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Objectively-measured sleep characteristics and the associated factors among rural and urban in-school Nigerian adolescents

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ABSTRACT

Purpose: Poor sleep is increasing worldwide but sleep studies, using objective measures, are limited in Africa. Thus, we described the actigraphy-measured sleep characteristics of Nigerian in-school adolescents and the differences in these sleep characteristics in rural versus urban-dwelling adolescents using actigraphy plus a sleep diary.

Methods: This comparative, quantitative study involved 170 adolescents aged 13–19 attending six rural and six urban schools in southwestern Nigeria. Participants wore actiwatches and filled sleep diaries concurrently for one week. We ran a mixed model analysis with each sleep characteristic as a dependent variable in each model and the fixed effects of age, weekday versus weekend, rural versus urban residence, sex, and religion.

Results: The adolescents were 54.1 % females with a mean age of 15.6 ± 1.3 years. Overall, adolescents' mean bedtime was 22.50 ± 0.85, mean waketime was 5.73 ± 0.68 and mean total sleep time (TST) was 06.07 ± 0.95 h. On both weekdays and weekends, urban adolescents had significantly later bedtimes, earlier waketimes, shorter time-in-bed (TIB) and TST (all $p < 0.05$) while rural adolescents had lower sleep efficiency, more frequent awakenings and WASO (all $p < 0.05$). In mixed-model analyses, older adolescents had later bedtimes ($p = 0.035$) and shorter TST ($p = 0.047$), urban adolescents had later bedtimes, earlier wake times, shorter TIB and TST than rural adolescents (all $p < 0.05$), and on weekdays, all adolescents had earlier bedtimes, waketimes, shorter TIB and TST than on weekends (all $p < 0.05$).

Conclusion: Adolescents, especially the urban ones, had insufficient sleep with a catch-up-sleep on weekends. Multipronged interventions, including controlling causes of late bedtimes and delaying school start-times are needed to improve sleep, especially among older and urban adolescents.

1. Background

Poor sleep is widely recognized as an important cause of morbidity. Short sleep duration has been associated with such morbidities as adverse physical health and behavioural problems among adolescents in high-income countries. [1–3]. Other sleep characteristics such as sleep quality, daytime sleepiness, sleep apnoea and regularity have also been well-studied in high-income settings using objective sleep measures. Though some reports on adolescent sleep exist in the African setting, most of these studies utilized retrospective sleep questionnaires. [4,5]. Furthermore, these studies utilized different forms of sleep questionnaires which may not always have the same validity/cultural sensitivity for the African populations.

While sleep questionnaires are quite useful for the collection of large population data, studies in the field of adolescent sleep health have utilized a wide variety of methodologies. These diverse sleep measures have different strengths and weaknesses based on the ease of utilization, cost, availability, duration of use required, level of expertise needed for their administration, and the reliability of the data obtained. The use of questionnaires in sleep research helps to capture a large population of

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respondents for cross-sectional studies [6–8] but entails a retrospective recollection of sleep-wake rhythms with a likely recall bias. The data derived from studies in high-income countries, suggests that information from sleep questionnaires is not as reliable as data obtained when objective measures are utilized. [6]. These more reliable measures include the use of actigraphy and/or polysomnography. [6,9]. Though the PSG provides accurate and reliable measures of sleep architecture, it has the disadvantage of not being feasible for large population studies and its conduct outside the natural sleep environment may make the measured sleep-wake rhythms of a once-off night atypical.

Actigraphy involves the use of actiwatch, a wristwatch-like device to measure sleep-wake rhythm, together with sleep diaries. [10,11]. It provides a prospective and objective measurement of sleep characteristics in the home setting, usually over a three to fourteen-day period. Hence, the use of sleep questionnaires is useful and feasible for large population studies. Nevertheless, objective sleep measures using actigraphy or polysomnography provide stronger evidence for both research and clinical decisions. In Nigeria, there are a few questionnaire-based reports of sleep insufficiency and poor sleep quality in adolescents, especially in the last decade. [12–16]. None of the sleep studies conducted in Nigerian adolescents utilized sleep diaries, actigraphy or polysomnography. Hence there is a need for an objective measurement of the sleep characteristics of Nigerian adolescents.

The sociodemographic factors associated with adolescent sleep health need to be more explored. Studies done among African adolescents have shown conflicting findings on the effect of individual and societal factors on adolescents' sleep health. While some studies have reported a lack of sex difference in sleep health [13,17], some have found poorer sleep among boys [12,18], and a few others reported a shorter sleep duration [19] and higher nighttime awakenings among girls than boys. [20]. The sleep duration and quality of adolescents have been reported to worsen as their age increases. [21]. Adolescents tend to have later bedtimes with increasing age with resultant shorter sleep duration as they have to wake up early to meet school demands. [22]. Among African adolescents, many studies have found similar worsening of sleep health as adolescents' age increases [12,13,23,24], though a few studies have reported a lack of association between age and sleep characteristics [25,26] as well as short sleep duration among younger adolescents compared to older ones. [27]. Hence, there is a need for further studies to improve the understanding of the individual factors affecting adolescent sleep health.

There are very few studies on the association between religion and sleep health. [28]. Types of religious affiliations and the belief system associated with religion have been shown to have an association with sleep but the direction of the association is yet to be well understood. [28,29]. Studies have found that religious beliefs could act as stress moderators which may either enhance [30,31] or impede [29] good sleep health. However, most of the available studies have been in adult populations. A qualitative study among Muslim and Jewish participants in Israel reported early wake times and short sleep duration due to the need to rise for morning prayers. [31]. Similar findings were reported among Muslim adolescents compared to Christian adolescents in a quantitative study in Côte d'Ivoire. [23]. In the United States, Catholics and Baptists were reported to have a shorter sleep duration than atheists. [29].

Another important societal aspect is the rural-urban disparities in sleep health which have been shown among African adolescents in general. [23,24]. We also reported this rural-urban disparity among Nigerian adolescents in our previous study using sleep questionnaires. [26]. These rural-urban disparities in adolescent sleep health have been reported in other climes. [32–34]. Pereira et al., [35] in a study among in-school rural adolescents in southern Brazil, found that among rural populations, adolescents without access to electricity had longer sleep duration. Their findings support the evidence that the transition from ancestral (pre-industrial) lifestyle to industrialised communities with artificial light exposure may contribute to short sleep duration in urbanised societies. [36]. In Nigeria, we have reported earlier bedtimes among rural adolescents compared to urban adolescents using sleep questionnaires and posited that this may be due to the poor electricity access in rural communities compared to urban communities. [26]. Furthermore, rural adolescents may have to perform chores or do early farm work that may contribute to late bedtimes, and/or early wake times and short sleep duration. [35]. Hence, we hypothesize that a difference may exist in the sleep health of rural adolescents when compared with the urban communities.

Finally, adolescents have been reported to have catch-up sleep over the weekends compared to weekdays [12,22], with their weekday sleep duration often shortened by various school-related demands. [12,37]. With the use of objective sleep measures in the current study, we hope to better understand those societal factors affecting adolescent sleep health. Therefore, our study aimed to answer the research questions: what are the actigraphy-measured sleep characteristics of Nigerian in-school adolescents in Nigeria and the differences in these sleep characteristics in rural versus urban communities?

2. Methods

This study utilized a quantitative approach with a cross-sectional design. It was conducted on a subset of the adolescents involved in an earlier study on the multi-dimensions of sleep health among rural versus urban adolescents. [26]. This study was conducted between September 2022 and June 2023.

2.1. Study setting

The study was conducted in the Osun East Senatorial District, Osun State Nigeria. The state is situated between latitude 7° 30′ 0″ N and longitude 4° 30′ 0″ E. [38]. Ile-Ife, the urban community is located from 275 m to 300 m above sea level. [39]. Hence, it is located very close to the equator and is not subject to significant seasonal changes in photoperiod that can affect the circadian rhythms of the inhabitants. The study is in seven communities within the Senatorial District. These communities have similar ethnic and religious characteristics. The rural communities comprised more people in the low and middle social classes while there were more people in the middle and high social classes residing in the urban community as described in our previous publication. [26]. Also, the rural communities have fewer social amenities and electricity access than the urban community, similar to other rural and urban areas in Nigeria where the electricity access rate in urban communities is 83.9 % compared to 24.6 % in rural communities. [40]. We selected these communities from the three local governments that are close geographically so that the main difference in the populations will be solely based on the rural versus urban features of the communities.

2.2. Study population

A sample was recruited from the 900 adolescents who participated in the initial phase of the study. [26]. These participants were required to wear actigraphy-recording devices for a 7-day duration to give an objective measure of their sleep characteristics. At the same time, these adolescents were required to keep a diary of their sleep habits. The research assistants gave daily reminders to the adolescents through home visits or phone calls to ascertain that the actigraphs were consistently worn.

2.3. Ethical considerations

The ethical approval for the study was obtained from the Health and Research Ethics Committee of the University of Witwatersrand (M210745) and the Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria (IPHOAU/12/1850. Written informed consent was obtained from each parent of the adolescent while assent was obtained from the respective adolescents. The purpose of the study, its benefits, and any likely risks were explained to the participants. Also, it was clearly stated that their participation was voluntary and that they could stop their participation at any time during the study with no consequences for them. They were informed about the ways confidentiality was ensured and the likely uses of the data generated.

2.4. Data collection

The sociodemographic characteristics of the adolescents were obtained via a previously pilot-tested questionnaire which contained questions on the age, sex, place of residence, religion and nature of the school of the adolescents.

2.4.1. Actigraphy

We used the Condor ActTrust 2, which measures and monitors activity and light exposure. The participants were given an actiwatch in the school at the beginning of the study. After adolescents had worn the actiwatch for 7 days, we downloaded the data and analysed them using the ActStudio Version 1.0.6.0 Model AT0503. We also extracted the sleep data using the Cole Kripke algorithm. Participants simultaneously received a printed sleep diary to record their daily sleep-wake schedule over the 7 days. A standard operating procedure (SOP) was used for the data collection with actiwatches and the sleep scoring with the ActStudio software and sleep diaries. The definition of rest interval was based on the procedure described by Chow et al. [41] The analysis of the actigraphy recordings focused on the main sleep episodes. As we scrutinized the actigraphy files, we noticed a few episodes of possible naps (secondary sleep episodes) but we could not distinguish them from periods of low activity as the adolescents very rarely reported those potential secondary sleep episodes in their sleep diaries. Thus, we did not attempt to analyze naps in this study. The actigraphy device recorded the days that participants used the device and we included at least one weekend night in those minimum of 3 days of actigraphy data useable. Most of our data had five –to -six days of data used. Friday nights and Saturday nights were coded as weekend nights. Thus, we excluded all those who had weekday recordings only.

2.4.2. Sleep variables

From the actigraphs, after cleaning the sleep onset and sleep offset times using the sleep diaries, we used the Cole-Kripke algorithm embedded within the ActStudio version 1.0.6.0 software to extract the following sleep characteristics: bedtime (BT), wake time (WT), time in bed (TIB), total sleep time (TST), sleep onset latency (SOL), sleep efficiency (SE), wake after sleep onset (WASO) and number of awakenings.

2.5. Data management and analysis

Data analysis was conducted with the Stata SE 15.1 software. We presented the description of sociodemographic characteristics using frequencies and percentages and compared the rural-urban differences in these characteristics using the Chi-square test for categorical variables and the independent *t*-test for the continuous variables. The paired *t*-test was used to compare the sleep characteristics obtained over the weekdays from weekends.

We ran mixed model analyses where we included each sleep variable (as described above) as a dependent variable in each model and we added the fixed effects of age, time of week (weekday vs weekend; with weekend including the nights from Friday to Saturday and from Saturday to Sunday while all other nights were considered weekdays), rural versus urban residence, sex, and religion.

3. Results

We recruited 244 adolescents (among the initial larger study involving 900 participants) [26] for the study to wear actiwatches for a 7-day period. We excluded from the analysis 13 adolescents who did not use the actiwatches correctly and 61 adolescents who used the actiwatches for $\leq$3 days. In the end, we included in the analysis of this sub-study the 170 participants with useable data.

Among the 170 adolescents analysed, there was no statistically significant difference in sex distribution, though there was a female preponderance (54.12 %) in the total cohort. The mean age of the respondents was 15.55 $\pm$ 1.34 years. The rural-dwelling adolescents had a significantly older mean age (15.75 $\pm$ 1.33 years) than their urban-dwelling (15.33 $\pm$ 1.33 years) counterparts ($p < 0.001$). Furthermore, two-thirds of the adolescents (68.24 %) were in the middle adolescent age group for the overall population. There was no statistically significant difference in the age category between urban and rural adolescents. There was a higher number of adolescents attending public schools among rural adolescents ($p < 0.001$). The majority of the adolescents were Christians, and there was no statistically significant difference in the distribution of religion among the adolescents in both rural and urban schools. The other details on the sociodemographic characteristics of the adolescents were provided in Table 1.

3.1. Sleep characteristics of the adolescents in rural versus urban communities as measured by actigraphy

According to Table 2, the mean bedtime of the urban adolescents

Table 1
Socio-demographic characteristics of the respondents.

Sociodemographic characteristics	Rural (N = 91) N (%)	Urban (N = 79) N (%)	Overall (N = 170) N (%)	Statistics
Sex				
Female	44 (48.35)	48 (60.76)	92(54.12)	$\chi2 = 2.622$ $p = 0.105$*
Male	47 (51.65.)	31 (39.24)	78(45.88)	
Age in years				
Mean age (mean ± SD)	15.75 ± 1.33	15.33 ± 1.33	15.55 ± 1.33	t = 6.06 ***p*=<0.042**
Age categories				
13–14 (early adolescence)	16 (17.58)	24 (30.38)	40(23.53)	$\chi2 = 3.851$ $p = 0.146$*
15–17 (middle adolescence)	67 (73.63)	49 (62.03)	116 (68.24)	
18–19 (late adolescence)	8(8.79)	6(7.59)	14(8.24)	
Religion (n=165#)				
Christianity	79 (91.86)	75 (94.94)	154 (93.33)	$\chi2 = 11.822$ $p = 0.429$
Islam	7(8.14)	4(5.06)	11(6.67)	
Social class				
Upper	3(3.30)	17 (21.52)	20(11.76)	$\chi2 = 9.2291$ p < **0.001***
Middle	28 (30.77)	40 (50.63)	68(40.00)	
Lower	60 (65.93)	22 (27.85)	82(48.24)	
Nature of School				
Public	76 (83.52)	21 (26.58)	97(57.06)	$\chi2 = 55.946$ p=<**0.001***
Private	15 (16.48)	58 (73.42)	73(42.94)	
Class in school				
JSS1-JSS3	6(6.59)	1(1.27)	7(4.12)	$\chi2 = 3.040$ $p = 0.081$
SSS1-SSS2	85 (93.41)	78 (98.73)	163 (95.88)	

Table 2
Rural-urban difference in the mean sleep characteristics for the entire study period.

Sleep variables	Rural Mean ± SD	Urban Mean ± SD	t^a/p
Bedtime	22.41 ± 0.85	22.73 ± 0.82	t = −2.536 **p=0.012**
Wake time	5.89 ± 0.58	5.54 ± 0.74	t=3.460 p=**0.001**
Time-in-bed	7.49 ±0 .99	6.81 ± 1.02	t = 4.383 p=**<0.001**
Total sleep Time	6.26 ± 1.01	5.85 ± 0.84	t = 2.919 **p=0.004**
Sleep efficiency (%)	84 ± 8	86 ± 6	t = −2.426 **p=0.016**
SOL	0.10 ± 0.07	0.08 ± 0.10	t = 1.247 p = 0.214
WASO	1.08 ± 0.57	0.85 ± 0.74	t = 2.815 **p=0.005**
Awakenings (n/night)	12 ± 5	10 ± 5	t = 2.554 **p=0.012**

All time variables are in decimal hours.
[a] unpaired *t*-test.

(22.73 ± 0.82) was later than the rural adolescents (22.41 ± 0.85) (p = 0.012). Also, the urban adolescents had an earlier mean waketime (5.54 ± 0.74) than their rural counterparts (5.89 ± 0.58) (p = 0.001). Furthermore, this study showed a shorter actigraphy-measured mean TST (5.85 ± 0.84 h) among urban adolescents compared to rural adolescents (6.26 ± 1.01 h) (p < 0.001). Similarly, the urban adolescents had a lower actigraphy-measured mean TIB (6.81 ± 1.02 h) than their rural counterparts (7.49 ± 0.99 h) (p = 0.004). Conversely, the mean sleep efficiency of the urban adolescents (86 ± 6 %) was significantly higher than that of the rural adolescents (84 ± 8 %) (p = 0.016). The rural adolescents had higher mean wake-after-sleep-onset (WASO) and frequency of awakening than their urban counterparts (p = 0.005 and 0.012).

3.2. Weekday-weekend difference in the sleep characteristics of the overall participants as measured by actigraphy (See Table 3)

Our study showed an overall significantly shorter actigraphy-measured mean TST (5.97 ± 0.94 h) on weekdays compared to weekends (6.26 ± 1.39 h) (p = 0.028). The mean bedtime was earlier on weekdays (22.50 ± 2.89) than on weekends (22.73 ± 1.18) (p = 0.048). Similarly, the adolescents had earlier mean wake times on weekdays (5.58 ± 0.65) than at weekends (6.09 ± 1.04) (p < 0.001). The mean TIB of 7.08 ± 1.08 h obtained on weekdays was shorter than the mean of 7.36 ± 1.52 h on weekends (p < 0.045). In summary, the adolescents had significantly later mean bedtimes, earlier mean wake times, significantly shorter mean TIB and shorter TST on weekdays. The other sleep characteristics were not significantly different among the adolescents on weekdays versus weekends. Using actigraphy, the mean bedtime of all the adolescents for the entire days of the study was 22.62 ± 1.05, while their mean wake time was 5.84 ± 0.90 and the mean TST was 6.11 ± 1.20 h.

Table 3
Difference in mean sleep characteristics of the whole sample between weekdays and weekends as measured with actigraphy.

Sleep variables	Weekend Mean ± SD	Weekday Mean ± SD	Overall Mean ± SD	t^a/p
Bedtime	22.73 ± 1.18	22.50 ± 0.89	22.62 ± 1.05	t = 1.988 **p=0.048**
Wake time	6.09 ± 1.04	5.58 ± 0.65	5.84 ± 0.90	t=5.170 p=**<0.001**
Time in bed	7.36 ± 1.52	7.08 ± 1.08	7.22 ± 1.33	t = 2.015 **p=0.045**
Total sleep Time	6.26 ± 1.39	5.97 ± 0.94	6.11 ± 1.20	t = 2.201 p=**0.028**
Sleep efficiency (%)	85 ± 9	85 ± 7	85 ± 8	t = 0.328 p = 0.743
SOL	0.08 ± 0.10	0.09 ± 0.11	0.09 ± 0.10	t = −1.322 p = 0.187
WASO	0.98 ± 0.64	0.97 ± 0.54	0.97 ± 0.59	t = 0.142 p = 0.661
Awakenings (n/night)	11 ± 7	11 ± 5	11 ± 6	t = 0.309 p = 0.757

All time variables are in decimal hours.
[a] Paired *t*-test.

3.3. Weekday-weekend difference in the sleep characteristics of the adolescents in rural versus urban communities as measured by actigraphy (See Table 4)

On weekdays, the urban adolescents had significantly later mean bedtimes, than the rural adolescents (p = 0.019) (see Table 4). Also, they presented earlier mean wake times, shorter mean TIB and shorter TST (all $p < 0.001$). On the other hand, rural adolescents had more frequent awakenings than their urban counterparts on weekdays (p = 0.006).

On weekends, the mean TIB of the urban adolescents was significantly shorter than that of the rural adolescents (p = 005), while the rural adolescents had significantly lower sleep efficiency ($p = 0.005$), higher wake-after-sleep onset (WASO) ($p = 0.004$), and a higher mean frequency of awakening ($p = 0.004$) than the urban adolescents. Mean bedtimes, mean wake times, mean TST, and sleep onset latency, were not different in urban vs. rural adolescents.

3.4. Multivariable analysis of the factors associated with sleep characteristics of rural vs urban adolescents (see Table 5)

Using the mixed-model analysis to determine the factors associated with sleep characteristics of rural versus urban adolescents, we found

Table 4
Rural-urban difference in mean sleep characteristics on weekdays and weekends.

Sleep variables	Rural (n = 91) Mean ± SD	Urban (n = 79) Mean ± SD	Overall (n = 170) Mean ± SD	P value
Weekdays				
Bedtime	22.36 ± 0.84	22.67 ± 0.10	22.50 ± 0.89	***p*= 0.019**
Wake time	5.75 ± 0.56	5.38 ± 0.70	5.58 ± 0.65	***p*<0.001***
Time in bed	7.39 ± 0.96	6.71 ± 1.11	7.07 ± 1.08	***p*<0.001***
Total sleep Time	6.21 ± 0.93	5.71 ± 0.89	5.97 ± 0.94	***p*<0.001***
Sleep efficiency (%)	84.18 ± 7.46	85.73 ± 6.83	84.90 ± 7.19	$p = 0.163$
Sleep onset latency	0.10 ± 0.08	0.09 ± 0.06	0.09 ± 0.08	$p = 0.687$
WASO	1.04 ± 0.56	0.88 ± 0.51	0.97 ± 0.54	$p = 0.051$
Awakenings (n/night)	12.19 ± 5.34	10.01 ± 4.63	11.18 ± 5.13	***p*=0.006***
Weekend days				
Bedtime	22.56 ± 1.19	22.92 ± 1.15	22.73 ± 1.18	$p = 0.053$
Wake time	6.23 ± 0.92	5.93 ± 1.14	6.09 ± 1.04	$p = 0.063$
Time in bed	7.67 ± 1.52	7.02 ± 1.46	7.36 ± 1.52	***p*=0.005**
Total sleep time	6.41 ± 1.51	6.08 ± 1.22	6.26 ± 1.39	$p = 0.129$
Sleep efficiency (%)	83.45 ± 9.48	87.18 ± 7.22	85.19 ± 15.56	***p*=0.005**
Sleep onset latency	0.09 ± 0.11	0.07 ± 0.08	0.98 ± 0.10	$p = 0.174$
WASO	1.11 ± 0.68	0.82 ± 0.56	0.98 ± 0.64	***p*=0.004**
Awakenings (n/night)	12.34 ± 6.77	10.27 ± 6.07	11.38 ± 6.52	***p*=0.004**

WASO: wake after sleep onset; unpaired t-tests were run to compare the rural and the urban adolescents; all time variables are in decimal hours.

Table 5
Factors associated with sleep characteristics of rural versus urban adolescents using mixed-models analysis.

Dependent variable → Independent variables↓	Bedtime Beta estimate (adjusted) 95%CI	P-value	Wake time Beta estimate (adjusted) 95%CI	P-value	TIB Beta estimate (adjusted) 95%CI	P-value	TST Beta estimate (adjusted) 95%CI	P-value	SOL Beta estimate (adjusted) 95%CI	P-value	SE Beta estimate (adjusted) 95%CI	P-value	WASO Beta estimate (adjusted) 95%CI	P-value	[a] Awak. Beta estimate (adjusted) 95%CI	P-value
Age in years	0.10 0.01, 0.19	**0.035**	−0.01 −0.09, 0.07	0.798	−0.11 −0.23, 0.01	0.054	−0.11 −0.21, −0.01	**0.047**	−0.01 −0.01, 0.01	0.478	−0.11 −0.93, 0.70	0.784	−0.01 −0.06, 0.06	0.962	−0.28 −0.86,0.30	0.349
Weekday-Weekend	−0.23 −0.38, −0.08	**0.003**	−0.52 −0.63, −0.41	**<0.001**	−0.29 −0.47, −0.12 0.41	**0.001**	−0.28 −0.43, −0.11	**0.001**	0.02 −0.01, 0.05	0.153	−0.09 −1.08, 0.89	0.853	−0.02 −0.10, 0.05	0.512	−0.74 −1.38,-0.10	**0.023**
Residence (urban-rural)	0.34 0.08, 0.60	**0.010**	−0.32 −0.53, −0.12S	**0.002**	−0.66 −0.97, −0.35	**<0.001**	−0.39 −0.67, −0.11	**0.007**	−0.02 −0.05, 0.01	0.176	2.76 0.55, 4.98	**0.014**	−0.24 −0.40, −0.07	**0.005**	−2.24 −3.80,-0.65	**0.006**
Sex (Male-Female)	−0.02 −0.27, 0.24	0.891	0.17 −0.03, 0.36	0.102	0.18 −0.12, 0.49	0.237	0.24 −0.42, 0.51	0.096	−0.01 −0.03, 0.02	0.687	0.57 −1.56, 2.69	0.600	−0.02 −0.18, 0.14	0.832	−0.05 −1.55, 1.44	0.946
Religion (Christianity/Islam)	−0.08 −0.41, −0.01	0.751	−0.03 −0.40, −0.36	0.891	−0.11 −0.69, 0.48	0.721	0.02 −0.51, 0.55	0.943	0.01 −0.05, 0.06	0.798	1.85 −2.29, 5.98	0.382	−0.13 −0.45. 0.17	0.377	−1.38 −4.32, 1.55	0.356

TIB: Time in Bed; TST: Total sleep time, SOL: sleep onset latency, SE: sleep efficiency, WASO: wake after sleep onset.
Beta estimates for bedtime, waketime, time in bed, total sleep time, sleep onset latency and wake after sleep onset show decimal time, with −0.23 weekday compared to WE in bedtime meaning that all participants on average woke up 0.23x60 = 13.8 min earlier on weekdays compared to weekends.
All models were run using mixed model analysis specifying a normal distribution, except for the number of awakenings where we specified a Poisson distribution.
[a] Awak.: number of awakenings per night.

that the adolescents' sleep characteristics differed significantly based on their age, weekday versus weekend period and place of residence, but not their sex or religion Table 5. The older adolescents had later bedtimes ($p = 0.035$) and shorter TST ($p = 0.047$) than the younger adolescents. In those adjusted analyses, on weekdays, adolescents had earlier bedtimes ($p = 0.003$), earlier wake times ($p=<0.001$), shorter TIB ($p = 0.001$), and shorter TST ($p = 0.001$) compared to weekends. Furthermore, the urban adolescents had later bedtimes ($p = 0.010$), earlier wake times ($p = 0.002$), shorter TIB ($p < 0.001$) and TST ($p = 0.007$) compared to rural adolescents. On the other hand, the rural adolescents had significantly lower sleep efficiency ($p = 0.014$), higher WASO ($p = 0.005$) and more frequent awakenings ($p = 0.006$) than urban adolescents. There were no significant differences in the adolescent sleep characteristics by sex or religion.

4. Discussion

This study provides data on the sleep characteristics of 170 rural and urban in-school Nigerian adolescents using actigraphy recordings. Overall, the adolescents had a short TST (sleep duration) of about 6 h (Table 3) which is significantly lower than the recommended duration. [42]. Also, their age, place of residence and weekday versus weekend measurements showed statistically significant associations with the sleep characteristics measured. The older adolescents had later bedtimes, similar wake times and shorter TIB and TST than the younger adolescents. On weekdays compared to weekends, adolescents had earlier bedtimes, earlier wake times shorter TIB and TST. Furthermore, urban adolescents had later bedtimes, earlier wake times, and shorter TIB and TST compared to rural adolescents. On the other hand, rural adolescents had significantly lower sleep efficiency and higher wake after sleep onset than urban adolescents.

The adolescents studied had short sleep duration irrespective of their place of residence. As shown in Table 3, the overall mean sleep duration obtained by these adolescents was about 6 h which is significantly below the recommended 8.5–9.3 h. [42]. This short sleep duration is due to their late bedtimes and early wake times. While the late bedtime is in keeping with the tendency to sleep late due to physiological phase delay during adolescence, their wake time is early rather than late. The early wake time may be due to school and societal pressures, as reported in other settings. [42–44]. It is therefore important to understand the factors associated with the adolescent's sleep deprivation to develop appropriate interventions.

4.1. Adolescent sleep characteristics and age

We found that older adolescents had significantly later bedtimes and shorter sleep duration than their younger counterparts. The mean TST of 6.1 ± 1.2 h obtained for the overall population worsens as the age of the adolescent increases with a mean of 6.2 ± 1.4 h for early adolescents, 6.1 ± 1.5 h for middle adolescents and 6.0 ± 1.6 h for late adolescence. On weekdays, the mean TST was 6.0 ± 0.8 h for early adolescents, 6.0 ± 1.0 h for middle adolescents and 5.8 ± 1.0 h for late adolescence. The shorter sleep duration observed in these older adolescents concurs with previous findings of shorter sleep duration among older adolescents in our setting using sleep questionnaires. [12]. Being in the early adolescent age group was reported to be an independent predictor of sufficient sleep on weekends. [12]. Similar findings have been reported in other societies. [42,45]. The biological changes which begin at the onset of puberty and progress as the age of the adolescent increases are associated with progressively larger delayed sleep phase. [45,46]. In our study, bedtime was more delayed as the age of the adolescent increased, which aligns with previous findings. [46]. In addition to the biological explanations for delayed bedtimes in older adolescents, individual and social factors may also be contributory. Electronic device use at night has been associated with delayed bedtimes and short sleep duration. [12,44]. It is possible that older adolescents are more likely to use electronic devices at bedtime than younger adolescents. Furthermore, the older the adolescent is, the lower the parental supervision of their bedtime and overall sleep schedule. [45]. In an earlier study, we found that parental supervision of bedtimes showed a significant association with better sleep health. [26]. In addition, the academic demands, after-school classes and homework burden of older adolescents may be more than that of younger adolescents and may likely contribute to a further delay in their bedtimes. [45]. While bedtimes were more delayed with older age, we did not find more delay in the wake times with age, which may be due to fixed school start times. Thus the combination of delayed bedtimes and inability to delay wake times resulted in shorter sleep opportunities and duration with older age. This suggests that a simple intervention such as delaying school start times may help increase sleep duration during adolescence, as elsewhere in the world. [47,48].

4.2. Weekday versus weekend differences in adolescent sleep characteristics

The actigraphy measure of the adolescents' sleep characteristics provided an objective differentiation of weekend versus weekday values. The significantly later wake times of the adolescents on weekends support the previous reports of a tendency for adolescents to have catch-up sleep on weekends. [49]. This is attributed to insufficient sleep on school days such that the adolescents utilize the sleep opportunity provided by a free weekend to pay back the previous sleep debt. As shown in Table 3, the adolescents had a shorter sleep duration on weekdays compared to weekends, supporting the reasons for a tendency to catch up on lost sleep hours on weekdays. Also, the adolescents' later bedtime on weekends suggests that the adolescents tended to sleep according to their physiologic sleep drive and phase delay when the pressure of school demands is removed. The study population were drawn from both private and public secondary schools in the rural and urban communities, though the rural communities had mainly public schools (5 out of 6 schools). Generally, the schools had similar start times but varying school closing times. [26]. The school period in the secondary schools runs from 7:45 a.m. for public schools and 7:30–7:45 a.m. for private schools. The public schools typically close at 2:00 p.m. while the private schools close from 4:00 p.m. to 6:00 p.m. for most private schools. [12]. It is also possible that they tended to sleep late on weekends because of their increased use of electronic devices. However, there was no statistically significant difference in the weekday versus weekend SE, SOL, WASO and number of awakenings. Despite evidence for catch-up sleep on weekends by delaying wake times, the sleep duration on weekends remained under the recommended 8.5 h for adolescents.

4.3. Rural versus urban differences in actigraphy-measured adolescent sleep characteristics

This study showed later bedtimes among urban adolescents compared to their rural counterparts when investigated in multivariable analyses. Also, urban adolescents had earlier wake times and shorter sleep duration than their rural counterparts. Thus, urban adolescents had poorer sleep characteristics than their rural counterparts. The likely factors contributing to the poor sleep characteristics among urban adolescents include exposure to artificial light at night (ALAN) due to electricity supply which may not be available in rural settings. [50]. Furthermore, urban adolescents are likely to use electronic devices at bedtime which further causes a shift in bedtime. [51]. In a previous paper [26], we found no significant difference in the school start time of rural versus urban adolescents but we found a difference in the school end times, with the urban adolescents closing later ($p = 0.021$). Also, every later hour in the school end (closing) time showed a 1-fold increase in the odds of having poor sleep quality and excessive daytime sleepiness. [26]. Interventions targeting urban adolescents will need to explore further the factors contributing to their sleep health at home and in school.

Conversely, the rural adolescents in the present study had a lower sleep efficiency and a higher WASO. The urban adolescents likely had lower WASO and lower number of awakenings than rural adolescents due to the higher homeostatic sleep pressure built across time. According to the two-process model (Borbely et al., 1982), higher sleep pressure due to larger time spent awake in the 24-h day would lead to a higher amount of slow wave sleep during the sleep episode, which in turn would make waking during sleep less likely. Conversely the relatively lower sleep pressure in rural adolescents, in particular on weekends, may translate into a lower amount of slow wave sleep, which in turn may make awakenings from external signals more likely. From a previous study, we found that a bit more than two-thirds of the adolescents living in rural settings in this region of Nigeria were from a low social class [26], so their sleeping environment may be poorer than that of urban adolescents. Sleeping in poor sleeping environments may lead to a higher number of awakenings and WASO, and thus impair their sleep efficiency. Poor sleeping conditions as well as living in a disadvantaged neighbourhood have been reported to contribute to poor sleep health. [52,53]. Thus, the external signals which can interrupt sleep may be more frequently encountered in rural adolescents' environments than in urban adolescents' environments. In rural Nigeria, poor heat control in rural dwellings, the presence of mosquitoes, and overcrowding may all contribute to sleep disruption. It is also possible that urban adolescents may have more access to air conditioning which would both help with heat control and lower amount of mosquitoes that can disrupt sleep. Interventions focused on improving adolescent sleep must reduce factors contributing to later bedtimes and earlier wake times among urban adolescents while targeting improving sleep efficiency among rural adolescents.

4.4. Strengths and Limitations

This study is the first, to the best of the investigators' knowledge, to compare actigraphy-measured sleep characteristics among urban and rural African adolescents. The scoring of the actigraphy data with a concurrent sleep diary recording further strengthens the quality of the data. However, 74 of the 244 adolescents did not use the actigraphs correctly or for enough number of days within the 7-day period. As a result, only the 170 adolescents who used the actigraphs correctly for at least 4 days were included in the final analysis. We explored the reasons for poor use of the actigraphs among adolescents who did not use the actigraphs correctly. We found that some forgot to wear the actigraphs after bathing or washing, some were sceptical of the safety of the watch especially because the "black colour" of the actiwatch was associated with "evil", while one adolescent stopped using the actiwatch because she had allergic dermatitis after wearing it for a few days. Future studies involving the use of actiwatches in our setting will need to counsel adolescents and their parents on their safety and possibly exclude those with allergic skin conditions. In addition, we did not analyze naps due to the challenges reported in the methods section, but we recommend the use of phone recalls to document daily nap periods to aid analysis of secondary sleep episodes.

5. Conclusions

Objective measurement of adolescent sleep characteristics showed significant insufficient sleep duration and poor sleep efficiency. Among urban adolescents, insufficient sleep was mainly from delayed bedtimes and early wake times with a catch-up sleep on weekends, similar to reports in other climes. Adolescents in rural settings had lower sleep efficiency which also needs to be explored to understand the contributors and provide the appropriate interventions. Multipronged interventions are needed to improve sleep health, especially among older adolescents in urban communities.

CRediT authorship contribution statement

Oluwatosin Eunice Olorunmoteni: Writing – review & editing, Writing – original draft, Visualization, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Adesegun O. Fatusi:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Conceptualization. **F Xavier Gómez-Olivé:** Writing – review & editing, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Conceptualization. **Karine Scheuermaier:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Formal analysis, Data curation, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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