Original Research Article

The Effect of Daylight Saving Time Clock Changes on Wearable Device Biometrics

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Abstract: Daylight Saving Time (DST) changes externally impose physiological disturbances that can be clinically meaningful. Wearable devices that can monitor physiological biometrics can potentially act as an early warning system during these periods of circadian disruption. However, the effect of DST time changes on biometrics recorded via a wearable sensor have yet to be reported. Therefore, this study aimed to investigate the impact of clock changes at DST transitions on sleep and cardiovascular biometrics. Data were obtained from Biostrap EVO users (N = 1500) one week prior and following both phase advancing and phase delaying DST time changes. Biometrics were analyzed for changes in the seven days following a DST time change and compared to the same day-of-week prior to DST time change using mean and 95% confidence intervals following M-estimator adjustments for outliers. Results demonstrate that users tended to sleep less in the days after moving clocks forward and experienced a slight decrease in overall sleep quality and respiratory function. Comparatively, in the days after moving clocks backward, people slept more, experienced a reduction in overall sleep quality later in the week, and experienced adverse effects on their cardiovascular system. This study demonstrates the adverse impact of DST time changes that a wearable device can readily detect. Clinicians and practitioners should closely monitor at-risk patients during these periods to prevent severe adverse cardiovascular events.

Keywords: circadian, wearables, photoplethysmography, sleep

Introduction

Human biology is synchronized to a 24-hour rhythm that mirrors the approximate time for a single rotation of the Earth and thus matches corresponding light and dark cycles. Many physiological systems - and the integration between these systems - are dependent on the careful maintenance of these circadian (from the Latin *circa diem*, or "about a day") rhythms. The suprachiasmatic nucleus in the hypothalamus receives light signals from the anatomically proximal retinal tracts as a function of the photopigment melanopsin[1]. These retinal signals synchronize an intracellular transcription/translation cycle of CLOCK, BMAL, and several other proteins operating on a stabilized negative feedback loop[2] on an approximate 24-hour period. This information can then be systemically relayed via neuroendocrine pathways[3] and thus the entire organism can become entrained to the environment.

Other environmental cues, such as food[4] and exercise[5], can also act as zeitgebers (from the German translated as “time giver”) to synchronize these central and peripheral circadian rhythms. In humans, these factors are often associated with clock time, rather than light/dark cycles or our physiology (e.g., many businesses operate from 09:00h to 17:00h, regardless of sunset and sunrise, and thus one’s dietary and activity levels are partially dependent on this clock time). The timing and total amount of daylight varies throughout each year, especially at absolute latitudes further from zero. However, these changes occur relatively slowly and thus allow sufficient time for internal circadian rhythms to resynchronize with the adjusted light/dark cycle and establish clock-dependent activities at alternative points in this circadian pattern.

However, in many places, a discrepancy between the light/dark cycle, internal circadian clocks, and clock time is artificially manufactured twice per year. Daylight saving time (DST) is the practice of moving clock time one hour forward or backward, in the Spring and Autumn seasons, respectively. Although a single-hour clock shift may be considered relatively mild, especially when compared with jetlag of multiple hours or occasionally a complete day/night flip, several studies have suggested that DST can still have drastic impacts on health and wellbeing. For example, workplace injuries[6] and Australian male suicide rates[7] increase in the week following the time change. DST has also been associated with adverse health conditions known to have circadian variation in their occurrence, such as acute myocardial infarction[8] and ischemic stroke[9]. On the other hand, proponents of DST occasionally argue that there is a reduction in motor vehicle accidents, although this literature is complex and unclear[10].

The historical rationale for DST was associated with energy-saving practices in the evening, which some argue are now outdated[11]. Indeed, recently the topic of whether to retain or discontinue DST practices has been energetically debated by both scientists (e.g., the recent review by Cruz et al.[12] and the reply by Dr. José María Martín-Olalla[13]) and lawmakers[14]. Nevertheless, any decisions on this topic must be informed by a range of data and data sources, including physiological consequences of the DST time change. Moreover, if DST practices continue to be implemented, individuals should be aware of potential physiological changes that may permit corrective health behaviors and thereby more optimal physical functioning.

Wearable health monitoring technologies offer clinicians, researchers, and consumers the opportunity to monitor a wide range of health metrics frequently in a free-living environment. Alterations to these metrics may indicate potential adverse health conditions and thus can be used as an early warning detection system. However, to date, no study has investigated the effect of DST on biometrics captured by a wearable device among a large heterogenous sample. Therefore, the purpose of this study was to characterize the changes in biometrics and sleep metrics induced by DST among the general population. We hypothesized that DST would worsen all biometrics, particularly when moving clock time forward, as this will permit fewer hours to sleep during the transition.

Methods

Participants (n = 1500) for this study were selected from participating Biostrap users. The Biostrap EVO device utilizes red and infrared photoplethysmography (PPG) and a 6-axis inertial movement unit to derive biometrics and sleep data. A general database query extracted biometric data from April 2018 to December 2021 and included sleep, cardiovascular, and respiratory biometrics. Specifically, sleep onset and offset, sleep duration, sleep efficiency, Sleep Score (a propriety score calculated from a combination of factors including time in deep sleep, respiration rate, oxygen saturation, time to fall asleep, and total time spent awake, scored as 0 to 100), resting and nocturnal heart rate and heart rate variability (HRV), respiration rate, and SpO_2 were analyzed. Notably, the HRV metric assessed in the current study was the root mean square of successive differences metric (RMSSD) that is typically representative of parasympathetic nervous system activity[15]. Daily averages were computed for each metric prior to analysis.

For each biometric, we sought to determine the degree to which it was altered in the population on each of the seven days after a DST time change. To do so, for every day, we assessed the degree to which the biometric changed for each user compared with that biometric seven days earlier. The rationale for this approach is to remove irrelevant sources of variation in each metric. First, by aggregating within-user changes in a biometric for a given date and seven days earlier, the variation across users in typical values of that biometric is removed. Second, by taking the difference for a given date and seven days earlier, any variation accounted for by different seasons (e.g., taking more steps in the summertime) or day of the week (e.g., sleeping in on a Sunday) is removed. After differencing each biometric, observations were organized into three groups (Table 1)[†]: those that enclose a DST change with clocks

Table 1. Grouping of Observations

Groups	Time Change	Season of Occurrence^
DST_{FWD}	DST change with clocks moving forward	Spring
DST_{BWD}	DST change with clocks moving backward	Fall
DST_{NC}	No change	-

^in the Northern Hemisphere

moving forward, those that enclose a DST change with clocks moving backward, and those that don't enclose a DST change (as control group). Following the grouping of differenced observations, each group's 7-day differences were aggregated for each day of the week, using an M-estimator from the *statsmodels* Python package[16]. This statistical technique simultaneously calculates means and standard deviations while de-weighting outlier observations. For variables dependent on clock time (e.g., bedtime and wake time), this was computed both relative to clock time and the biological (internal) clock and for resting and nocturnal biometrics, where appropriate. Means and 95% confidence intervals were plotted and visually inspected to make inferences as to the effect of DST time change on each biometric. All data analysis was completed in Python, and data visualization was completed in R Statistical Software.

Results

Sleep Biometrics

Sleep start (i.e., bedtime) and end (i.e., wake time) differences relative to the clock time stayed close to zero, indicating people obeyed the new clock time, although

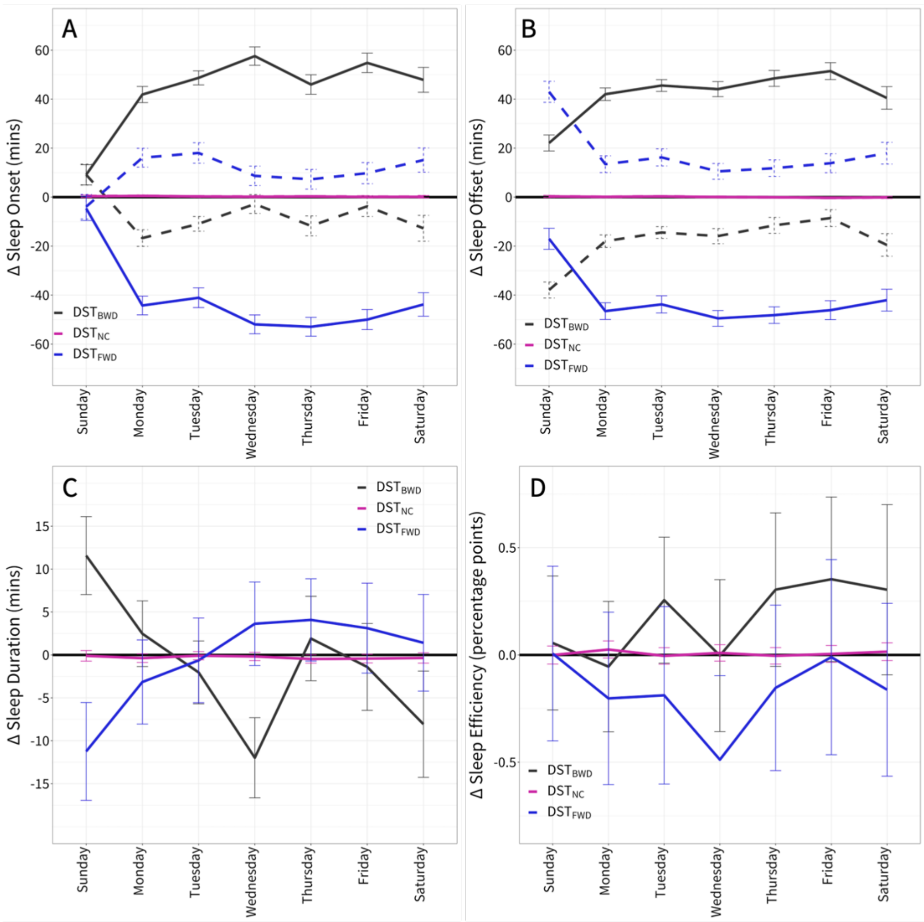

Figure 1. Change in sleep session start (A), sleep session end (B), sleep duration (C), and sleep efficiency (D). The day refers to the morning of the sleep session, e.g., data for Tuesday means Monday night's bedtime. The solid represents values relative to the biological (internal) clock, and the dashed line is relative to clock time.

slight increases and decreases were seen in each metric for Group 1 (DST forward; DST_{FWD}) and Group 2 (DST Backward; DST_{BWD}), respectively (Figure 1A-B). Consequently, sleep start and end time relative to the internal clock were substantially increased and decreased for DST_{FWD} and DST_{BWD}, respectively.

Sleep duration (Figure 1C) is thus significantly increased for DST_{BWD}, although this tends to decrease across the seven days following the time change. Further evidence of this occurring due to the DST time change can be observed in the opposite trend for DST_{FWD}, substantially reducing sleep duration soon after the DST time change but increasing their sleep duration across the seven days. The absolute change in sleep efficiency (Figure 1D) is relatively small, although this biometric does appear to be impaired in DST_{FWD} for several days.

Lastly, the Sleep Score (Figure 2) was substantially reduced immediately following DST in DST_{FWD} but trended back towards baseline within three days. Conversely, Sleep Score appeared to be less impacted in DST_{BWD}, substantially decreasing in the latter half of the seven days following the time change.

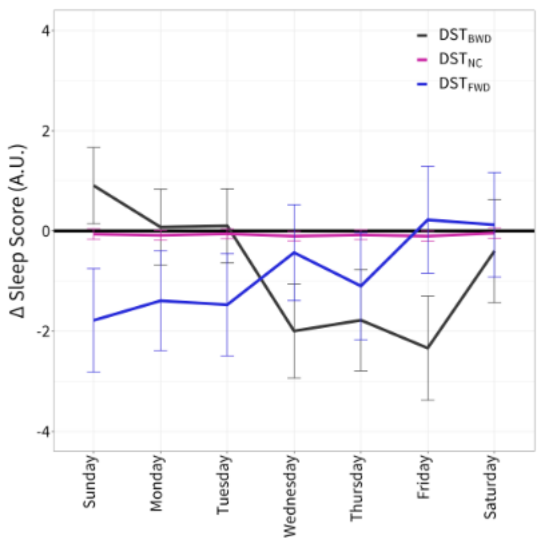

Figure 2. Change in sleep score from seven days prior.

<u>Cardiovascular Biometrics</u>

Resting heart rate (Figure 3A) and nocturnal recordings demonstrated an increase for DST_{BWD} but minor changes for DST_{FWD}. Relatedly, resting and nocturnal assessments of HRV (Figure 3B) demonstrated a decrease in DST_{BWD} and relatively little change in DST_{FWD}.

<u>Respiratory Biometrics</u>

The respiratory rate (Figure 4A) was marginally higher and lower for DST_{FWD} and DST_{BWD}, respectively, at the start of the week. Interestingly, DST_{BWD} tended to demonstrate an increasing trend until returning to and slightly above baseline levels. The respiration rate for $DST_{FWD,}$ however, stayed elevated. Notably, however, the absolute change in this metric was relatively small. This increased respiration rate is possibly influenced by the decrease in oxygen saturation (SpO_2; Figure 4B) observed in DST_{FWD}. After Sunday, no statistically significant change in SpO2 was observed for DST_{BWD}.

Discussion

This study aimed to characterize the change in biometrics as recorded by a wearable monitor during the week following a change in clock time in accordance with DST. It was demonstrated that sleep and cardiovascular measures are most sensitive to DST changes, with observable but less prominent impacts on respiration rate and oxygen saturation.

An increase in sleep duration when clocks are moved backward, and a decrease in sleep duration when clocks are set forward has been observed in a number of studies using both actigraphy monitors and sleep diaries (see Harrison et al.[17] for review), as is expected due to the extra hour between, say, midnight and 8:00am when the clocks move backward and one hour less between those times when clocks move forward. We demonstrated the same directionality of effect and similar magnitude to those previously reported[17]. Moreover, the present results also extend the current literature, as we demonstrated a time course for these sleep duration effects, returning to baseline by the end of the week following DST time changes.

Sleep efficiency is a measure of sleep quality that is not directly affected by changing clocks, as supported by the minimal change in sleep efficiency on the Sunday after a DST change. However, in the days after moving clocks forward, sleep efficiency appears to decrease even as sleep duration returns to normal levels. Sleep quality has been

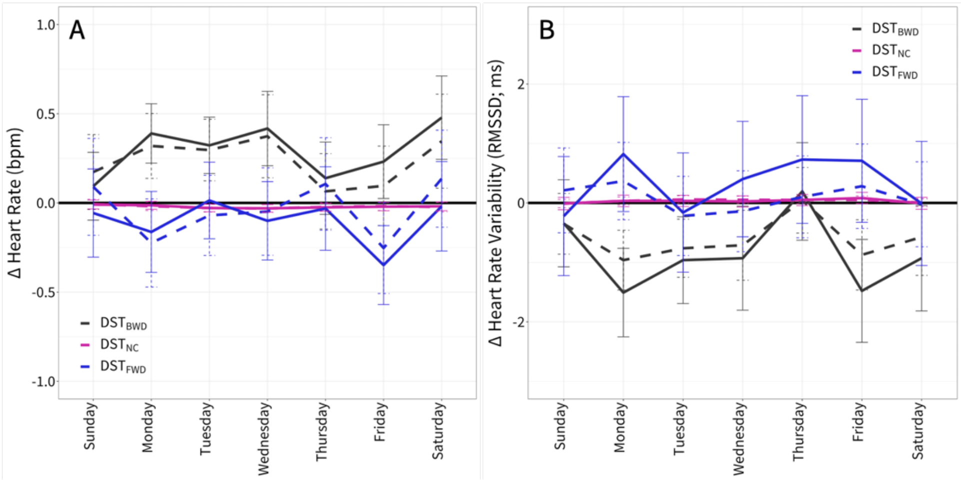

Figure 3. Change in resting heart rate (A) and heart rate variability from seven days prior. The solid represents resting values, and the dashed line is the nocturnal value for each metric.

previously demonstrated to be reduced during DST time changes[18], an effect potentially associated with a change in total sunlight exposure prior to sleep onset. Our data also demonstrate that when clocks move backward, sleep efficiency may be improved toward the end of the week after a DST change. Importantly, however, the magnitude of these changes is relatively small, and the medical significance of the health consequences are currently unclear and thus require additional research.

The effect of DST on Sleep Score demonstrates that when the clocks move forward, the Sleep Score is negatively affected at the beginning of the week when sleep duration is decreased due to the lost hour Sunday morning, but the Sleep Score recovers toward the end of the week. When clocks move backward, the Sleep Score is better early in the week, when sleep duration is increased, but its adverse effect comes later, and the Sleep Score suffers greatly between Wednesday and Friday. These results demonstrate that it may take up to seven days for individuals' Sleep Scores to return to baseline following a DST time change. Because the Sleep Score is a metric derived from a combination of factors, it is not clear which combination of factors is driving the change in Sleep Score and whether these factors are consistent across individuals. Nevertheless, while the health and wellbeing consequences of this reduction in Sleep Score should be a topic of further investigation, clinicians, patients, and all stakeholders should be aware of this effect when treating acute illness or scheduling recovery periods for medical procedures. Patients may want to take proactive and conscious efforts to improve their Sleep Score in this immediate post-time change period.

Generally, a decrease in an individual's resting heart rate and an increase in their resting heart rate variability correspond to less stress and overall better health. Our results demonstrate that when clocks are turned backward, resting heart rate is elevated, and resting heart rate variability is depressed from Monday onward. However, when clocks are turned forward, resting heart rate and resting heart rate variability appear to have no change and may, in fact, demonstrate a small beneficial change. These results are in the opposite direction of our initial hypotheses and other recent reports[19], since one might expect sleeping for an additional hour on Sunday would improve cardiovascular biometrics. An alternative explanation for these findings may include shifting the end of the day an hour earlier relative to sunset and thus having more daylight later in the day and potentially increased activity levels and a nocturnal compensatory effect. However, these post-hoc rationales require additional investigation in a controlled environment.

When the clocks move forward, the data suggest a higher respiratory rate and lower oxygen saturation. These two biometrics are intricately associated, where a decrease in SpO_2 commonly begets a higher respiratory rate.

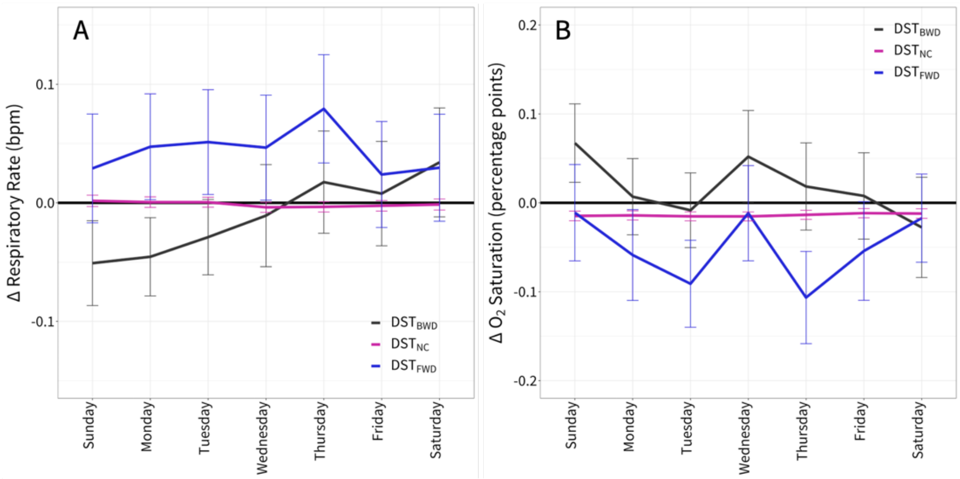

Figure 4. Change in respiratory rate (A) and O_2 Saturation (B) from seven days prior.

Conversely, when the clocks move backward, there is some beneficial change (i.e., lower) in respiratory rate for several days following a DST time change. Importantly, however, these effects are both small in magnitude, and their clinical significance is likely inconsequential.

This study has many strengths, including the large data set obtained in a real-world context, multiple biometrics representing a range of health and wellbeing components, and a unique analytical approach that permits discussion on the time course of DST effects. However, some limitations must be noted. For example, not all participants in the data set contributed an equal number of observations to the analysis, and thus the aggregates may be biased toward the subset of users with higher compliance during this period. Moreover, these data were obtained from existing Biostrap users, which constitute a demographic that may not be generalizable to all persons across all contexts. The volume of data incorporated in this analysis does, however, lend credence to these results applying to a somewhat heterogeneous population.

Conclusion

Changing clocks for Daylight Saving Time affects people's sleep and biometrics when moving clocks forward and backward. In the days after moving clocks forward (seven hours between midnight and 8:00 am, as happens in the United States in Spring), people overall sleep less, suffer some decrease in overall sleep quality until recovering by the end of the week, have some negative effect on respiratory function, and have at the most a slight improvement in cardiovascular function. In the days after moving clocks backward (nine hours between midnight and 8:00 am, as happens in the United States in Autumn), people overall sleep more, experience a decrease in overall sleep quality later in the week, experience adverse effects on their cardiovascular system, but potentially positive effects on their respiratory system.

Endnote

†Biometric 7-day differences accompanied by time zone offset changes of more than 60 minutes are ignored, as well as 60-minute time zone offset changes that happen outside of date ranges where DST changes occur anywhere in the world. We also limited our analysis to Sunday morning DST changes.

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Informed Consent Statement: The present study included only historical anonymized data and thus no prospective informed consent was required.

Data Availability Statement: The data presented in this study are not publicly available. Correspondence can be directed to K.A.L.

Conflicts of Interest: All authors are employees of Biostrap USA, LLC.

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