefulness after the scheduled early wakeups. When Saturday comes, that person feels he/she needs for extra hours of sleep at Friday-Saturday and Saturday-Sunday nights to get back to optimal condition and, doing so, he/she successfully catches up on lost sleep throughout just two weekend nights to be able, finally, to go back to feeling normal. However, conventional wisdom would not always be right, even when supported by the accurate estimations of weekly average sleep duration and careful reading scientific reports. Our simulation (Figure 1) suggested that people do not sleep the extra time they lost during workdays. Instead, their sleep is mostly of normal and optimal duration during two weekend nights whereas their sleep curtailment during workday is even larger than that provided by calculating the difference between weekend and weekday sleep durations. Therefore, we proposed the estimates of sleep loss that accounted for predictions of a sleep-wake regulatory model and allowed the uncovering a profound negative influence of our usual work/school schedules on weekday sleep duration and, hence, on health.

There are several limitations of the applied method of estimation of sleep curtailment. Only a small fraction of the samples was collected from actigraphic studies of sleep times. We previously showed that one of four sleep times, namely weekend risetime, might be overestimated for some of the samples (Putilov and Verevkin 2018; Putilov et al. 2019). Moreover, we modified the previously proposed measures of sleep phase and social jet lag by direct utilization of bed- and risetimes rather than sleep onsets and offsets for their calculation. The major reasons for this modification of the previously proposed estimates were the following. First, the authors of most of publications did not report sleep latencies. Second, since the authors of the vast majority of publications collected sleep times from either questionnaire self-reports or sleep diaries, it is hard to imagine that way by which these sleep latencies were self-measured by study participants. Third, in order to calculate most of the estimates, it was necessary to subtract one latency from another, at least, twice. For example, one latency was subtracted from another to obtain a weekend-weekday difference for each sample and then one of the obtained differences in sleep latency was subtracted from another difference in sleep latency to calculate a difference in this difference between two subsets of samples. Therefore, it is unlikely that our estimates might be significantly challenged even in the case of the existence of small (i.e. few minutes) difference between self-reported sleep latencies.

In conclusion, we proposed here a model-based approach for calculation of sleep curtailment caused by earlier weekday wakeups (e.g. due to observing perennial DST). Unlike the difference in time in bed, the suggested measure allows the estimation of actual sleep loss without comparison of samples in two conditions. Our estimates relying on this new methodology suggested that (1) neither chronotype nor weekend sleep times nor social jetlag can influence the change in sleep duration after an advancing shift of weekday wakeups, (2) E-type with later weekend sleep times and larger social jetlag is associated with a very large sleep loss and (3) our usual work/school schedules are the causes of an essential sleep loss even in M-types with early weekend sleep times and small social jetlag. Compared to this loss, an additional loss due to switching from ST to perennial DST are expected to be relatively small. The traditional way of calculation of sleep loss leads to rather paradoxical conclusions, e.g. (1) that sleep loss is larger when social jetlag is smaller, not larger, (2) that sleep loss is larger when weekend sleep times are earlier, not later, (3) that sleep in school students attending school in early hours is not shorter than sleep in school students attending school in later hours or in college/university students practicing a 1-h later wakeups, etc.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

AAP and VBD were supported by the Russian Foundation for Basic Research [grant numbers 19-013-00424 and 17-36-00025-OGN-A1]. MGP was supported by the "Russian Academic Excellence Project 5-100".

Ethics

The study reported in papers from which samples with sleep times were collected have been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans.

ORCID

Arcady A. Putilov http://orcid.org/0000-0003-2779-9046

References

Åkerstedt T, Gillberg M. 1981. The circadian variation of experimentally displaced sleep. Sleep. 4:159–169.

Arrona-Palacios A, Díaz-Morales JF. 2018. Morningness-eveningness is not associated with academic performance in the afternoon school shift: Preliminary findings. Br J Educ Psychol. 88(3):480–498.

Arrona-Palacios A, García A, Valdez P. 2015. Sleep-wake habits and circadian preference in Mexican secondary school. Sleep Med. 16(10):1259–1264.

Boergers J, Gable CJ, Owens JA. 2014. Later school start time is associated with improved sleep and daytime functioning in adolescents. J Dev Behav Pediatr. 35(1):11–17.

Borisenkov MF, Tserne TA, Panev AS, Petrova NB, Timonin VD, Kolomeichuk SN, Vinogradova IA, Kovyazina MS, Khokhlov NA, Kosova AL, et al. 2016. Seven-year survey of sleep timing in Russian children and adolescents: chronic 1-h forward transition of social clock is associated with increased social jetlag and winter pattern of mood seasonality. Biol Rhythm Res. 48:3–12.

Brandalize M, Pereira RF, Leite N, Filho GL, Louzada FM. 2011. Effect of morning school schedule on sleep and anthropometric variables in adolescents: a follow-up study. Chronobiol Int. 28(9):779–785.

Carissimi A, Dresch F, Martins AC, Levandovski RM, Adan A, Natale V, Martoni M, Hidalgo MP. 2016. The influence of school time on sleep patterns of children and adolescents. Sleep Med. 19:33–39.

Carskadon MA. 2011. Sleep in adolescents: The perfect storm. Pediatr Clin N Am. 58:637–647.

Daan S, Beersma DGM, Borbély AA. 1984. Timing of human sleep: recovery process gated by a circadian pacemaker. Am J Physiol Regulatory Integrative Comp Physiol. 246:R161–R178.

EBRS. (2019). To the EU Commission on DST. Available September 9, 2019: https://www.ebrs-online.org/news/item/dst-statement-ebrs-endorsed.

ESRS. (2019). Joint statement to the EU Commission on DST. Available September 9, 2019: https://esrs.eu/joint-statement-to-the-eu-commission/

European Commission. (2018). Public Consultation on EU Summertime Arrangements - Report of Results. Brussels, Belgium: European Commission. Available September 9, 2019 : https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018SC0406

Friborg O, Bjorvatn B, Amponsah B, Pallesen S. 2012. Associations between seasonal variations in day length (photoperiod), sleep timing, sleep quality and mood: a comparison between Ghana (5°) and Norway (69°). J Sleep Res. 21(2):176–184.

Giuntella O, Mazzonna F. 2019. Sunset time and the economic effects of social jetlag evidence from US time zone borders. J Health Econ. 65:210–226.

Gradisar M, Gardner G, Dohnt H. 2011. Recent worldwide sleep patterns and problems during adolesence: A review and meta-analysis of age, region, and sleep. Sleep Med. 12:110–118.

Gu F, Xu S, Devesa SS, Zhang F, Klerman EB, Graubard BI, Caporaso NE. 2017. Longitude position in a time zone and cancer risk in the United States. Cancer Epidemiol Prev Biomark. 26:1306–1311.

Hagenauer MH, Perryman JI, Lee TM, Carskadon MA. 2009. Adolescent changes in the homeostatic and circadian regulation of sleep. Dev Neurosci. 31:276–284.

Hashizaki M, Nakajima H, Shiga T, Tsutsumi M, Kume K. 2018. A longitudinal large-scale objective sleep data analysis revealed a seasonal sleep variation in the Japanese population. Chronobiol Int. 35:933–945.

Jagnani M (2019). Poor Sleep: Sunset Time and Human Capital Production. Available June 9, 2019: https://sites.google.com/view/maulikjagnani/research?authuser=0.

Jankowski KS. 2017. Social Jet Lag: sleep-Corrected Formula. Chronobiol Int. 34:531–535.

Johnsen MT, Wynn R, Allebrandt K, Bratlid T. 2013. Lack of major seasonal variations in self reported sleep-wake rhythms and chronotypes among middle aged and older people at 69 degrees North: The Tromsø Study. Sleep Med. 14(2):140–148.

Lima PF, Medeiros ALD, Araujo JF. 2002. Sleep-wake pattern of medical students: early versus late class starting time. Braz J Med Biol Res. 35(11):1373–1377.

Lo JC, Leong RL, Loh KK, Dijk DJ, Chee MW. 2014. Young adults' sleep duration on work days: Differences between East and West. Front Neurol. 5:81.

Lowden A, Lemos N, Gonçalves B, Öztürk G, Louzada F, Pedrazzoli M, Moreno KL. 2018. Delayed sleep in winter related to natural daylight exposure among arctic day workers. Clocks & Sleep. 1(1):105–116.

Lund HG, Reider BD, Whiting AB, Prichard JR. 2010. Sleep patterns and predictors of disturbed sleep in a large population of college students. J Adolesc Health. 46(2):124–132.

Miller NL, Shattuck LG, Matsangas P. 2010. Longitudinal study of sleep patterns of United States Military Academy cadets. Sleep. 33(12):1623–1631.

Peixoto CA, da Silva AG, Carskadon MA, Louzada FM. 2009. Adolescents living in homes without electric lighting have earlier sleep times. Behav Sleep Med. 7(2):73–80.

Perkinson-Gloor N, Lemola S, Grob A. 2013. Sleep duration, positive attitude toward life, and academic achievement: the role of daytime tiredness, behavioral persistence, and school start times. J Adolesc. 36(2):311–318.

Putilov AA. 1995. The timing of sleep modelling: circadian modulation of the homeostatic process. Biol Rhythm Res. 26:1–19.

Putilov AA, Verevkin EG. 2018 November 05. Simulation of the ontogeny of social jet lag: a shift in just one of the parameters of a model of sleep-wake regulating process accounts for the delay of sleep phase across adolescence. Front Physiol. 9:1–11. 1529. doi:10.3389/fphys.2018.01529.

Putilov AA, Verevkin EG, Donskaya OG, Tkachenko ON, Dorokhov VB. 2019. Model-based simulations of weekday and weekend sleep times self-reported by larks and owls. Biol Rhythm Res. 50: Online link. doi: 10.1080/09291016.2018.1558735.

Roenneberg T, Kuehnle T, Juda M, Kantermann T, Allebrandt K, Gordijn M, Merrow M. 2007. Epidemiology of the human circadian clock. Sleep Med Rev. 11:429–438.

Roenneberg T, Kuehnle T, Pramstaller PP, Ricken J, Havel M, Guth A, Merrow M. 2004. A marker for the end of adolescence. Curr Biol. 14:1038–1039.

Roenneberg T, Winnebeck EC, Klerman EB. 2019a. Daylight saving time and artificial time zones – a battle between biological and social times. Front Physiol. 10:944.

Roenneberg T, Wirz-Justice A, Skene DJ, Ancoli-Israel S, Wright KP, Dijk DJ, Zee P, Gorman MR, Winnebeck EC, Klerman EB. 2019b. Why should we abolish daylight saving time? J Biol Rhythms. 34:227–230.

Shochat T, Santhi N, Herer P, Flavell SA, Skeldon AC, Dijk D-J. 2019. Sleep timing in late autumn and late spring associates with light exposure rather than sun time in college students. Front. Neurosci. 13:882.

Skeldon AC, Dijk DJ. 2019. School start times and daylight saving time confuse California lawmakers. Curr Biol. 29:R278–R279.

SRBR (2019). Daylight Saving Time Presskit. Available September 9, 2019: https://srbr.org/advocacy/daylight-saving-time-presskit/.

Urner M, Tornic J, Bloch KE. 2009. Sleep patterns in high school and university students: a longitudinal study. Chronobiol Int. 26(6):1222–1234.

VoPham T, Weaver MD, Vetter C, Hart JE, Tamimi RM, Laden F, Bertrand KA. 2018. Circadian misalignment and hepatocellular carcinoma incidence in the United States. Cancer Epidemiol Prev Biomark. 27:719–727.

Warner S, Murray G, Meyer D. 2008. Holiday and school-term sleep patterns of Australian adolescents. J Adolesc. 31:595–608.

Watson NF. 2019. Time to show leadership on the daylight saving time debate. J Clin Sleep Med. 15:815–817.

Wittmann M, Dinich J, Merrow M, Roenneberg T. 2006. Social jetlag: misalignment of biological and social time. Chronobiol Int. 23:497–509.