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Variation in Actigraphy-Estimated Rest-Activity Patterns by Demographic Factors:

Rest-Activity Patterns in Adults and Children

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Abstract

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Rest-activity patterns provide an indication of circadian rhythmicity in the free-living setting. We aimed to describe the distributions of rest-activity patterns in a sample of adults and children across demographic variables. A sample of adults (N=590) and children (N=58) wore an actigraph on their non-dominant wrist for 7 days and nights. We generated rest-activity patterns from cosinor analysis (MESOR, acrophase and magnitude) and non-parametric circadian rhythm analysis (IS: intradaily stability; IV: interdaily variability; L5: least active 5-hour period; M10: most active 10-hour period; and RA: relative amplitude). Demographic variables included age, sex, race, education, marital status, and income. Linear mixed effects models were used to test for demographic differences in rest-activity patterns. Adolescents, compared to younger children, had: 1) later M10 midpoints (β=1.12 hours [95% CI: 0.43, 1.18] and lower M10 activity levels; 2) later L5 midpoints (β=1.6 hours [95% CI: 0.9, 2.3]) and lower L5 activity levels; 3) less regular rest-activity patterns (lower IS and higher IV); and 4) lower magnitudes (β=−0.95 [95% CI: −1.28, −0.63]) and relative amplitudes (β=−0.1 [95% CI: −0.14, −0.06]). Mid-to-older adults, compared to younger adults (ages 18 to 29 years), had: 1) earlier M10 midpoints (β=−1.0 hours [95% CI: −1.6, −0.4]; 2) earlier L5 midpoints (β=−0.7 hours [95% CI: −1.2, −0.2]); and 3) more regular rest-activity patterns (higher IS and lower IV). The magnitudes and relative amplitudes were similar across the adult age categories. Sex, race and education level rest-activity differences were also observed. Rest-activity patterns vary across the lifespan, and differ by race, sex and education. Understanding population variation in these patterns provides a foundation for further elucidating the health implications of rest-activity patterns across the lifespan.

Keywords

Actigraphy; Epidemiology; Rest-activity patterns; Demographics

Introduction

The timing and regularity of energetic behaviors (e.g. physical activity and sleep) may influence metabolism and the risk of developing obesity, type 2-diabetes, and certain cancers, independent of overall exposure (Garaulet, Gomez-Abellan et al., 2013; Innominato, Focan et al., 2009; Laposky, Bass et al., 2008). The underlying mechanisms are likely related to the impact of circadian desynchrony - for instance through night shift work —that results from the misalignment between energetic behaviors and physiological functions that are driven by internal biological clocks (Bass & Takahashi, 2010; Laposky, Bass et al., 2008). Indeed, there are compelling data from nocturnal animal models that knocking out circadian clock genes disrupts 24-hour rest-activity rhythms and increases food intake during the light cycle, consequently leading to increased fat mass and impaired metabolism (Turek, Joshu et al., 2005; Williams & Schwartz, 2005). Furthermore, short-term forced desynchronization studies conducted in laboratory-settings have also implicated circadian misalignment with impaired metabolism in humans (Buxton, Cain et al., 2012; Leproult, Holmback et al., 2014; McHill, Melanson et al., 2014; Scheer, Hilton et al., 2009).

Although forced desynchronization protocols in highly controlled laboratory settings can provide detailed physiological data, studies done in those settings may not reflect typical variations in sleep-wake and energetic behaviors in every day settings. In community settings, assessments of rhythms require collecting data at multiple time points across several days. One means of non-invasively collecting objective activity and sleep-wake-rhythms is through the use of actigraphy. Specifically, actigraphy can be used to derive reliable estimates of 24-hour rest-activity rhythms through the use of rhythmometric methods that parametrically model the periodicity of the rest-activity rhythm (cosinor model) or through the use of non-parametric models for quantifying the stability of the rest-activity rhythm (Calogiuri, Weydahl et al., 2013). The majority of studies that have used these methods have been small scale clinical studies (typically fewer than 50 participants) involving adults with cancer (Pati, Parganiha et al., 2007), obesity (Bandin, Martinez-Nicolas et al., 2014), depression (Hori, Koga et al., 2016), dementia (Anderson, Hatfield et al., 2009), and bi-polar disorder (Rock, Goodwin et al., 2014; Salvatore, Ghidini et al., 2008), and in children with attention-deficit hyperactivity disorder (ADHD) (Van der Heijden, Smits et al., 2005).

There is some evidence of an association between age and rest-activity patterns (Czeisler, Dumont et al., 1992; Roenneberg, Kuehnle et al., 2004), and some data indicating that rest-activity patterns differ by ethnicity (Smith, Burgess et al., 2009). However, no community based study has yet systematically investigated 24-hour rest-activity patterns in relation to demographic factors. Characterization of rest-activity patterns in the population can potentially help identify groups at risk for disrupted circadian patterns, and suggest individuals who may benefit from intervention. The present study systematically describes 24-hour rest-activity patterns in a sample of U.S. adults and children, using both cosinor and non-parametric modeling approaches. In addition, we also aimed to determine if there were associations with demographic factors (age, sex, race, education level, household income, and marital status) and actigraphy estimated 24-hour rest-activity patterns. Furthermore, we wanted to establish the feasibility of this data collection approach in community settings.

Methods

Participants

We used data from three studies that asked participants to wear an accelerometer on their non-dominant wrist for one week, day and night. The National Cancer Institute’s Transdisciplinary Research on Energetics and Cancer (TREC) initiative, a collaborative network of four academic institutions, supported two of the three studies (Patterson, Colditz et al., 2013). The first TREC supported study (2012–2013) enrolled adult women living in/near Philadelphia, PA, San Diego, CA, and St Louis, MO; as well as a sub-sample of adult women enrolled in the Nurses’ Health Study II living throughout the U.S. (N=276 with valid actigraphy data and complete demographic data) (Kerr, Marinac et al., 2016; Mitchell, Godbole et al., 2016). The adult women had to be aged 21–75 years old, have a BMI between 21.0 and 39.9 kg/m^2, and be able to move about unassisted. Shift-workers and those who planned to travel across time zones during the accelerometer-monitoring period were ineligible. The St Louis sample specifically included women who were full or part-time employed. The Philadelphia sample specifically included breast cancer survivors; 17% of the San Diego sample were confirmed breast cancer survivors. The Nurses’ Health Study II was sampled to evenly represent varying population densities and all Census regions of the US

(African American were oversampled). Hereafter, this study will be referred to as the Year 2 Cross TREC Center Study (Y2-XTREC).

The second TREC supported project (2015–2016) enrolled adult men and women aged 21–60 years living in/near Philadelphia, PA, San Diego, CA, and St Louis, MO (N=110 with valid actigraphy data and complete demographic data). Participants were eligible for this study if they did not report any illness requiring bed rest, any sleep disorder, and did not have a disability restricting movement (including neurological disorders causing persistent tremors). Shift-workers and those who planned to travel across time zones during the accelerometer-monitoring period were excluded, as were females who were pregnant or breastfeeding. Hereafter, this project will be referred to as "Impact of Nocturnal Zeitgebers on Energy in TREC" (INZEIT).

The third study was completed in 2014–2015 and included children (N=58 with valid actigraphy data and complete demographic data), and adults (N=115 with valid actigraphy data and complete demographic data) who were living in/near San Diego (iWatch). These participants had to be able to walk unassisted, speak English, and not be in the second or third trimester of a pregnancy if female. Hereafter, this project will be referred to as iWatch-A for the adults and iWatch-C for the children and. The participants in all three studies provided informed consent. The children (<18 years old) provided assent and a parent/guardian provided consent. Institutional Review Boards approved all three study protocols.

Actigraphy Protocol

The participants in each study wore an ActiGraph GT3X+ accelerometer (ActiGraph, Pensacola, FL) on their non-dominant wrist, for 24 hours per day (except when bathing or swimming), for one week. A paper diary was provided for the participants enrolled in the Y2-XTREC and iWatch studies to report any times they removed their accelerometer, and the times they went to bed and woke each night and morning, respectively. The parents/guardians of the children enrolled in iWatch completed the sleep diaries on their behalf. The participants enrolled in INZEIT used a mobile smartphone application to report the same data. At the end of their wear period, the participants returned their accelerometers in the mail or in person and the data were downloaded using ActiLife software (version 6.7 [or later], ActiGraph, Pensacola, FL). We considered a day valid if >10 hours of activity counts were collected. Participants had to provide at least 3 days of recordings to be included into our analysis. All data files were visually screened at local data collection sites before being centrally processed at UCSD (Y2-XTREC and iWatch) or the Brigham and Women's Hospital (INZEIT).

Cosinor Variables

The accelerometer count data (1 sample per minute) were transformed using a natural log function. We then fitted a single-component cosine curve representing a 24-hour period to the count data, using regression analysis in Matlab/Octave. The regression model can be described as: $Y(t) = M + A\cos\left(\frac{2\pi t}{T} + \phi\right) + e(t)$, where T is the period of the cosinusoid (set to equal 24 hours), M is the Midline Estimated Statistic Of Rhythm (MESOR, which represents the mean activity count of the fitted 24 hour rhythm pattern), ϕ is the acrophase (the time of peak activity), and A is the amplitude (also called magnitude, and represents the difference between the model fit peak value and the MESOR). We derived the parameters M, ϕ, and A by minimizing the residual sum of squares between the data and the model-estimated values (Cornelissen, 2014).

Non-Parametric Variables

Rest-activity circadian rhythms do not perfectly follow a sinusoidal waveform, and so it is important to consider alternatives to the cosinor method, such as non-parametric approaches, to investigate 24 hour rest-activity patterns. We calculated the following non-parametric features using accelerometer count data (1 sample per minute): 1) the intradaily variability (IV); 2) the interdaily stability (IS); 3) the time occurrence and corresponding activity counts of the most active 10 hour period (M10) and of the least active 5 hour period (L5); and 4) the relative amplitude (RA) (Van Someren, Swaab et al., 1999). The formulae for calculating IV, IS and RA are given in Supplementary Table 1. The IV provides an estimate of the fragmentation of the 24 hour rest-activity rhythm (IV ≈ 0 for a perfect sine wave, IV ≈ 2 for Gaussian noise). Higher IVs would be observed among those who often nap during the daytime and are more frequently awake during the night. The IS provides an estimate of how closely the 24 hour rest-activity rhythm follows the 24 hour light-dark cycle (IS ≈ 0 for Gaussian noise, IS ≈ 1 for perfect stability). As such, a higher IS indicates good synchronization to light and other environmental cues that regulate the biological clock. The M10 reflects how active the wake periods are and the M10 midpoint provides an indication of whether a person is most active earlier or later in the day. In contrast, the L5 reflects resting levels during the night and a lower L5 indicates less more restful sleep. Furthermore, the time of day when L5 occurs (L5 midpoint) provides an indication of whether a person prefers to go to bed earlier or later in the day. Finally, the relative amplitude is the difference between M10 and L5 in the average 24-h pattern, normalized by their sum; higher relative amplitudes therefore indicate a more robust 24 hour rest-activity rhythm, reflecting both relatively lower activity during the night and higher activity when awake.

The codes for the cosinor and non-parametric variables have been made available on the National Sleep Research Resource (https://sleepdata.org/community/tools/acticircadian).

Sleep Variables

The accelerometry data were also processed to derive estimates of total sleep duration (hours per night). The sleep period was defined using the bed and wake times reported by the participants, and the Cole-Kripke algorithm was applied to estimate total sleep duration (Cole, Kripke et al., 1992). Compared to polysomnography (PSG), wrist accelerometry has high sensitivity (percent of PSG identified sleep minutes scored as sleep minutes by actigraphy [>90%]) and moderate specificity (percent of PSG identified wake minutes scored as wake minutes by actigraphy [~30–40%]) (Sadeh, 2011).

Demographics

Demographic factors were measured by questionnaire in the Y2-XTREC and INZEIT studies, and during the screening phone call in the iWatch study. Age (children: 5–9y, 10–14y or 15–18y; adults: 18–29y, 30–39y, 40–49y, 50–59y, 60–69y or ≥70y), sex (female or male), race (Asian, Black, White or Other), education level (high school or less, some college/associate degree, college degree or graduate degree), marital status (never married, divorce/separated, widowed or married/living as married), and household income (<$50K, $50–70K or >$70K) were all self-reported.

Statistical Analyses

To describe our sample characteristics we used means and standard deviations for the continuous variables, and frequencies and percentages for the categorical variables. The descriptive statistics are presented for each study, and for children and adults enrolled in iWatch. We also describe the rest-activity variables by each level of the demographic variables. Spearman correlations between the rest-activity variables were calculated and we considered the correlations to be weak to strong as follows: 0.00–0.19 (very weak), 0.20–0.39 (weak), 0.40–0.59 (moderate), 0.60–0.79 (strong) and 0.80–1.00 (very strong) (Swinscow, 1997). The strong and very strong correlations are described in detail.

To determine if demographic characteristics were associated with rest-activity patterns we used linear mixed effects models, and analyzed the adult and children data separately. First, we tested for demographic-cohort interactions to determine if any of the demographic associations with the rest-activity outcomes differed across the three adult study cohorts. We did not observe strong evidence of any such statistical interactions; we therefore combined all adult datasets together to test for demographic associations with the cosinor and non-parametric rest-activity outcome variables. Specifically, linear mixed models, with a random effect for family id to account for any correlation among family members enrolled in iWatch, were used for this purpose (iWatch-A: 5 adult family clusters; iWatch-C: 17 sibling clusters). All demographic variables were included together in the same models, and models were adjusted for study (INZEIT, Y2-XTREC or iWatch-A) and site of data collection (Harvard: nationwide; UPenn: Philadelphia, PA; UCSD: San Diego, CA; WUSTL: St Louis, MO).

For the children data, linear mixed models, with a random effect for family id to account for any correlation among siblings enrolled in iWatch-C, were used to test for demographic associations with the cosinor and non-parametric rest-activity outcome variables. The demographics used in the childhood analyses were age, sex and race. All demographic variables were included together in the same models. All statistical analyses were completed using Stata 14.1 (StataCorp LP, College Station, TX).

Results

Demographic Characteristics (Table 1)

Our analytical samples included 501 adults and 58 children. The average age of the adult sample was 52 years, and ranged between 57.7 (±18.3) years in iWatch-A and 35.8 (±11.2) years in INZEIT. The average age of the pediatric sample was 11.6 (±3.8) years. The majority of the adult sample was comprised of females (attributable to the Y2-XTREC being exclusively female), whereas the pediatric sample included an equal proportion of males and females. Among adults, 74% reported being White and 16% reported being Black or African

American; the pediatric sample was primarily comprised of White (52%) children, with Black or African American (9%) and Asian (16%) children also represented. The proportion of adults living in a household with an income below $50,000 was 37%; 33% of adults had a college degree and 62% reported being married. Adults provided a mean of 7.4 (SD 1.4) days of valid actigraphy data, whereas children provided a mean of 5.8 (SD 1.0) of valid days of actigraphy data.

Rest-Activity Characteristics (Table 1)

The average MESOR among all adults was 3.89 (±0.45) natural log (ln) counts; in children the average was 4.05 (±0.46) ln counts. Among all adults the average acrophase (time of peak activity, hours) was 2:37 (±1:20) pm, whereas the average was 3:17 (±1:22) pm for the children. The average magnitude in the adult sample was 2.69 (±1.36) ln counts; for the children and adolescent sample the average was 3.12 (±0.65) ln counts. Regarding the non-parametric rest-activity phenotypes, the average IS was 0.49 (±0.12) among all adults and 0.55 (±0.13) in the pediatric sample. The average IV among all adults was 0.86 (±0.24) and 0.76 (±0.20) in the pediatric sample. The average M10 midpoint (equivalent to the acrophase, hours) was 2:11 (±1:36) pm among all adults and 3:17 (±1:29) pm in the pediatric sample. The average M10 activity level was 1,260 (±369) counts for the adults and 1767 (±585) counts for the children. In contrast, the average time of lowest activity (L5 midpoint, hours) was 2:41 (±1:22) am among all adults and 3:21 (±1:21) am in the pediatric sample. The average L5 activity level was 161 (±95) counts for the adults and 108 (±48) counts for the children. The relative amplitude averaged 0.77 (±0.11) in adults and 0.87 (±0.07) in the pediatric sample. The means and standard deviations for each rest-activity pattern variable, by each category level for the demographic factors, are given in Supplementary Tables 2 (adults) and 3 (children), and for the confirmed breast cancer survivors in Supplementary Table 4.

Spearman Correlations (Tables 2 and 3)

In adults, strong and very strong positive correlations were observed between the following variables (in rank order): acrophase and L5 midpoint, acrophase and M10 midpoint, MESOR and M10 midpoint, L5 midpoint and M10 midpoint, magnitude and RA, RA and total sleep duration, and magnitude and M10 midpoint. Negative correlations of at least strong strength were observed between the following variables in adults (in rank order): L5 counts and RA, and L5 counts and total sleep duration.

In children, strong and very strong positive correlations were observed between the following variables (in rank order): acrophase and L5 midpoint, acrophase and M10 midpoint, L5 midpoint and M10 midpoint, magnitude and RA, magnitude and M10 counts, MESOR and M10 counts, RA and total sleep duration, magnitude and IS, M10 counts and RA, and IS and RA. Negative correlations of at least strong strength were observed between the following variables in children (in rank order): L5 counts and RA, L5 counts and total sleep duration, Magnitude and IV, IS and IV, L5 midpoint and RA, and acrophase and RA.

Age Associations (Table 4)

Compared to 18–29 year-olds: 1) MESORs were lower for those over 70 years (i.e. lower overall activity levels); 2) acrophases and M10 midpoints were earlier among those over 40 years and 30 years (i.e. earlier peak activity); 3) L5 midpoints were earlier among those over 40 years (i.e. earlier nadir activity); 4) ISs were higher (i.e. greater daily stability) and IVs were lower (i.e. less intradaily variability) among those over 40 years; 5) L5 counts were lower for those over 70 years (i.e. more rest during their least active 5 hours); and 6) M10 counts were lower among those over 60 years (i.e. less physically active during their most active 10 hours). In other words, the shift in acrophase, M10 midpoints and L5 midpoints show a shift of activity to earlier timings in older versus younger adults. The magnitudes and relative amplitudes were similar across the adult age categories, as was average sleep duration. Additional age comparisons, between all other age categories are illustrated in Supplementary Figure 1.

Compared to children aged 5–9 years old, older children had lower MESORS; later acrophases and M10 midpoints; later L5 midpoints; and lower ISs and higher IVs; and lower L5 and M10 levels. Furthermore, older children had lower magnitudes and relative amplitudes, and lower total sleep duration. Additional age comparisons, between the two older age categories are given in Supplementary Table 5.

Sex Associations (Table 5)

MESOR, acrophase, IV, L5, L5 midpoint, and M10 midpoint were similar for males and females. However, compared to males, female adults had a higher magnitude and relative amplitude, a higher IS, a higher M10 level and a higher average sleep duration. In children, only the IV was associated with sex (females had a lower IV compared to males).

Race Associations (Table 5)

Compared to White adults, Black or African-American adults had a lower magnitude and relative amplitude, a lower IS, a lower M10 level and reduced average sleep duration. Asian adults also had a lower average magnitude and a lower M10 level, compared to White adults. Furthermore, Asian adults compared to White adults had a lower MESOR. We observed no other race associations in adults. The African American associations we observed in adults were directionally consistent in the pediatric sample, with the exception of the M10 level. In addition, we found a lower M10 level in Asian children compared to White children. Taken together, African Americans and Asians had less stable and also less strong rest-activity patterns compared to Whites.

Income, Education and Marital Status Associations (Table 6)

Compared to adults with a high school education (or less), adults with at least some college education had lower MESORs; later acrophases and M10 midpoints; later L5 midpoints; lower ISs and higher IVs; and lower L5 and M10 levels; and higher total sleep duration. We did not observe any associations between income categories and the rest-activity pattern outcomes. Compared to married adults, adults who have never been married had a later acrophase and M10 midpoint; and a lower IS and a higher IV. In addition, widowed adults had a lower magnitude and relative amplitude, a lower IS, and a lower total sleep time compared to married adults. In other words, higher educated adults and also married adults had later timings of their activities.

Discussion

We have comprehensively described rest-activity patterns among a U.S. sample of adults and children using data from multiple day actigraphy, and applying both cosinor and non-parametric approaches. Notably, the timing and stability of rest-activity patterns were strongly associated with age. Compared to younger children, older children had later timings of peak activity and peak inactivity, lower activity levels during their least and most active hours, and less stable rest-activity patterns. In contrast, older adults had earlier timings of peak activity and peak inactivity, and their rest-activity patterns were more stable, compared to younger adults. Therefore, the timing of rest-activity patterns was more delayed in older children than in younger children and more advanced in older adults compared to middle-aged adults. We also observed rest-activity pattern differences between Whites and African Americans. Compared to Whites, African Americans had less stable daily rest-activity patterns. Interestingly, this race difference was consistent among adults and children. In contrast, the sex differences we observed were restricted to the adult sample; compared to males, we found that female adults had more stable rest-activity patterns with higher peak activities. Higher educated adults had a later timing of their activities and also showed less stable rest-activity patterns (lower IS and higher IV).

All cosinor and non-parametric rest activity variables were included in our analyses, but some of these variables were strongly correlated with one another. Indeed, acrophase, MESOR, and magnitude were most strongly correlated with the non-parametric counterparts M10 midpoint, M10 counts, and RA, respectively. Specifically focusing on the non-parametric variables, while most were moderate to weakly correlated with one another, we did observe: 1) a strong negative correlation between L5 counts and RA (indicating that RA is primarily driven by L5 counts and not M10 counts), and 2) a strong positive correlation between L5 midpoint and M10 midpoint. It therefore may not be necessary to use all variables in future studies. In deciding which to use, we reiterate that actigraphy estimated rest-activity patterns do not perfectly follow a sinusoidal waveform; therefore the non-parametric variables may be more appropriate for use. And while there were some strong correlations among the non-parametric variables, the correlations were not perfect and we suggest that all non-parametric variables be calculated in future studies. Other investigators have tested correlations between cosinor and non-parametric rest-activity variables. Thomas et al. did so among 43 mother and infant pairs and, Zornoza-Moreno et al. did so for infants during their first 6 months of life. Analogous to our report, they found strong correlations for RA and magnitude, and acrophase and L10 midpoint (Thomas, Burr et al., 2015; Zornoza-Moreno, Fuentes-Hernandez et al., 2011).

Most studies that have measured rest-activity patterns in adults and children have been clinical in nature; typically to investigate how a treatment or therapy for a mental health problem was associated with rest-activity patterns (Gershon, Ram et al., 2016; Robillard, Naismith et al., 2014; Smagula, Ancoli-Israel et al., 2015). However, Sani et al. did use waist-accelerometry to derive cosinor rest-activity outcomes in an international community-based sample of over 2,300 African ancestry adults (25–45 year olds) from the U.S., South Africa, Ghana, Seychelles, and Jamaica (Sani, Refinetti et al., 2015). The authors reported associations between age and acrophase, where peak activity occurred earlier in the day for older compared to younger adults. We observed a directionally consistent association with age and acrophase; in fact, age was the strongest predictor of rest-activity patterns in our study. In addition, Sani et al. also observed higher MESORs in lower developed countries compared to the higher developed countries, as assessed by the Human Developmental Index (Sani, Refinetti et al., 2015). In contrast, we did not observe associations between household income and MESOR (or any other rest-activity variable) in our study. There are key methodological differences between our study and the study by Sani et al., notably the settings and the body placement of the accelerometers (wrist and hip), so comparisons should be made with caution. Also, our sample was predominantly White and those enrolled in the Sani et al study were of African ancestry. We found important differences in the stability of rest-activity patterns for African-Americans compared to Whites. Interestingly, Eastman et al. showed in a small sample that African-Americans had shorter endogenous free-running circadian periods than European-Americans (Eastman, Molina et al., 2012; Eastman, Suh et al., 2015). This could make it more difficult to adjust to phase delays, resulting in circadian rhythm disruption. Given that circadian misalignment has been implicated in the development of chronic diseases that have an underlying race/ethnicity disparity, it will be important to investigate these ancestry differences in greater detail in future studies. Indeed, circadian misalignment has been implicated in the pathogenesis of many physiological systems that could increase susceptibility to physical (cardiovascular disease, diabetes, obesity, cancer) and psychiatric diseases (depression, bipolar, schizophrenia, attention deficit disorders) (Baron & Reid, 2014). Future interventions could therefore be designed to test a number of emerging hypotheses related to behavioral timing and circadian rhythms, specifically in key demographic subpopulations.

We included total sleep duration for descriptive purposes and to aid with the interpretation of the demographic associations with the 24-hour rest-activity outcomes. In contrast to 24-hour rest-activity patterns, there are extensive descriptive epidemiologic data showing that age, male sex, non-White race and lower socioeconomic position are associated with lower total sleep duration (Biggs, Lushington et al., 2013; Burgard & Ailshire, 2013; Floyd, Medler et al., 2000; Hale & Do, 2007; McLaughlin Crabtree, Beal Korhonen et al., 2005; Whinnery, Jackson et al., 2014). We observed a number of demographic factors associated with total sleep duration, and the directions of these associations were similar to those from previous studies. These data therefore serve as “positive controls” and suggest that our rest-activity pattern results could be representative of the broader U.S. population. However, further efforts at understanding population variation and selection criteria in larger scale representative studies in the U.S. are needed. Importantly, L5 counts was negatively correlated with total sleep duration, but this was the only rest-activity variable the demonstrated a strong correlation, suggestive that the rest-activity variables provide additional information that is not captured by actigraphy estimated total sleep duration.

Among the strengths of this research, we estimated rest-activity patterns across three adult studies and one pediatric study using standardized methods. We estimated both cosinor and non-parametric rest-activity pattern variables, which is a novel contribution to the literature given that most studies have tended to only incorporate cosinor methods. By combining data from three adult studies we increased the demographic diversity of our sample, enabling in-depth demographic associations to be investigated. However, our sample is not representative of all U.S. adults and it is a limitation that we used a convenience sample to address our study aims. Our study also has other limitations. Analyses were exploratory and descriptive in nature and not subject to correction for multiple comparisons, so that the likelihood of false positive findings is increased. There is little research on the number of recording days to produce reliable estimates of rest-activity patterns (Thomas & Burr, 2008), and thus we cannot rule out that a greater number of recordings may be needed to derive better estimates. Rest-activity patterns provide insight into circadian rhythms, but do not directly estimate a circadian rhythm of a physiological system. Our study was cross-sectional in design and longitudinal studies using our methodology are needed, especially to test for dynamic age-related changes in rest-activity patterns. We included children, but our pediatric sample was limited to a single site (San Diego, CA) and parental/guardian level demographic data were not available in this sample. Follow-up studies are needed that include a larger number of children with demographic information about parents/guardians. The sex differences we observed need to be interpreted with caution owing to the larger percentage of females to males in our adult sample.

Conclusion

Our data demonstrate that rest-activity patterns are potentially dynamic across the lifespan, which is consistent with other data using self-report and work schedule data on timing of sleep and physical activity. The later timing and reduced stability in rest-activity patterns observed in adolescence and in early-to-mid-adulthood warrant further investigation in prospective, longitudinal studies. Overall, our study provides a starting point for community-based investigations of rest-activity patterns and provides a number of hypothesis-generating avenues for analytical epidemiologic studies to investigate the health implications of variation in rest-activity pattern across the lifespan.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

Declaration of Interest statement

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Table 1.

Demographic characteristic of the analytical study sample

	All Adults (N=501)	INZEIT (N=110)	Y2-XTREC (N=276)	iWatch-A (N=115)	iWatch-C (N=58)
Age, mean (SD), years	51.8 (14.9)	35.8 (11.2)	55.7 (9.5)	57.7 (18.3)	11.6 (3.8)
BMI, mean (SD), kg/m^2 / Z-score[a]	27.4 (5.7)	27.0 (5.8)	27.8 (5.7)	27.0 (5.4)	0.15 (1.3)
TST, mean(SD), h per night	6.9 (1.0)	7.0 (0.9)	6.8 (0.9)	7.1 (1.1)	8.0 (0.8)
21–29y / 5–9y [b]	57 (11.4)	48 (43.6)	2 (0.7)	7 (6.1)	20 (34.5)
30–39y / 10–14y [b]	56 (11.2)	21 (19.1)	14 (5.1)	21 (18.3)	21 (36.2)
40–49y / 15–18y[b]	81 (16.2)	21 (19.1)	43 (15.6)	17 (14.8)	17 (29.3)
50–59y	143 (28.5)	19 (17.3)	109 (39.5)	15 (13.0)	-
60–69y	109 (21.8)	1 (0.9)	93 (33.7)	15 (13.0)	-
≥70y	55 (11.0)	-	15 (5.4)	40 (34.8)	-
Female, N (%)	404 (80.6)	68 (61.8)	276 (100)	60 (52.2)	30 (51.7)
White, N (%)	372 (74.3)	67 (60.9)	218 (79.0)	87 (75.7)	30 (51.7)
Black or AA, N (%)	78 (15.6)	24 (21.8)	49 (17.8)	5 (4.4)	5 (8.6)
Asian, N (%)	23 (4.6)	8 (7.3)	5 (1.8)	10 (8.7)	9 (15.5)
Other, N (%)	28 (5.6)	11 (10.0)	4 (1.5)	13 (11.3)	14 (24.1)
Income <\$50K, N (%)	187 (37.3)	62 (56.4)	71 (25.7)	54 (47.0)	-
Income \$50–70K, N (%)	78 (15.6)	16 (14.6)	47 (17.0)	15 (13.0)	-
Income >\$70K, N (%)	236 (47.1)	32 (29.1)	158 (57.3)	46 (40.0)	-
High School or Less, N (%)	64 (12.8)	21 (19.1)	27 (9.8)	16 (13.9)	-
Some College, N (%)	118 (23.6)	21 (19.1)	57 (20.7)	40 (34.8)	-
College Degree, N (%)	167 (33.3)	47 (42.7)	99 (35.9)	21 (18.3)	-
Graduate Degree, N (%)	152 (30.3)	21 (19.1)	93 (33.7)	38 (33.0)	-
Married, N (%)	308 (61.5)	39 (35.5)	196 (71.0)	73 (63.5)	-
Divorced, N (%)	65 (13.0)	10 (9.1)	44 (15.9)	11 (9.6)	-
Widowed, N (%)	20 (4.0)	2 (1.8)	10 (3.6)	8 (6.1)	-
Never Married, N (%)	108 (21.6)	59 (53.6)	26 (9.4)	23 (20.0)	-
MESOR, mean (SD), ln counts	3.88 (0.45)	3.91 (0.47)	3.87 (0.42)	3.88 (0.48)	4.05 (0.46)
Acrophase, mean (SD), Dec. hours	14.6 (1.33)	15.1 (1.35)	14.5 (1.34)	14.5 (1.22)	15.3 (1.36)
Magnitude, mean (SD), ln counts	2.64 (0.46)	2.63 (0.50)	2.64 (0.46)	2.65 (0.46)	3.12 (0.65)
IS, mean (SD)	0.49 (0.12)	0.46 (0.12)	0.48 (0.13)	0.53 (0.12)	0.55 (0.13)
IV, mean (SD)	0.86 (0.24)	0.93 (0.23)	0.82 (0.25)	0.89 (0.22)	0.76 (0.20)
L5, mean (SD), Counts	161.3 (95.0)	180.3 (81.2)	158.8 (104.5)	149.1 (80.2)	108.0 (48.4)
L5 Midpoint, mean (SD), Dec. hours	3.13 (2.96)	3.54 (3.02)	2.82 (2.40)	3.49 (3.92)	3.35 (1.35)
M10, mean (SD), Counts	1260.1 (368.9)	1312.1 (378.4)	1252.1 (361.8)	1229.4 (374.9)	1767.1 (584.9)
M10 Midpoint, mean (SD), Dec. hours	14.2 (1.59)	14.8 (1.56)	14.1 (1.55)	13.9 (1.60)	15.3 (1.49)
RA, mean (SD)	0.77 (0.11)	0.75 (0.10)	0.78 (0.12)	0.78 (0.10)	0.87 (0.07)

Abbreviations: AA, African American; BMI, body mass index; Dec. hours, decimal hours (e.g. 14.5 = 2:30pm); IS, inter-daily stability; IV, intra-daily variability; L5, least active 5-hour period; M10, most active 10-hour period; TST, total sleep time. Missing data: 7 adults had missing BMI data (1 INZEIT, 5 Y2-XTREC, and 1 iWatch-A).

[a]BMI Z-score units apply to those enrolled in iWatch-C.

[b]The pediatric age categories only apply to those enrolled in iWatch-C.

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Table 2.

Spearman correlation coefficients for the cosinor and non-parametric rest-activity pattern variables in adults

		Cosinor			Non-parametric							
		Mesor (ln counts)	Acrophase (Dec. hours)	Magnitude (ln counts)	IS	IV	L5 (Counts)[a]	L5 Midpoint (Dec. hours)	M10 (Counts)	M10 Midpoint (hours)	RA	TST (Hours/d)
Cosinor	**Mesor (ln counts)**	1.00	-	-	-	-	-	-	-	-	-	-
	Acrophase (Dec. hours)	−0.02	1.00	-	-	-	-	-	-	-	-	-
	Magnitude (ln counts)	0.38	−0.17	1.00	-	-	-		-	-	-	-
Non-parametric	**IS**	0.17	−0.22	0.52	1.00	-	-	-	-	-	-	-
	IV	−0.17	0.21	−0.37	−0.29	1.00	-	-	-	-	-	-
	L5 (Counts)	0.56	0.16	−0.34	−0.33	0.14	1.00	-	-	-	-	-
	L5 Midpoint (Dec. hours)	−0.09	0.90	−0.15	−0.16	0.16	0.08	1.00	-	-	-	-
	M10 (Counts)	0.72	−0.08	0.62	0.16	−0.29	0.26	−0.11	1.00	-	-	-
	M10 Midpoint (Dec. hours)	−0.03	0.85	−0.11	−0.22	0.18	0.13	0.70	−0.10	1.00	-	-
	RA	−0.15	−0.19	0.69	0.40	−0.29	−0.82	−0.13	0.29	−0.17	1.00	-
	TST (Hours/d)	−0.45	0.04	0.34	0.22	−0.09	−0.71	0.09	−0.10	0.06	0.64	1.00

Abbreviations: Dec. hours, decimal hours (e.g. 14.5 = 2:30pm); IS, intradaily stability; IV, interdaily variability; L5, least active 5-hour period; M10, most active 10-hour period; RA, relative amplitude; TST, total sleep time.

[a]The L5 count variable was log transformed to correct for skewness.

Table 3.

Spearman correlation coefficients for the cosinor and non-parametric rest-activity pattern variables in children

		Cosinor			Non-parametric							
		Mesor (ln counts)	**Acrophase (Dec. hours)**	**Magnitude (ln counts)**	**IS**	**IV**	**L5 (Counts)[a]**	**L5 Midpoint (Dec. hours)**	**M10 (Counts)**	**M10 Midpoint (Dec. hours)**	**RA**	**TST (Hours/d)**
Cosinor	**Mesor (ln counts)**	1.00	-	-	-	-	-	-	-	-	-	-
	Acrophase (Dec. hours)	−0.38	1.00	-	-	-	-	-	-	-	-	-
	Magnitude (ln counts)	0.58	−0.58	1.00	-	-	-	-	-	-	-	-
Non-parametric	**IS**	0.41	−0.56	0.71	1.00	-	-	-	-	-	-	-
	IV	−0.46	0.44	−0.63	−0.63	1.00	-	-	-	-	-	-
	L5 (Counts)	0.15	0.39	−0.46	−0.46	0.15	1.00	-	-	-	-	-
	L5 midpoint (Dec. hours)	−0.42	0.95	−0.57	−0.58	0.47	0.41	1.00	-	-	-	-
	M10 (Counts)	0.72	−0.55	0.81	0.53	−0.51	−0.17	−0.57	1.00	-	-	-
	M10 midpoint (Dec. hours)	−0.27	0.93	−0.43	−0.51	0.32	0.37	0.85	−0.37	1.00	-	-
	RA	0.32	−0.61	0.82	0.67	−0.44	−0.79	−0.62	0.69	−0.49	1.00	-
	TST (Hours/d)	−0.02	−0.55	0.58	0.42	−0.30	−0.72	−0.50	0.33	−0.50	0.72	1.00

Abbreviations: Dec. hours, decimal hours (e.g. 14.5 = 2:30pm); IS, intradaily stability; IV, interdaily variability; L5, least active 5-hour period; M10, most active 10-hour period; RA, relative amplitude; TST, total sleep time.

[a]The L5 count variable was log transformed to correct for skewness.

Table 4.

Age Associations with Rest-Activity Variables

		INZEIT, Y2-XTREC & iWatch-A (N=501)						iWatch-C (N=58)	
		Ref: 18–29y						Ref: 5–9y	
		30–39y	**40–49y**	**50–59y**	**60–69y**	**≥70y**		**10–14y**	**15–18y**
MESOR (ln counts)	Beta (SE)	−0.01 (0.09)	−0.12 (0.09)	−0.13 (0.09)	−0.18 (0.10)	**−0.28 (0.11)**		−0.19 (0.12)	**−0.52 (0.14)**
	P-value	0.89	0.17	0.16	0.06	**0.01**		0.13	**<0.001**
Magnitude (ln counts)	Beta (SE)	−0.03 (0.09)	−0.01 (0.09)	−0.05 (0.09)	0.02 (0.10)	−0.09 (0.11)		**−0.59 (0.14)**	**−0.95 (0.16)**
	P-value	0.71	0.88	0.54	0.85	0.42		**<0.001**	**<0.001**
Acrophase (Dec. hours)	Beta (SE)	−0.47 (0.26)	**−0.74 (0.26)**	**−1.10 (0.26)**	**−1.21 (0.28)**	**−1.16 (0.31)**		0.42 (0,22)	**1.67 (0.33)**
	P-value	0.07	**0.004**	**<0.001**	**<0.001**	**<0.001**		0.05	**<0.001**
IS	Beta (SE)	0.03 (0.02)	**0.06 (0.02)**	**0.08 (0.02)**	**0.11 (0.03)**	**0.13 (0.03)**		**−0.06 (0.03)**	**−0.18 (0.03)**
	P-value	0.15	**0.008**	**<0.001**	**<0.001**	**<0.001**		**0.02**	**<0.001**
IV	Beta (SE)	−0.02 (0.05)	**−0.10 (0.05)**	−0.07 (0.05)	**−0.12 (0.05)**	−0.07 (0.06)		0.06 (0.05)	**0.19 (0.06)**
	P-value	0.64	**0.04**	0.13	**0.02**	0.18		0.28	**0.002**
L5 (Counts)[a]	Beta (SE)	0.08 (0.10)	−0.05 (0.10)	0.02 (0.10)	−0.12 (0.10)	**−0.28 (0.12)**		0.20 (0.11)	**0.37 (0.13)**
	P-value	0.39	0.59	0.85	0.24	**0.01**		0.08	**0.006**
L5 Midpoint (Dec. hours)	Beta (SE)	−0.40 (0.27)	**−0.67 (0.27)**	**−1.05 (0.27)**	**−0.91 (0.29)**	**−0.64 (0.32)**		0.39 (0.26)	**1.60 (0.36)**
	P-value	0.13	**0.01**	**<0.001**	**0.002**	**0.04**		0.14	**<0.001**
M10 (Counts)	Beta (SE)	53.8 (72.8)	−24.5 (72.8)	−82.6 (73.2)	**−163.5 (78.7)**	**−322.6 (86.6)**		**−485.4 (122.0)**	**−709.1 (149.8)**
	P-value	0.46	0.74	0.26	**0.04**	**<0.001**		**<0.001**	**<0.001**

		INZEIT, Y2-XTREC & iWatch-A (N=501)						iWatch-C (N=58)	
		Ref: 18–29y						Ref: 5–9y	
M10 Midpoint (Dec. hours)	Beta (SE)	**−0.61 (0.30)**	**−1.00 (0.30)**	**−1.32 (0.31)**	**−1.46 (0.33)**	**−1.91 (0.36)**		**0.01 (0.19)**	**1.12 (0.35)**
	P-value	**0.04**	**0.001**	**<0.001**	**<0.001**	**<0.001**		**0.96**	**0.002**
RA	Beta (SE)	−0.03 (0.02)	0.00 (0.02)	−0.03 (0.02)	0.00 (0.02)	−0.01 (−0.03)		**−0.05 (0.02)**	**−0.10 (0.02)**
	P-value	0.23	0.96	0.20	0.92	0.80		**0.005**	**<0.001**
TST (Hours/d)	Beta (SE)	0.04 (0.19)	0.14 0.19)	0.01 (0.20)	0.17 (0.21)	0.32 (0.23)		**−0.53 (0.17)**	**−0.99 (0.22)**
	P-value	0.84	0.46	0.97	0.43	0.17		**0.001**	**<0.001**

Abbreviations: Dec. hours, decimal hours (e.g. 1.5 = 1 hours and 30 minutes); IS, intradaily stability; IV, interdaily variability; L5, least active 5-hour period; M10, most active 10-hour period; RA, relative amplitude; TST, total sleep time.

[a] The L5 count variable was log transformed to correct for skewness.

Table 5.

Sex and Race Associations with Rest-Activity Variables

		INZEIT, Y2-XTREC & iWatch-A (N=501)				iWatch-C (N=58)			
		Ref: Male	Ref: White			Ref: Male	Ref: White		
		Female	Asian	Black/AA	Other	Female	Asian	Black/AA	Other
MESOR (ln counts)	Beta (SE)	0.07 (0.06)	**−0.20 (0.10)**	0.04 (0.06)	0.03 (0.09)	0.01 (,0.12)	−0.14 (0.16)	0.25 (0.20)	−0.01 (0.16)
	P-value	0.22	**0.04**	0.53	0.73	0.94	0.38	0.21	0.95
Magnitude (ln counts)	Beta (SE)	**0.29 (0.06)**	**−0.27 (0.09)**	**−0.37 (0.06)**	−0.12 (0.08)	−0.04 (0.15)	−0.24 (0.19)	**−0.65 (0.23)**	−0.05 (0.19)
	P-value	**<0.001**	**0.005**	**<0.001**	0.14	0.80	0.20	**0.005**	0.78
Acrophase (Dec. hours)	Beta (SE)	−0.05 (0.17)	0.36 (0.28)	0.21 (0.17)	0.06 (0.25)	0.48 (28)	0.44 (0.44)	0.46 (0.56)	0.71 (0.45)
	P-value	0.77	0.20	0.22	0.81	0.09	0.32	0.41	0.11
IS	Beta (SE)	**0.04 (0.01)**	−0.01 (0.02)	**−0.05 (0.02)**	−0.01 (0.02)	0.04 (0.03)	−0.03 (0.04)	**−0.10 (0.05)**	−0.01 (0.04)
	P-value	**0.02**	0.78	**0.001**	0.51	0.21	0.49	**0.04**	0.89
IV	Beta (SE)	−0.02 (0.03)	0.08 (0.05)	0.02 (0.03)	−0.02 (0.04)	**−0.13 (0.05)**	0.10 (0.07)	0.07 (0.09)	−0.05 (0.07)
	P-value	0.52	0.12	0.62	0.72	**0.02**	0.14	0.44	0.49
L5 (Counts)[a]	Beta (SE)	−0.11 (0.06)	−0.03 (0.10)	**0.31 (0.06)**	0.17 (0.09)	0.09 (0.12)	−0.02 (0.16)	0.30 (0.20)	−0.06 (0.17)
	P-value	0.07	0.74	**<0.001**	0.06	0.47	0.88	0.14	0.73
L5 Midpoint (Dec. hours)	Beta (SE)	0.05 (0.17)	0.33 (0.29)	0.26 (0.17)	0.10 (0.26)	0.41 (0.32)	0.45 (0.45)	0.30 (0.58)	0.57 (0.47)
	P-value	0.76	0.24	0.13	0.69	0.20	0.32	0.60	0.22
M10 (Counts)	Beta (SE)	**142.7 (46.5)**	**−191.3 (77.8)**	**−151.7 (47.6)**	−33.9 (69.6)	−234.3 (137.8)	**−367.9 (180.0)**	−164.2 (228.1)	−281.2 (187.3)
	P-value	**<0.001**	**0.01**	**0.001**	0.63	0.09	**0.04**	0.47	0.13

		INZEIT, Y2-XTREC & iWatch-A (N=501)						iWatch-C (N=58)				
		Ref: Male		**Ref: White**				**Ref: Male**		**Ref: White**		
		Female		**Asian**	**Black/AA**	**Other**		**Female**		**Asian**	**Black/AA**	**Other**
M10 Midpoint (Dec. hours)	Beta (SE)	0.07 (0.19)		0.35 (0.32)	0.05 (0.20)	−0.22 (0.29)		0.39 (0.27)		0.49 (0.55)	0.43 (0.71)	0.67 (0.54)
	P-value	0.70		0.28	0.79	0.44		0.15		0.38	0.54	0.21
RA	Beta (SE)	**0.05 (0.01)**		−0.03 (0.02)	**−0.09 (0.01)**	−0.03 (0.02)		−0.03 (0.02)		−0.02 (0.02)	−0.04 (0.03)	−0.02 (0.02)
	P-value	**<0.001**		0.24	**<0.001**	0.10		0.09		0.41	0.22	0.49
TST (Hours/d)	Beta (SE)	**0.35 (0.12)**		0.36 (0.21)	**−0.58 (0.13)**	−0.26 (0.18)		−0.10 (0.20)		−0.28 (0.26)	**−1.00 (0.34)**	−0.41 (0.28)
	P-value	**0.004**		0.09	**<0.001**	0.17		0.60		0.28	**0.003**	0.14

Abbreviations: Dec. hours, decimal hours (e.g. 1.5 = 1 hour and 30 minutes); IS, intradaily stability; IV, interdaily variability; L5, least active 5-hour period; M10, most active 10-hour period; RA, relative amplitude; TST, total sleep time.

[a]The L5 count variable was log transformed to correct for skewness.

Table 6.

Income, Education and Marital Status Associations with Rest-Activity Variables

		INZEIT, Y2-XTREC & iWatch-A (N=501)							
		Ref: <$50K		Ref: High School or Less			Ref: Married		
		$50–70K	**>$70K**	**Some College**	**College**	**Graduate Degree**	**Divorced**	**Widowed**	**Never**
MESOR (ln counts)	Beta (SE)	−0.09 (0.06)	0.05 (0.06)	**−0.25 (0.07)**	**−0.24 (0.07)**	**−0.25 (0.07)**	−0.04 (0.06)	−0.04 (0.10)	−0.09 (0.06)
	P-value	0.17	0.44	**<0.001**	**<0.001**	**<0.001**	0.48	0.68	0.18
Magnitude (ln counts)	Beta (SE)	0.02 (0.06)	0.02 (0.06)	−0.08 (0.07)	0.00 (0.07)	−0.08 (0.07)	−0.11 (0.06)	**−0.26 (0.10)**	−0.08 (0.06)
	P-value	0.75	0.75	0.22	0.95	0.27	0.07	**0.01**	0.19
Acrophase (Dec. hours)	Beta (SE)	0.18 (0.18)	0.05 (0.17)	**0.65 (0.19)**	**0.40 (0.19)**	0.53 (0.20)	0.14 (0.17)	−0.27 (0.29)	**0.39 (0.18)**
	P-value	0.31	0.76	**0.001**	**0.04**	0.008	0.42	0.36	**0.03**
IS	Beta (SE)	−0.01 (0.02)	−0.02 (0.01)	**−0.04 (0.02)**	**−0.05 (0.02)**	**−0.04 (0.02)**	−0.02 (0.02)	**−0.06 (0.03)**	**−0.04 (0.02)**
	P-value	0.55	0.10	**0.02**	**0.002**	**0.02**	0.14	**0.02**	**0.02**
IV	Beta (SE)	0.01 (0.03)	0.03 (0.03)	**0.12 (0.03)**	**0.13 (0.03)**	**0.17 (0.04)**	**0.07 (0.03)**	0.03 (0.05)	**0.09 (0.03)**
	P-value	0.86	0.30	**0.001**	**<0.001**	**<0.001**	**0.02**	0.53	**0.009**
L5 (Counts)[a]	Beta (SE)	−0.11 (0.07)	0.02 (0.06)	**−0.22 (0.07)**	**−0.28 (0.07)**	**−0.20 (0.08)**	0.11 (0.06)	0.19 (0.11)	0.11 (0.07)
	P-value	0.11	0.79	**0.002**	**<0.001**	**0.009**	0.08	0.09	0.11
L5 Midpoint (Dec. hours)	Beta (95% CI)	0.23 (0.18)	0.06 (0.17)	**0.66 (0.20)**	0.33 (0.20)	0.42 (0.21)	0.02 (0.18)	−0.53 (0.30)	0.36 (0.19)
	P-value	0.21	0.72	**0.001**	0.09	0.05	0.92	0.08	0.06
M10 (Counts)	Beta (SE)	−77.0 (49.8)	−34.2 (46.5)	**−222.1 (54.4)**	**−168.0 (54.2)**	**−186.2 (56.7)**	−71.3 (48.9)	−109.1 (82.3)	−45.7 (51.7)
	P-value	0.12	0.46	**<0.001**	**0.002**	**0.001**	0.14	0.19	0.38

		INZEIT, Y2-XTREC & iWatch-A (N=501)							
		Ref: <$50K		**Ref: High School or Less**			**Ref: Married**		
		$50–70K	**>$70K**	**Some College**	**College**	**Graduate Degree**	**Divorced**	**Widowed**	**Never**
M10 Midpoint (Dec. hours)	Beta (SE)	0.30 (0.21)	0.01 (0.19)	**0.81 (0.22)**	**0.56 (0.22)**	**0.76 (0.23)**	0.20 (0.20)	−0.45 (0.34)	**0.56 (0.21)**
	P-value	0.15	0.98	**<0.001**	**0.01**	**0.001**	0.32	0.19	**0.008**
RA	Beta (SE)	0.01 (0.01)	0 (0.01)	0.01 (0.02)	0.03 (0.02)	0.01 (0.02)	**−0.03 (0.01)**	**−0.06 (0.02)**	−0.02 (0.01)
	P-value	0.53	0.84	0.70	0.05	0.50	**0.04**	**0.02**	0.10
TST (Hours/d)	Beta (SE)	0.24 (0.13)	−0.17 (0.12)	**0.42 (0.14)**	**0.39 (0.14)**	0.38 (0.15)	−0.19 (0.13)	**−0.53 (0.22)**	0.03 (0.14)
	P-value	0.07	0.18	**0.003**	**0.007**	0.01	0.14	**0.02**	0.80

Abbreviations: Dec. hours, decimal hours (e.g. 14.5 = 2:30pm); IS, intradaily stability; IV, interdaily variability; L5, least active 5-hour period; M10, most active 10-hour period; RA, relative amplitude; TST, total sleep time.

[a] The L5 count variable was log transformed to correct for skewness.