Sleep Science and Practice

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Lingering impacts on sleep following the Daylight Savings Time transition in the Project Baseline Health Study

Zachary Owen[†], Sohrab Saeb[*†], Sarah Short, Nicole Ong, Giulia Angi, Atiyeh Ghoreyshi and Shannon S. Sullivan

Abstract

Background: The "spring forward" change to Daylight Savings Time (DST) has been epidemiologically linked with numerous health and safety risks in the days following the transition, but direct measures of sleep are infrequently collected in free-living individuals.

Methods: The Project Baseline Health Study (PBHS), a prospective, multicenter, longitudinal representative U.S. cohort study that began in 2017 launched a Sleep Mission in March 2021 to characterize sleep using patient-reported and wearable device measures, in free-living circumstances during the DST switch. Estimated sleep period duration, subjective restedness, and sleep quality were compared before and after the DST transition during specified timeframes.

Results: Of the total PBHS population of 2502 participants, 912 participants received an invitation and 607 responded by March 6th. Among those, 420 participants opted into the Sleep Mission (69.2%). The transition to DST resulted in both acute and lingering impacts on sleep. Acute effects included a 29.6 min reduction in sleep period ($p = 0.03$), increases in the proportion of patients who reported 'sleeping poorly' (from 1.7 to 13.6% [$p < 0.01$]), and with scores falling into the 'unrested' category (from 1.7 to 8.5% [$p = 0.046$]). There was also a downward trend in the proportion of participants reporting being rested in the morning following the DST transition (from 62.7% on March 7 to 49.2% on March 14 [$p = 0.10$]). Lingering effects included a 18.7% relative decrease in the daily likelihood of participants reporting restedness (from 49.2% in the week prior to the DST transition to 40.0% in the week after [$p < 0.01$]).

Conclusion: The DST transition is associated with an acute reduction in sleep period, as well as an increased proportion of individuals reporting poor sleep and unrestedness. The DST transition also resulted in lingering impacts on self-reported restedness, lasting into the week following the transition. This work adds to a growing understanding of the persistence of impacts on sleep health metrics due to the DST transition.

Keywords: Daylight saving Time, Sleep period, Sleep quality assessment, Project Baseline Health Study, Real world evidence

Introduction

The yearly transition to Daylight Savings Time (DST) each spring in the U.S. has been associated with a myriad of negative health and safety effects, ranging from stroke (Sipilä et al. 2016), myocardial infarction (Manfredini et al. 2018; Janszky and Ljung 2008), and atrial fibrillation-related hospital admissions (Chudow et al. 2020). The DST transition has also been associated with

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disruptions in motor vehicle safety and a 6% increase in traffic fatalities in the first few days following the change (Ferrazzi et al. 2018; Fritz et al. 2020). Recent data also indicates a substantial increase in human-error related medical mistakes the first week after switching to DST (Kolla et al. 2020). These outcomes could be attributed to a variety of reasons including circadian timing shifts, light exposure, and sleep loss. Because DST results in less morning light and more evening light exposure, it has been argued to be suboptimally aligned with human circadian biology and possibly contribute to social jet lag and a more chronic state of sleep loss (Rishi et al. 2020; Cruz et al. 2019; Medina et al. 2015; Giuntella and Mazzonna 2019; Roenneberg et al. 2019). Nonetheless, the limited literature on outcomes is mixed, with reports indicating that the long-term effects of DST may be associated with fewer traffic accidents in the late afternoon due to extension of daylight relative to clock time and other factors (Carey and Sarma 2017).

A number of medical and research societies have published statements in support of elimination of twice-yearly clock time shifts, citing disrupted sleep/wake patterns, reduced total sleep time and quality, and pursuant negative health effects (Rishi et al. 2020; European 2019; Malow 2022). Most studies on the negative health and safety events around the DST transition do not quantify these outcomes relative to either measures of sleep, or to subjective report of restedness. Thus the need to understand first the link between the time change and changes in sleep timing and quality as a prerequisite to understanding downstream negative health outcomes (Malow et al. 2020).

The objective of the present investigation is to measure sleep and subjective sleep experience metrics in a real-world population before, during, and after the transition to DST. The primary aim of this study was to understand the immediate and lingering (~ 1 week) impacts of the DST transition on March 14, 2021 on sleep. The secondary aims were to measure the impact of the time change on subjective morning reports of restedness and sleep quality.

Methods

Population

All participants were recruited from the Project Baseline Health Study (PBHS), currently underway in North Carolina and California, as reported elsewhere (Arges et al. 2020); in short, the parent cohort study was designed to establish a reference health state and to develop a platform that integrates and analyzes personalized, longitudinal multi-dimensional data. Data from this observational study is collected within a traditional clinical context as well as from day-to-day life of people outside of conventional medical research or clinical care settings. Written informed consent was obtained from all participants enrolled in the PBHS, and the study was approved by both a central Institutional Review Board (WCG IRB) and IRBs at each of the participating institutions. The Spring Forward Sleep Mission was approved by the Scientific Executive Committee supervising the PBHS. This Mission content and plan was also approved by the Western IRB.

Study period

The study period was March 1 - March 31, 2021.

Recruitment

On March 1, 2021, 2436 active participants received an invitation email to opt-in to the Spring Forward Sleep Mission, and 1586 participants opened the invitation email. In order to participate, participants were directed to update their PBHS-issued smartwatch firmware (Study Watch, see description below). This smartwatch was already in participants' possession, as it was deployed to measure health variables as part of the overall PBHS (Arges et al. 2020). If a participant happened to update the firmware on their smartwatch during the opt-in period for the Sleep Mission, they could have also viewed and completed the opt-in for the Mission directly on the watch itself. Overall, 1136 participants completed a firmware update, and 966 participants completed the opt-in process on the Study Watch over the course of the study period.

Inclusion and exclusion criteria for analysis

Participants could opt-in to participate in the study at any time point after the invitation was issued, including after March 13, 2021, therefore parameters were set to define the study group for analysis. To be included, participants must have opted into the Sleep Mission by the end of March 6, 2021. March 6 was selected to allow for a minimum of one week of data collection prior to the day of time change, which enabled day-of-the-week pre- and post- DST sleep comparisons. Even if participants opted in by this date, they were excluded from analysis if they had fewer than one episode of sleep data collection from March 6 to 13 or from March 14 to 21.

The DST transition occurred at 2am local time on March 14; for purposes of these analyses, we take the convention of labeling this 'night' as March 13, 2021. We defined 'night' as the longest sleep interval in the noon-to-noon period commencing on that date. See Fig. 1 for details regarding the pool of participants who met the eligibility criteria for analysis.

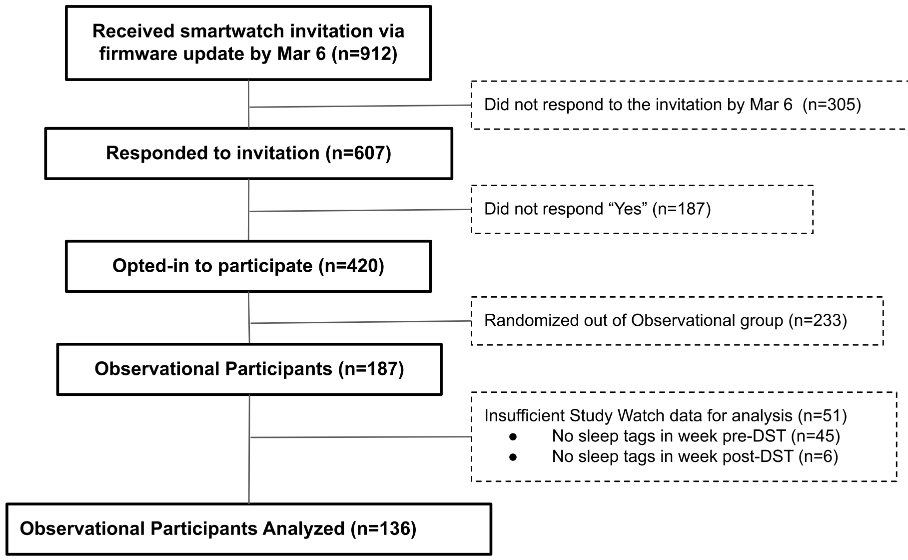

Fig. 1 Flow chart of the steps followed for the inclusion of participants in this analysis. In summary, to be included for analysis, participants must have opted in by March 6, 2021 and provided a minimum of one night of data both in the week before and the week after the DST transition occurring at 2:00 am on March 14, 2021

Verily Study Watch

The Verily Study Watch ("Study Watch") is a smartwatch used in the PBHS for the collection and monitoring of physiological activity and environmental data with high sampling frequency, and in-field assessments of patient-reported data (Arges et al. 2020). Encrypted data collected by the Study Watch is transmitted securely via a separate network access point (i.e., study hub) to the secure cloud server. Participants were asked to wear their watch to sleep each night throughout March 2021, without instructions about specific side. In addition, they were asked to push a button on the side of the Study Watch face to indicate when they got into bed to sleep and when they got out of bed after the intended sleep period. The button-push episodes are termed 'tags' for the purposes of these analyses. Upon completion of each morning tag, participants were asked four questions. These questions appeared in sequential order on the face of the Study Watch directly (example, see Fig. 2):

- Question 1: How long did it take you to fall asleep last night?
- Question 2: How long did it take you to get out of bed after waking?
- Question 3: How well did you sleep last night?
- Question 4: How rested do you feel right now?

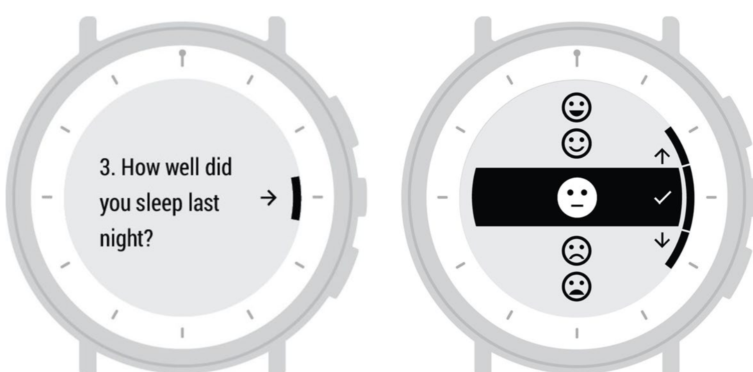

Fig. 2 Schematic with an example of the user interface for a morning question posed by the Study Watch. The left screenshot shows how the question was displayed on a participant's watch, and the right screenshot shows the options that the participant had to choose from

Participants could respond by scrolling through a range of responses. For questions involving time (1 and 2), the response options were: "Less than 5 minutes," "5–15 minutes," "15–30 minutes," "30–45 minutes," "45–60 minutes," "60–90 minutes," "90–120 minutes," "> 120 minutes," and "don't know." For question 3, participants selected from a 5-point smiley face Likert scale (see Fig. 2), where the faces from top to bottom corresponded to "very well," "well," "neutral," "poorly," and "very poorly." Similarly for question 4, where the faces indicated "very rested," "rested," "neutral," "unrested," and "very unrested."

Analysis

Real-time participant tags were used to define the time attempting to sleep. Total Sleep Period (TSP) was calculated based on participant tags, defined as the time from sleep tag start to the sleep tag end, minus participant-reported sleep onset latency and participant-reported time from awakening to getting out of bed (Fig. 3) (Aili et al. 2017). Because participant-reported sleep onset and offset responses were provided as ranges, the midpoint value of the selected range was assumed for the purposes of calculating TSP (e.g., assuming 10 min for a reported sleep onset of "5–15 minutes"). A value of 150 min was assumed for a response of "> 120 minutes." Fewer than 2% of respondents answered "don't know" to sleep time questions. This group was too small for inclusion in the analysis of the sleep period.

Several subjective sleep related measures were estimated using Study Watch tags. 'Sleeping well' was defined as participants selecting the top two smileys to respond to "How well did you sleep last night?". Conversely, 'Sleeping poorly' included responses with the bottom two smileys. Well-rested was defined as responses to "How rested do you feel right now?" with the top two smileys. Unrested was defined as responses to "How rested do you feel right now?" with the bottom two smileys (Fig. 2).

We assessed the impact of DST transition on the study metrics in two different ways: "Acute" and "lingering." "Acute" effects were calculated by comparing these metrics for the night starting on Saturday, March 13, 2021, to those of the same participant for the prior Saturday, on March 6, 2021. "Lingering" effects were calculated by comparing these metrics on weekday nights of the week following the DST transition to those of the week prior to the DST transition.

For both acute and lingering effects, all analyses compared the within-participant mean changes of each metric between the two time frames using Wilcoxon signed-rank test against the null hypothesis of identical means between the time frames.

For categorical variables in the lingering analysis, we calculated the "likelihood" of a variable falling into a specific category, e.g. "restedness" for Question 4, by averaging its binary value within participants for all available tags in the week before and the week after the time change. Statistics are reported on the difference of these likelihoods.

Results

By the predetermined final date for Sleep Mission opt-in, March 6, 2021, 607 individuals responded to the invitation and 420 opted in (69.2% opt-in rate). Of these, 233 participants were allocated to a separate investigation of a sleep advice intervention; these results are not reported here. The remaining 187 participants were considered to be observational. Of these, 45 were excluded due to having no Study Watch sleep tags collected between March 6 and 13, and 6 additional participants were excluded due to having no such data between March 14 and 21. This resulted in a final analysis cohort of 136 participants (see Fig. 1).

Table 1 provides demographic and limited medical history information for all 136 participants whose data was included in the analysis. Participants were predominantly female (60.3%) and white (74.3%), with a mean age of 61.3 years (Standard Deviation, SD, 15.2 years). The top 3 medical conditions in the

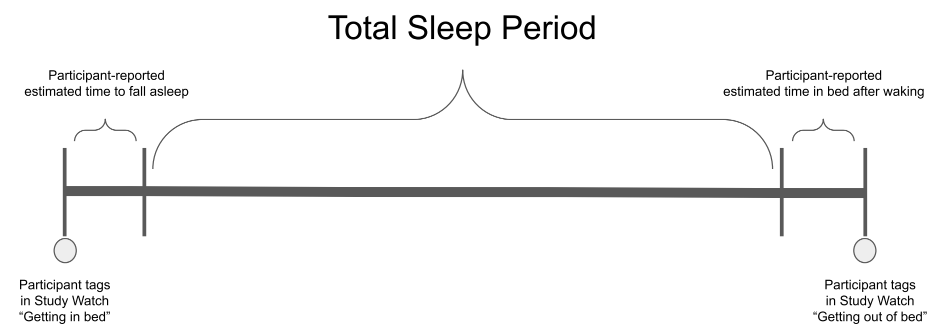

Fig. 3 Timeline schema representing how the metric 'TSP' was defined

Table 1 Study population characteristics, participants who opted in and contributed data for the Sleep Mission. For reference, the characteristics of the full PBHS cohort are included; characteristics for which this study cohort showed significant differences compared to the originating PBHS population are indicated in the column with the *p*-value for these comparisons

	Sleep Mission, analysis cohort **$n = 136$**	**PBHS Cohort** **$N = 2502$**	***P*-value**
Mean age, y (SD)	61.3 (15.2)	52.8 (17.1)	< 0.01*
Female, n (%)	82 (60.3)	1375 (55.0)	0.34
Enrolled in California, n (%)	85 (62.5)	1500 (60.0)	0.64
Race/Ethnicity, n (%)			
White	101 (74.3)	1582 (63.2)	0.01*
Black	14 (10.3)	400 (16.0)	0.49
Asian	11 (8.1)	260 (10.4)	0.78
Native Hawaiian and/or Pacific Islander	3 (2.2)	27 (1.1)	0.90
American Indian or Alaska Native	1 (0.7)	31 (1.2)	0.95
Other	6 (4.4)	202 (8.1)	0.67
Hispanic ethnicity	7 (5.1)	291 (11.6)	0.45
Education, n (%)			
High school or less	6 (4.4)	183 (7.3)	0.74
Some college	33 (24.3)	478 (19.1)	0.50
College	43 (31.6)	678 (27.1)	0.54
Graduate degree or higher	47 (34.6)	708 (28.3)	0.38
Income, n (%)			
< $25,000	7 (5.1)	207 (8.3)	0.72
$25,000–49,999	20 (14.7)	266 (10.6)	0.62
$50,000–99,99	32 (23.5)	514 (20.5)	0.70
$100,000-149,999	24 (17.6)	337 (13.5)	0.60
$150,000-199,999	12 (8.8)	204 (8.2)	0.94
>= $200,000	24 (17.6)	377 (15.1)	0.75
Marital status, n (%)			
Married	73 (53.7)	1112 (44.4)	0.13
Divorced	14 (10.3)	198 (7.9)	0.78
Formerly in long term relationship	4 (2.9)	104 (4.2)	0.89
Living together	9 (6.6)	217 (8.7)	0.81
Never in long term relationship	14 (10.3)	253 (10.1)	0.98
Separated	3 (2.2)	53 (2.1)	0.99
Widowed	11 (8.1)	80 (3.2)	0.56
Other			
Mean PHQ-9 score	3.1	3.7	0.16
Mean daily steps in first 30 days, median (IQR)	7802 (4922)	8417 (4830)	0.15
Self-reported sleep apnea diagnosis, n (%)	24 (17.6)	191 (7.6)	0.21
Top 3 Medical Conditions, n(%)			
Hypertension	48 (35.3)	728 (29.1)	0.38
Gastroesophageal reflux disease	40 (29.4)	484 (19.3)	0.18
Osteoarthritis	39 (28.7)	556 (22.2)	0.39

**P*-values are based on the null hypothesis that the two populations have the same distribution for the respective variable. For binary variables such as "Female, N (%)", we use the difference of binomial proportions; for continuous variables such as age, we use Wilcoxon rank-sum test. *P*-values marked with asterisks indicate statistical significance ($p < 0.05$)

cohort were hypertension (35.3%), gastroesophageal reflux disease (29.4%), and osteoarthritis (28.7%). Compared with the full PBHS cohort, participants in this study were significantly older (61.3 vs. 52.; $p < 0.01$) and more likely to be white (74.3% vs. 63.2%, $p = 0.01$); however, the top three medical conditions were not significantly different from the entire PBHS cohort.

Acute effects

Among the 59 participants contributing sleep tags for both the night of the DST transition and the prior Saturday night, the transition to DST resulted in an average TSP decrease of 29.6 min ($p = 0.03$), from 7 h to 51 min on prior Saturday night to 7 h and 21 min on the night of the transition (Fig. 4). In terms of subjective restedness, 31 of the 59 participants had unchanged restedness scores from the week prior. There was a 5-fold increase in the proportion of participants with scores in the unrested category ($p = 0.05$), from 1.7 to 8.5% (Fig. 5A). There was also a trend towards fewer participants reporting being rested in the morning following the DST transition, from 62.7% on March 7 to 49.2% on March 14, representing a 21.5% relative decrease ($p = 0.10$). In addition, there was an 8-fold increase ($p < 0.01$), from 1.7 to 13.6%, in the proportion of participants who reported sleeping poorly on the night of DST transition in comparison to the previous Saturday night (Fig. 5B).

Lingering effects

Among the 120 participants contributing at least one sleep tag for the weeknights (i.e., nights beginning Sunday through Thursday) in the weeks immediately before and after the DST transition, the number reporting at least one night of 'unrested' sleep increased from 24 to 34 individuals. There was a persistent reduction in the daily likelihood of reporting restedness, from 49.2% in the week prior to the DST transition to 40.0% in the week after the DST transition, representing a 18.7% relative decrease ($p < 0.01$). There was no significant lingering reduction of reported TSP after the DST transition compared to before the transition.

Discussion

This study measures and characterizes real-world impacts on sleep and subjective restedness associated with the "spring forward" DST change, providing valuable details on the DST effects on a diverse cohort of individuals. While prior epidemiological reports have associated DST with negative health and safety outcomes, this report offers novel insight into the potential mechanisms mediating those downstream effects - including actual amount of sleep loss and recovery trajectory (if it occurs), changes in sleep timing, measures of patient-reported restedness and sleep experience, and length of time over which negative impacts dissipate - for which our understanding remains incomplete. Moreover, this study leverages a novel approach of data capture for this type of research, deploying a wearable device in a diverse cohort of participants in free living environments.

As expected, the night of the DST transition was associated with a shorter sleep period compared to the Saturday night one week prior, consistent with other reports in the literature (Lahti et al. 2006; Sexton and Beatty 2014; Toth Quintilham et al. 2014; Tonetti et al. 2013). Yet, there was inadequate evidence to suggest that the average participant "lost" an entire hour of sleep, as we observed an average reduction in total sleep period of 29.6 min. Lahti et al. had found a sleep time reduction of 60.14 min in 10 healthy free-living adults and a reduction in sleep efficiency of 10%, whereas assessment of how individuals use their time yields an estimated loss of 15 to 20 min of sleep (Aili et al. 2017; Lahti et al. 2006).

Self-reports of sleeping poorly increased acutely on the morning following the DST transition, and unrestedness persisted into the week afterwards. Among those responding to these two questions in the weekdays after the DST transition, we observed a 18.7% ($p < 0.01$) drop in the likelihood of reporting restedness. These morning reports pointing to reduced adequacy of sleep and

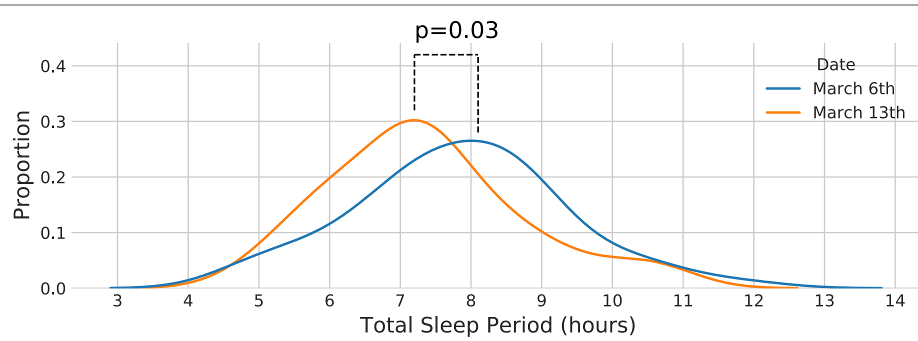

Fig. 4 Line graphs representing TSP distributions before (blue) and after (orange) the DST transition in the cohort of study participants ($N = 59$). Average TSP was 7 h and 51 min before the DST transition (blue curve), and 7 h and 21 min after the transition (orange curve), indicating an average reduction of 29.6 min (Wilcoxon signed-rank test $p = 0.03$)

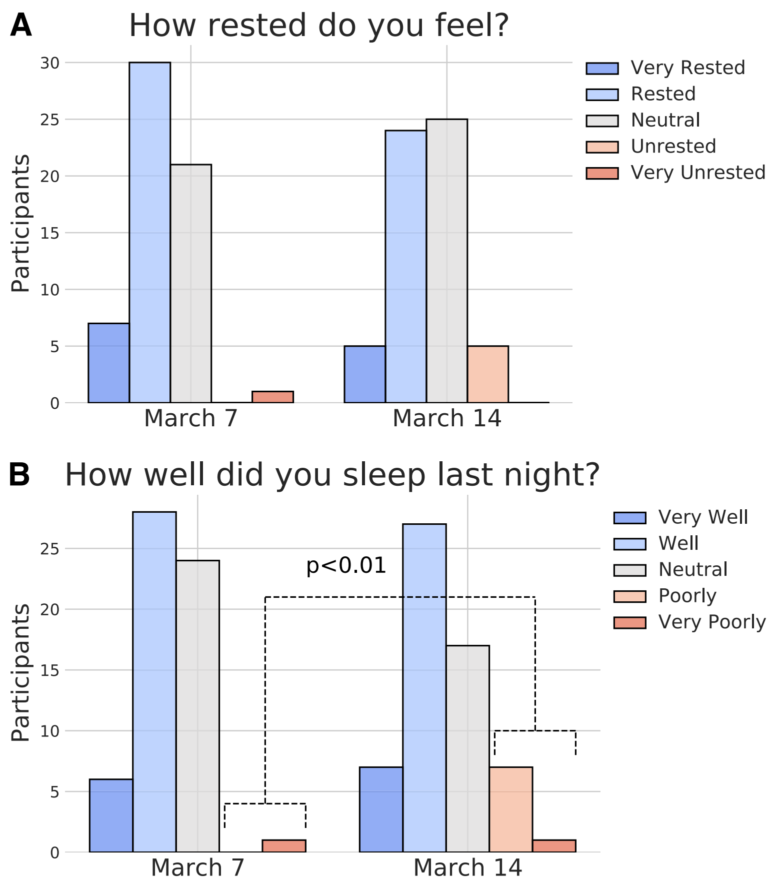

Fig. 5 Distribution of responses to the morning questions **A** "How rested do you feel?", and **B** "How well did you sleep last night?" posed the mornings after Saturday March 7 (pre-DST transition) and after Saturday March 14 (post-DST transition). The bars show the number of participants whose response fell into each category. For the question "How well did you sleep last night?", there was a significant increase ($p < 0.01$) in the proportion of participants who responded "poorly" or "very poorly" on the night of DST transition in comparison to the previous Saturday night

restedness add to the evolving picture of the biophysical impacts of this time shift, with direct measures that represent a novel and convenient way to capture real-time, real-world subjective (self-reported) feedback on sleep.

The use of the question 'how well did you sleep' as a proxy for sleep quality has been well-reported, based on the validated Karolinska sleep diary (Akerstedt et al. 1994; Akerstedt et al. 1994). It is thought that this question is responsive on a night-to-night basis; in prior studies, responses after a single night could be correlated to polysomnography findings (Keklund and Akerstedt 1997). To our knowledge, this is the first study to pose these questions directly after rising, on a wrist worn device. It is of interest to determine whether this method of obtaining subjective data from participants has greater utility than previous pencil-and-paper methods in real world situations. A key element is the querying of participants to respond at a particular point after rising, rather than waiting until later in the morning or day, which may reduce recall bias. This is outside the scope of the present study but merits further investigation.

The primary strength of this study is that it combines real-time wearable-based acquisition of participant self-report on commonly collected sleep diary parameters, as well as morning assessments of sleep and restedness, to better characterize the possible burden of the DST transition on sleep in participants enrolled in the PBHS. The umbrella setup of the PBHS is that of a free-living cohort which participates in a variety of study-related activities, and the study features a variety of engagement mechanisms, including return of results efforts (Sayeed et al. 2021). Even in this context, the opt-in rate of 69.2% is very high when compared to traditional uptake of studies offered in remote circumstances, for which participation may range between 11% and 47.4%, based on reports from disease specific registry studies lasting between one day and three months (Dinur et al. 2020; Crouthamel et al. 2018). That said, not all participants who opted in contributed enough data to meet minimum thresholds for analysis, and this may well have affected power to detect changes related to sleep.

There are a number of limitations inherent in a study of this nature; primary among them are biases related to participation, since those opting in to participate in the study may be fundamentally more interested in or focused upon sleep. Recruitment from the PBHS limited participants primarily to geographical areas in North Carolina and California, which may impact light-dark exposures as well as outdoor activity and step count analysis. Such factors may reduce generalizability of the study data. We also note that the participants in the Sleep Mission tended to be middle aged or older adults, and this group may not have had the same demands of work life or family life that younger individuals may have experienced, also potentially limiting generalizability. Additionally, even among participants meeting the inclusion criteria, not all participants tagged sleep or wore their Study Watch on all nights over the month-long study. While we report the change in the number of participants reporting poor restedness and poor sleep before and after the DST transition, we also adjusted for biases in sampling frequency. Namely, we calculated average responses for individual participants, for each question, over each period, which we compared before and after DST.

Prior reports indicate that different methodologies yield different sleep measurements; in particular, the agreement between actigraphic measures of sleep and self reported measures of sleep has been estimated between 78 and 81% (Girschik et al. 2012; Matthews et al. 2018). In our study, though, self reporting was done as close to real-time as possible, and was not retrospective, which could mitigate this variability. Nevertheless, inaccuracies in participant-reported sleep onset latency and time in bed after waking would have been propagated in the analysis of TSP, likely resulting in underreporting of differences. Additionally, this investigation explored a number of potential ways of measuring impacts of the DST transition beyond the primary objective, and was not powered to fully examine each one. Such reported trends require additional study to understand the nature of the impact on DST.

Conclusion

This study reports on real-world impacts on estimated sleep, subjective restedness and sleep quality associated with the "spring forward" DST change, measured using a wearable device. Reductions in sleep period were noted on the night of the DST transition. The DST transition also resulted in negative impacts on participants' qualitative sleep experience.

Abbreviations

BHS: Baseline Health Study; DST: Daylight Savings Time; PBHS: Project Baseline HealthStudy; TSP: Total Sleep Period.

Acknowledgements

Authors wish to thank PBHS participants, investigators, and study personnel from Duke University, Stanford University, California Health and Longevity Institute, and Verily Life Sciences.

Authors' contributions

Z.O., So.S, Sa.S., and Sh. S. planned and executed statistical analysis and contributed to the manuscript text, table, and figures. Z.O., Sh. S., Sa.S., N.O., A.G. and G.A contributed to study vision, design, and execution. Sh. S. and Z.O. wrote the main manuscript text and all authors reviewed the manuscript and provided edits and feedback. The author(s) read and approved the final manuscript.

Funding

Funding for the PBHS is provided by Verily Life Sciences.

Availability of data and materials

The deidentified PBHS data corresponding to this study are available upon request for the purpose of examining its reproducibility. Interested investigators should direct requests to sosata@verily.com. Requests are subject to approval by PBHS governance.

Declarations

Ethics approval and consent to participate

and consent: This sleep mission was reviewed and approved by the Western Institutional Review Board (Western IRB). For Project Baseline Health Study (PBHS), written consent has been obtained from all participants enrolled in the PBHS and the study is approved by both a central IRB (Western IRB) and IRBs at each of the participating institutions.

Consent for publication

Not applicable.

Competing interests

All authors were employed by and owned equity on Verily Life Sciences during the study.

Received: 22 December 2021 Accepted: 23 November 2022
Published online: 26 December 2022

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