

Descriptive epidemiology of objectively-measured, free-living sleep parameters in a rural African setting.

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Research note

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Abstract

Objectives To investigate the descriptive nature of objectively-measured, free-living sleep quantity and quality, and the relationship to adiposity, in a rural African setting in 145 adults (≥ 40 years, female: $n=104$, male: $n=41$). Wrist-mounted, tri-axial accelerometry data was collected over nine days. Measures of sleep quantity and quality, and physical activity were extracted from valid minute-by-minute data. From stature, body mass and waist circumference, body-mass-index and conicity index were calculated. Self-reported data included behavioural, health and socio-demographic variables. Community consultation followed the quantitative data analyses, for validation and interpretation of findings. **Results** Females had more nocturnal sleep than males (7.2 vs. 6.8 hours/night, $p=0.0464$) while males recorded more diurnal sleep time ($p=0.0290$). Wake after sleep onset and number of awakenings were higher in females, and sleep efficiency was higher in males ($p\leq 0.0225$). Sleep indices were generally similar between weekdays and weekends, except for sleep fragmentation index ($p=0.0458$). Sleep quantity, but not sleep quality was independently and inversely associated with adiposity ($p=0.0453$). Physical activity and morbidity measures were significantly and consistently associated with sleep and adiposity measures ($p<0.0458$). The qualitative data explained some of the unexpected associational directions of the independent variables correlated with sleep variables.

Introduction

Sleep is recognized as an important lifestyle contributor to morbidity and mortality [1]. While extensive Sleep Health Epidemiology literature exists for high income countries, there is a paucity of data from low and middle-income countries, especially objective measures of sleep, such as actigraphy [2]. Within the South African context, studies have utilized self-report measures in adult populations [3–11], but there is a dearth of sleep data using objective-measures from South African, and specifically rural African setting [12]. Recently, Mashinya et al. reported a significant, inverse multivariate-adjusted relationship between self-reported, nocturnal sleep duration and adiposity in a rural African setting [13]. Given the lack of objectively-measured, free-living sleep parameters in any South African setting, the objective of this study was to use wrist-actigraphy to derive sleep parameters in a rural African setting during a cross-sectional survey, and thus extend the findings of self-report sleep duration and adiposity [13].

Methods

Dikgale Health and Demographic Surveillance System site (DHDSS) sample

A convenience sample of 167 adult participants were recruited from the DHDSS site [14]. These participants formed part of the larger AWI-Gen Phase 1 Study cohort (≥ 40 years) [15], the methodological details of which are reported in detail elsewhere [13, 15]. Briefly, trained field workers collected self-reported, measured and biological data from participants by means of questionnaires, anthropometry, ultrasound scans, and venipuncture [13, 15]. From standard measures of body mass (kg), stature (m) and

waist circumference (cm), we calculated body mass index (BMI, kg/m²) and conicity index (CI) [16]. The latter measure to allow a single-measure of body shape to be used in multi-variate analyses. Questionnaire data included behavioural, health and socio-demographic variables and is reported in detail elsewhere [13, 15]. The ultrasound scans and blood-derived variables were not considered for this analysis.

Accelerometer data collection and data reduction

Participants agreed to wear a small, light-weight, wrist-worn tri-axial accelerometer for 9 days (4.6 cm x 3.3 cm x 1.5 cm, 19 grams, ActiGraph wGT3X-BT, Actigraph, LLC, Pensacola, FL, 2013) [17–20]. Prior to use, the monitors were connected to an IBM-compatible computer via USB interface and initialized to sample at 30 Hz, using proprietary software (Actilife 6.13.4, Actigraph, LLC, Pensacola, FL, 2009–2015). The monitors were affixed with a proprietary woven nylon wristband on the non-dominant wrist, and unless there was to be a sustained period of water immersion, participants were requested not to remove the monitors. On the ninth day, the monitors were collected from the participants. Thereafter, the raw recorded data was downloaded from the monitors onto an IBM-compatible computer and stored for later analysis. Prior to re-use of the monitors, the batteries were fully recharged and the memory cleared of previous data. The wrist straps were washed using a disinfectant solution, rinsed in water and air-dried.

Using proprietary software (Actilife 6.13.4, Actigraph, LLC, Pensacola, FL, 2009–2015), valid data (at least one weekday and one weekend day) was obtained by first converting downloaded, raw data files to 60 second epochs. Thereafter, the Cole-Kripke sleep scoring algorithm was used to determine minute-by-minute asleep/awake status [21], and the Actilife-modified Tudor-Locke algorithm to identify sleep periods [22, 23]. Valid wear-time was evaluated using the Choi algorithm [24, 25], with sleep time marked as wear time, and a valid day requiring ≥ 10 hours of wear time. Vector Magnitude (VM)- and Ambulation-defined physical activity variables were defined as counts/day and counts/minute, and steps/day and steps/minute, respectively [26]. Sleep indices included Total Sleep Time (TST), Sleep Efficiency (SE), Wake After Sleep Onset (WASO) and Sleep Fragmentation Index (SFI) [27–29].

Valid physical activity and sleep data was downloaded in a summarised and detailed format in Microsoft Excel™ files and additional variables were extracted: diurnal and nocturnal sleep time, sleep periods during defined hours, and sleep variation across days (within-person total sleep time SD). Diurnal and nocturnal periods were defined as 06h00-18h00 and 18h01-05h59, respectively. The number of sleep periods initiated between 00h01-05h59 defined an additional sleep quality indicator. A sleep period falling completely within the period 06h00-18h00 was defined as potentially a “daytime napping” period. Sufficient sleep time was defined as 7–9 hours [30] and SE as at least 85% [31]. Data was then imported into statistical and graphical software for further analyses.

Statistical analyses

Descriptive statistics comprised means (one standard deviation), median (inter-quartile range) and proportions. Relationships between categorical variables were examined through the Chi-square Test. For continuous data, independent and dependent t tests examined differences between the sexes and

weekday/weekend days and where required the appropriate non-parametric test was employed (Mann-Whitney U Test, Wilcoxon Signed Rank Test). Due to non-normality, continuous variables were transformed to categorical variables (tertiles) as required. Bi-variate relationships were examined using correlation coefficients.

Multiple linear regression models were examined for predictors of sleep indices (TST, SE, WASO, SFI) and body composition measures using selected socio-demographic, behavioural and biological variables. Forced and Backward selection ($p_{in} = 0.05$, $p_{out} = 0.10$) models were employed. Separate sex-specific analyses were run, specifically to include parity in the female analysis. For multi-variate adiposity analyses TST and SE were used in forced models, while TST, SE, WASO, SFI were entered in selection models.

To analyze the trend across days for objectively-measured sleep indices, the day-by-day data was analysed by fitting a mixed-effects model (Fixed effect, Type III, Restricted Maximum Likelihood), using a compound symmetry covariance matrix. Missing values were considered missing completely at random. The Geisser-Greenhouse correction was adopted throughout. Multiple comparisons tests (Tukey) compared sleep indices across each day. The day-by-day trends of sleep indices were graphed using violin plots (medium smoothing).

Data were analysed using appropriate statistical software (IBM SPSS Statistics: Release 25 IBM Corporation, Armonk NY, 2017 and GraphPad Prism: version 8.3.0, GraphPad Software, La Jolla CA, 2019). Significance for all inferential statistics was set at $p < 0.05$.

Informant consultation

To add contextual detail to the quantitative results, we obtained feedback from DHDSS fieldworkers ($n = 2$) and the community engagement officer through an interview. Key findings were discussed and informants were encouraged to provide feedback, which was captured via notes. After the interview, the notes were distributed for confirmation.

Results

Of the 167 raw data files, 157 had valid data for at least one weekday and one weekend day. Once combined with the questionnaire and body composition data, 145 had complete data. Participants averaged 7.54 (0.61) days of valid data, with 94.3% (7.6) wear time and 5.7% (7.6) of non-wear time. The average number of week days and weekend days with valid data was 5.9 (0.5) and 2.0 (0.2) days, respectively. Except for self-reported PA ($p = 0.002$), there were no significant differences in socio-demographic, behavioural or biological variables between the study participants and the full DHDSS AWI-Gen sample [13].

A total of 1148 sleep periods were recorded, of which 13 (1.1%) fell completely within 06h00-18h00. Four of these sleep periods were recorded by HIV⁺ participants, of which three periods (309–340 minutes, 5–14 awakenings, WASO 28–57 minutes) were recorded by one HIV⁺ male (56 years, 19.2 kg/m²). Only

WASO (55 vs. 49 minutes) and NOA (16 vs. 14 awakenings) were significantly higher in HIV⁺ compared with HIV⁻ participants ($p \leq 0.0404$).

Females were significantly higher in adiposity, prevalence of hypertension, consumed more sugar sweetened beverages ($p \leq 0.0375$), and had significantly higher levels of objectively-measured PA ($p = 0.0007$) (Table 1). No males were obese ($\geq 30 \text{ kg/m}^2$) and significantly more males compared with females, reported current alcohol use ($p < 0.0001$) (Table 1).

[Insert Table 1 here]

Sleep quantity (nocturnal) was significantly higher in females ($p \leq 0.0464$), while sleep quality indices were significantly poorer in females ($p \leq 0.0290$) (Table 2). Males slept more during the day ($p = 0.0290$), were in bed more than 90 minutes earlier than females ($p = 0.0016$) and had significantly more sleep periods starting between 00:01–05:59 ($p = 0.0084$) (Table 2). There was no association between sufficient sleep categories for TST or nocturnal sleep time, and gender or day of the week ($p \geq 0.4904$) (Table 2).

Sleep quality (SFI) was significantly poorer on weekdays ($p = 0.048$) and significantly more sleep periods starting between 00:01–05:59 ($p = 0.0443$) occurred on weekdays (Table 2).

There was no significant association between self-reported TST (Table 1) and objectively-measured TST (Table 2) ($p \geq 0.0568$).

[Insert Table 2 here]

Significantly more nocturnal sleep time was accrued on Tuesday and Wednesday compared with the weekend ($p \leq 0.0409$) (Fig. 1A), and a similar pattern was found for TST (Fig. 1B). Less than 40% of the participants slept 7–9 hours (Fig. 1B). Generally, the NOA and WASO were significantly higher on Tuesday-Wednesday, compared with the Saturday-Monday ($p \leq 0.0451$) (Fig. 1C-D). Activity counts during sleep were significantly higher on Wednesday compared with Saturday ($p = 0.0076$) (Fig. 1E) and 60–70% of participants achieved $\geq 85\%$ SE (Fig. 1F). There was no significant difference across days for diurnal sleep time ($p = 0.3463$), any fragmentation index ($p \geq 0.2828$), or length of awakenings ($p = 0.3463$).

[Insert Fig. 1 here]

Except for TST (forced WC model: $\beta = -0.033$, $p = 0.0453$), sleep indices were not related adiposity measures in multi-variate analyses (Table S1-S2, see Additional file 1). In contrast, current morbidity status, socio-demographic indices and lifestyle factors were significantly associated with adiposity indices (Table S1-S2, see Additional file 1). In female models, parity was not related to adiposity level ($p > 0.05$).

PA was consistently and significantly, inversely associated with TST and SE ($p \leq 0.0077$), while socio-economic and -demographic indices were significantly associated with sleep indices ($p \leq 0.0389$) (Table S3-S4, see Additional file 1). In female models, parity was significantly and directly associated with TST and SE ($p \leq 0.0430$) (Table S4, see Additional file 1).

PA was significantly and directly related to WASO and SFI in forced and backward-selection sleep models ($p \leq 0.0360$).

Discussion

This analysis is novel in that, as far as the authors are aware, this is the first free-living, actigraphy-measured sleep data from a South African setting, and more specifically a rural African setting.

The main findings of this analysis were first that females tended to sleep more than males, although sleep quality tended to be worse in females. Second, sleep variables were generally similar between weekdays and weekend days. Third, only one sleep variable was associated with measures of adiposity, while PA variables were significantly related to adiposity and sleep variables. Fourth, morbidity measures were consistently associated with adiposity and sleep variables.

To date, the average self-reported sleep time for black South Africans (male/female, rural/urban) is ± 9 hours (range: 8-10.4 hours) [3, 5, 7–11, 13]. While some studies have reported gender differences for TST in rural samples (females > males, $p < 0.001$) [3, 13], Peltzer et al. found the reverse (males > females, $p < 0.05$) [7], and others found no gender differences, specifically in urban samples [8, 11]. In contrast, our objective-measure showed lower TST for both genders compared with self-report measures (± 2 hours). In agreement with some self-report studies [3, 13], females recorded more nocturnal sleep time than males ($p = 0.0464$).

Our results for sufficient sleep (46.9%) fell within the range reported for self-report measures (38-64.2%) [3, 5, 6, 9, 27]. In contrast, we found a higher prevalence for short sleep (49.0% vs. 5.7–20.8%) and a lower prevalence for long sleep (4.1% vs. 29.5–54.8%) than self-report measures, respectively [5–7, 9].

Sleep quantity was similar, while sleep quality was better in our study compared with Mozambican settings [12], and quite similar to Sri Lankan adults [32].

Untreated HIV + status was associated with poor sleep quality in rural Africans [3], which is somewhat in agreement with our results.

Sleep variables were not significantly and consistently related to adiposity. Self-report measures have found significant associations between TST and blood pressure [3, 5], insulin resistance [9] and adiposity [8]. In addition, some of the independent variables associated with sleep variables in our study were not in the expected direction and difficult to explain. Hence, the need to collect additional qualitative data (see Additional file 2).

In conclusion, this report presents some of the first objectively-measured, free-living sleep data from a South African setting, and highlights the need to understand the contextual issues around sleep in this rural population.

Limitations

Due to the small sample size and cross-sectional, convenience sampling in this study, the results cannot be readily generalized to the rural populations from whence the participants were recruited, nor can causality be shown.

Abbreviations

AWI-Gen

Africa Wits-INDEPTH partnership for Genomics studies

BMI

body mass index

Conicity Index

CI

DHDSS

Dikgale Health and Demographic Surveillance System

NOA

Number of Awakenings

PA

Physical Activity

SE

Sleep Efficiency

SFI

Sleep Fragmentation Index

TST

Total Sleep Time

WASO

Wake After Sleep Onset

WC

Waist circumference

Declarations

Ethics approval and consent to participate

Ethics approval for the AWI-Gen Phase 1 survey data and the accelerometer data collection was obtained from the Medunsa Research and Ethics Committee of the University of Limpopo

(MREC/HS/195/2014:CR). The participants recruited into the original studies were informed about the study objectives, expected outcomes, benefits and the risks associated with it. Written informed consent was obtained from the participants prior to interviews and measurements.

Availability of data and material

The dataset analysed during the current study is available from the corresponding author on reasonable request.

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Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author's contributions

IC was the principal investigator of the accelerometer data on which this manuscript is based, who initiated the research and obtained funding, co-wrote and edited the research proposal, supervised the data entry, analyzed the data and wrote the first draft manuscript. MM co-wrote and edited the research proposal, collected field data, supervised the field work, performed the data entry, commented on- and contributed to the manuscript. MA was the principal site-investigator of the AWI-Gen Phase 1 study, co-wrote and edited the research proposal, and commented on- and contributed to the manuscript.

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Supplementary Files Legend

Additional File 1: Table_S1-S4.docx

Table S1. Forced multiple linear regression models for anthropometric variables

Table S2. Backward-selection multiple linear regression models for anthropometric variables

Table S3. Forced multiple linear regression models for sleep variables

Table S4. Backward-selection multiple linear regression models for sleep variables

Additional File 2: Informant_Consultation.docx

Qualitative feedback from the Informant consultation interview

Tables

Table 1 Descriptive statistics of demographic, behavioural and biological characteristics by sex				
	All	Female	Male	p-value
	(n=145)	(n=104)	(n=41)	
Socio-demographic				
Age (years)	52.6 (7.0)	52.1 (6.7)	54.1 (7.5)	0.1455
Marital status (Married/Co-habiting) †	55.9 (81)	55.8 (58)	56.1 (23)	0.6342
Level of education (formal education) †	95.2 (138)	95.2 (00)	95.1 (39)	0.9966
Employed (Yes) †	26.2 (38)	26.0 (27)	26.8 (11)	0.9148
SES Quintile	3.6 (1.3)	3.6 (1.3)	3.5 (1.3)	0.5496
Housing density *				
People/room	0.8 (0.8)	0.9 (0.7)	0.7 (0.7)	0.0430
People/bedroom	1.5 (1.3)	1.7 (1.3)	1.3 (1.0)	0.0280
Behavioural				
Diet *				
Fruit and vegetable intake (servings/day)	1.3 (0.9)	1.3 (1.2)	1.1 (0.4)	0.0710
Sugar sweetened beverages (servings/day)	0.3 (0.1)	0.3 (0.1)	0.3 (0.0)	0.0050
Tobacco use (current smoke and/or smokeless; Yes)	48.3 (70)	45.2 (47)	56.1 (23)	0.2366
Alcohol use (current; Yes)	20.0 (29)	8.7 (9)	48.8 (20)	<0.0001
Self-reported Physical Activity *				
MVPA (minutes/week)	990 (968)	1020 (1005)	840 (1170)	0.2740
Self-reported Sleep				
Sleep (hours/night)	9.2 (1.6)	9.1 (1.4)	9.5 (1.8)	0.1924
Weekday sleep (hours/night)	8.9 (1.7)	8.7 (1.5)	9.4 (2.0)	0.0694
Weekend sleep (hours/night)	9.8 (2.2)	9.8 (2.3)	9.7 (1.8)	0.8137
Objectively-measured Physical Activity				
VM counts/day (x 10 ⁶)	2.33 (0.70)	2.47 (0.63)	1.99 (0.76)	0.0007
VM counts/minute	1621 (486)	1715 (435)	1383 (530)	0.0007
Steps per day	14 416 (4637)	14 140 (3718)	15 116 (6411)	0.3645
Step cadence (steps/minute)	10.0 (3.2)	9.8 (2.6)	10.5 (4.5)	0.3652)
Biological				
Waist circumference (cm)	90.0 (1.6)	93.5 (1.6)	81.2 (10.0)	<0.0001
Body mass index (kg/m ²)	28.1 (7.8)	30.6 (7.6)	21.9 (3.9)	<0.0001
Body mass index categories †				
Under- normal weight (<25 kg/m ²)	37.2 (54)	24.1 (25)	70.7 (29)	<0.0001

Overweight (25 – 29.99 kg/m ²)	24.1 (35)	22.1 (23)	29.3 (12)	
Obese (≥30 kg/m ²)	38.6 (56)	53.8 (56)	0.0 (0)	
HIV status (Yes) †	22.1 (32)	21. (22)	24.4 (10)	0.6722
Hypertension (Yes) †	50.3 (73)	55.8 (58)	36.6 (15)	0.0375
Diabetes Mellitus (Yes) †	4.1 (6)	3.8 (4)	4.9 (2)	0.5451
Parity	-	4.2 (1.8)	-	

Data reported as mean (SD), * median (IQR) or † % (n); HIV: Human Immunodeficiency Virus; MVPA: Moderate to Vigorous Physical Activity; SES: Socio-Economic Status; VM: Vector Magnitude

Table 2 Objective measures of sleep quantity and -quality indices across sex and day of the week

	Sex			Day of the week		
	Females (n=104)	Males (n=41)	p- values	Weekday (n=145)	Weekend (n=145)	p- values
Quantity						
Sleep Time (minutes/day)						
Total	458 (67)	454 (105)	0.8175	456 (86)	458 (91)	0.6828
Diurnal *	15 (37)	20 (59)	0.1560	10 (43)	14 (39)	0.6110
Nocturnal	433 (60)	410 (72)	0.0464	427 (70)	427 (76)	0.9380
Nocturnal/Total sleep (%)	95.0 (5.7)	91.6 (9.9)	0.0463	94.4 (7.7)	93.8 (8.9)	0.3553
Diurnal sleep time \geq 1 minute #						
Prevalence †	83.7 (87)	80.5 (33)	0.6495	54.0 (102)	46.0 (87)	0.0645
Duration (minutes) *	56 (71)	69 (73)	0.0290	55 (73)	64 (64)	-
Sleep period starting between 00:01-05:59 †	34.6 (36)	58.5 (24)	0.0084	31.0 (45)	20.7 (30)	0.0443
Sleep period between 06:00-18:00 †	5.8 (6)	9.8 (4)	0.3935	4.1 (6)	4.1 (6)	1.0000
Clock time (hh:mm)						
In bed	19:50 (2:03)	18:14 (2:49)	0.0016	19:19 (2:53)	19:31 (3:40)	0.5725
Out of bed	5:18 (1:10)	5:50 (2:13)	0.1544	5:28 (1:50)	5:29 (1:43)	0.8690
Sleep latency (minutes) *	0.3 (0.7)	0.5 (0.7)	0.9440	0.4 (0.8)	0.3 (1.0)	0.6890
Sufficient sleep categories †						
Total sleep time						
<7 hours/day	33.7 (35)	41.5 (17)	0.6669	35.9 (52)	40.0 (58)	0.7647
7-9 hours/day	51.0 (53)	43.9 (18)		47.6 (69)	44.1 (64)	
>9 hours/day	15.4 (16)	14.6 (6)		16.6 (24)	15.9 (23)	
Nocturnal sleep time						
<7 hours/night	46.2 (48)	56.1 (23)	0.4904	47.6 (69)	44.8 (65)	0.6954
7-9 hours/night	50.0 (52)	39.0 (16)		48.3 (70)	49.0 (71)	
>9 hours/night	3.8 (4)	4.9 (2)		4.1 (6)	6.2 (9)	
Quality						
Wake after sleep onset (minutes)	53 (16)	44 (17)	0.0022	51 (18)	50 (20)	0.8219

Number of awakenings	15 (4)	12 (4)	0.0011	14 (5)	14 (5)	0.9577
Average awakening length (minutes)	3.8 (1.0)	4.1 (1.6)	0.3339	4.0 (1.4)	3.9 (1.5)	0.5015
Sleep efficiency (%)	87.7 (4.2)	89.6 (4.5)	0.0225	88.1 (4.6)	88.4 (4.9)	0.2440
Achieved $\geq 85\%$ †	79.8 (83)	82.9 (34)	0.6683	75.9 (110)	76.6 (111)	0.8903
Within-person sleep time SD (minutes) *	85.1 (48.5)	90.6 (80.9)	0.2480	84.3 (60.8) \$	66.2 (63.2) \$	-
Movement index (%)	15.5 (3.8)	16.6 (3.6)	0.1266	16.0 (4.0)	15.5 (4.4)	0.0617
Fragmentation index (%)	11.0 (4.4)	11.3 (4.2)	0.7219	11.4 (4.7)	10.7 (5.7)	0.1755
Sleep fragmentation index (%)	26.6 (7.1)	27.9 (6.8)	0.2986	27.4 (7.4)	26.2 (8.7)	0.0458
VM average counts	34 847 (12 090)	27 495 (10 686)	0.0006	33 042 (13 162)	31 966 (13 767)	0.2951

Data reported as mean (SD), * median (IQR) or † % (n); # n differs from column totals; \$ n differs from column totals 142 and 141, respectively; Diurnal: 06h00 - 18h00; Nocturnal: 18h01 - 05h59; SD: standard deviation; VM: Vector Magnitude

Figures

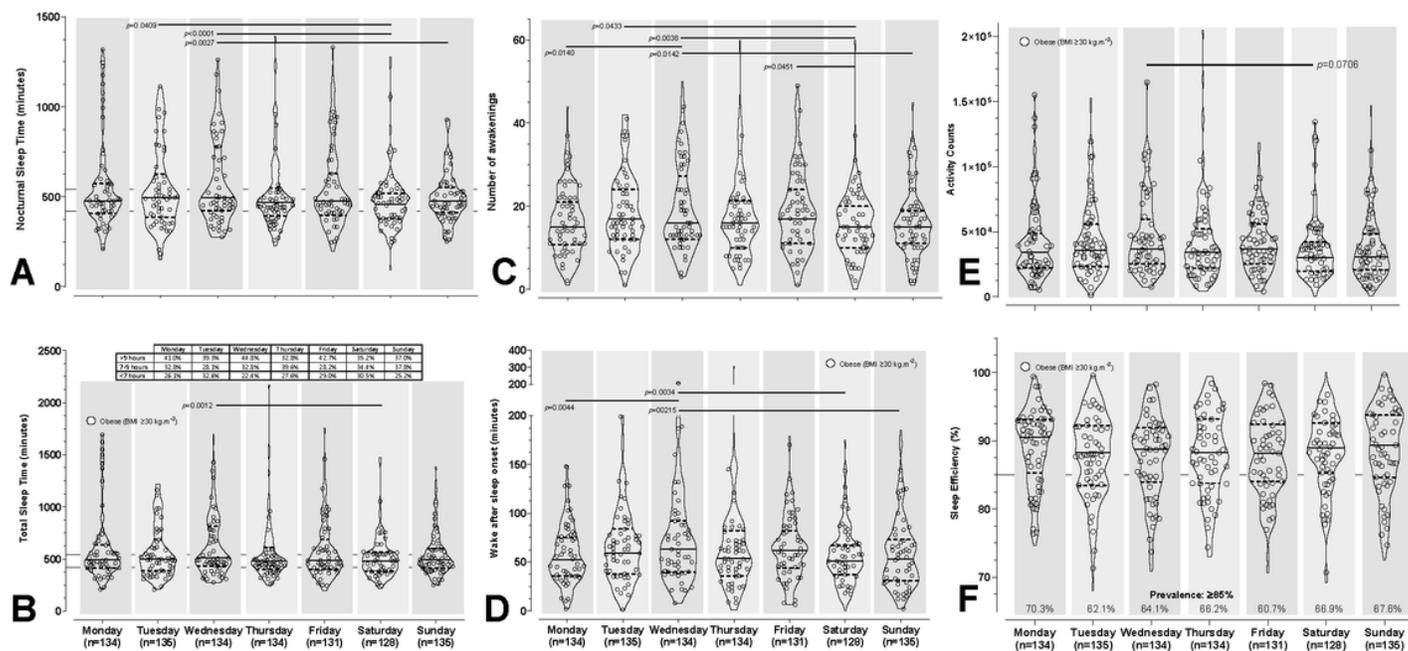


Figure 1

Accelerometry-derived sleep-quantity and -quality measures across days of the week. A. Nocturnal sleep time (minutes); B. Total sleep time (minutes); C. Number of awakenings; D. Wake after sleep onset (minutes); E. Activity counts during sleep time; F. Sleep efficiency (percentage) The horizontal lines above the day of the week indicate significant post hoc differences (Tukey procedure) between days at either end of the line.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [TableS1S4.docx](#)
- [InformantConsultation.docx](#)