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Objective sleep in pregnant women: a comparison of actigraphy and polysomnography

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Abstract

Objectives: To compare different actigraphy scoring settings with polysomnography (PSG) for 1 night of total sleep time (TST), sleep efficiency (SE), wake after sleep onset (WASO), and sleep onset latency (SOL) in healthy pregnant women between 6 and 7 months of gestation.

Design: Secondary analysis using data from a case-control study.

Setting: A large university-affiliated hospital in the Midwestern United States.

Participants: A total of 78 pregnant women were recruited, among which 38 healthy women with uncomplicated pregnancies were included for this analysis.

Measurements: Participants had an overnight PSG assessment at a sleep center while simultaneously wearing an actigraph (Minimitter; Philips Respironics, Andover, MA). Sleep parameters from both devices included TST, SE, WASO, and SOL. Four scoring settings were used to obtain these parameters from actigraphy. Bland-Altman tests were used to evaluate the agreement between sleep variables scored independently from actigraphy and PSG.

Results: The default scoring setting (10-by-40) yielded significantly different results from the PSG ($P < .01$). The 10 immobile/mobile minutes for sleep onset/end with an activity threshold of 10 (10-by-10) produced estimations of TST, SE, and WASO closest to those produced by PSG. When this setting was used, the mean differences between PSG- and actigraphy-assessed TST, SE, and WASO were -1.9 minutes, -0.4% , and 7.4 minutes. When the 10 and 15 immobile/mobile minutes for sleep onset/end were used, the difference between PSG- and actigraphy-assessed SOL was approximately 4 to 5 minutes.

Conclusions—Findings from this study do not support the use of default actigraph settings in pregnant women. In contrast, the 10-by-10 scoring setting provided the greatest agreement and least bias in comparison with PSG for sleep measurements. The 10-by-10 scoring setting is recommended to be used in studies consisting of pregnant women.

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Disclosure
None.

Ethical approval

This study was approved by the University of Illinois at Chicago Institutional Review Board (20140485-82078-1).

Keywords

Actigraphy; Agreement; Polysomnography; Pregnancy; Scoring setting; Sleep

Introduction

A majority of pregnant women experienced disturbances in sleep due to pregnancy-related hormonal and physical changes, especially in the second half of pregnancy.^{1,2} The severity and frequency of sleep disturbances likely increase as pregnancy progresses.³ Accumulating evidence indicates that sleep disturbance during pregnancy, including short sleep duration and poor sleep quality, is an important risk factor for adverse maternal and fetal outcomes such as gestational diabetes, pre-eclampsia, and higher rates of preterm labor.⁴⁻⁶ Currently, there is a growing interest among researchers and clinicians in examining the influence of sleep on pregnancy-related health outcomes.^{7,8} Such research and clinical assessments rely on the accurate evaluation of sleep parameters, which may facilitate the early identification and management of sleep disturbances and likely minimize or possibly prevent adverse maternal and fetal outcomes.

Sleep can be assessed using subjective methods and objective devices. Subjective sleep can be easily measured using questionnaires. Nevertheless, those questionnaires are typically self-reported, which could introduce recall bias and undermine the accuracy of the data.⁹ Polysomnography (PSG) is the gold standard for objective measurement of sleep.¹⁰ However, the use of PSG has been limited because of intensive labor and high cost. Meanwhile, with the advance of technology, actigraphy is becoming a commonly used method to assess objective sleep. Compared to PSG, actigraphy is simple, cost-effective, and noninvasive.¹¹ It also allows long-term sleep pattern monitoring in an individual's natural sleep environment.¹² Therefore, actigraphy has gained significant acceptance in sleep research and has been widely used as an alternative when the use of PSG is not feasible.¹¹

An accelerometer in the actigraph detects body movements, and device-specific commercially available software is used to transform the recorded movements into sleep parameters. The software setting for the actigraph device yields epoch scored sleep or wake data using activity counts above a set wake threshold.¹¹ The choice of the setting is the cornerstone for accurate assessments of specific sleep parameters including total sleep time (TST), sleep efficiency (SE), sleep onset latency (SOL), and wake after sleep onset (WASO). The default algorithm has been commonly used,^{13,14} which permitted the greatest comparison across studies when using the same actigraph device and software in a given population. However, existing algorithms developed for the general adult population (eg, males and females across different ages) may not perform well when used in special populations, such as pregnant women who have more disrupted sleep. Thus, a different setting may be needed. During pregnancy, frequent urination, fetal movement, heartburn, difficulty finding a comfortable sleep position, and abnormal respiratory events^{15,16} could lead to multiple nocturnal awakenings and decreases in total sleep time and sleep efficiency. These changes may affect the accuracy of activity-based actigraphy in assessing sleep.

Currently, there is a gap regarding the agreement between actigraphy and PSG in measuring different sleep parameters in pregnant women.

Agreement evaluates the degree to which 2 measurements tend to agree, which is different from validity or the widely used approaches for reliability assessment.¹⁷ Actigraphy has been suggested to be reliable in individuals with various disorders, such as insomnia, circadian rhythm disorder, and dementia.^{18,19} Actigraphy was also validated against PSG in healthy adults,²⁰ children,²¹ and others with various conditions.^{22–25} Nevertheless, the agreement between actigraphy and PSG in assessing different sleep parameters has rarely been reported. In the few studies conducted in patients with Parkinson disease,²⁴ younger adults with type 1 diabetes,²³ and children,²¹ a lack of agreement was reported between PSG and actigraphy using the default setting to measure sleep parameters. Failing to consider the agreement between actigraphy and PSG may result in misleading impressions of actigraphy's suitability for use in research and clinical practice.¹⁷ Therefore, the purpose of this study was to compare the scoring of TST, SE, WASO, and SOL obtained from PSG with different actigraph scoring settings (including the default setting) in pregnant women between 6 and 7 months of gestation. Findings from this study will contribute to our knowledge in the use of actigraphy in pregnant women, which are of particular importance to midwifery and sleep-related health professions.

Participants and methods

Design and sample

This report is a secondary analysis of data from a case-control study which aimed to investigate sleep-related determinants of gestational diabetes. A total of 78 women were recruited, including pregnant women with newly diagnosed gestational diabetes²⁶ (n = 38) and healthy controls (n = 40). Participants were matched on age, race, parity, and body mass index. The inclusion criteria were (1) aged 18–42 years; (2) gestational age 24–36 weeks of pregnancy; and (3) able to understand, speak, and write in English. The exclusion criteria were (1) multiple gestations (ie, twins or triplets), (2) prepregnancy diabetes (type 1 or 2), (3) history of gestational diabetes, (4) known sleep disorders identified during sleep screening, (5) current neurological or psychiatric disorders, (6) excessive alcohol intake (average alcohol consumption ~30 g/d), and (7) illegal drug use. Data from the 40 healthy controls were used. For an acceptable sleep study, PSG-recorded sleep should be at least 4 hours.²⁷ One participant was excluded because the total sleep time was less than 4 hours. One participant did not have concurrent PSG and actigraph recording and thus was excluded. A total of 38 participants were included in the final analysis.

Procedures

The study was approved by the University of Illinois at Chicago (UIC) Institutional Review Board. Participants were recruited from obstetric clinics at the University of Illinois hospital between December 2014 and March 2017. Women who were eligible and agreed to participate provided informed consent. Medical, obstetric, and sleep histories were obtained at baseline evaluation. All participants completed a demographic questionnaire and the Epworth Sleepiness Scale prior to PSG recording. They underwent an overnight sleep

assessment simultaneously by PSG and actigraphy at the UIC Sleep Science Center. Sleep data from the PSG and actigraphy were scored independently. Sleep data derived from PSG were scored by a sleep technologist based on standard criteria.²⁸ The lights-on and lights-off times recorded by the PSG sleep technologist were used to determine the rest interval.

Measures

Four objective sleep parameters were obtained from PSG recording and actigraphy. They included TST (minutes between sleep onset and wake time), SOL (minutes between lights off and the first sleep episode), WASO (minutes awake between sleep onset and wake time), and SE (the percentage of time asleep from lights off to lights on).

Polysomnography

The computer-based PSG recordings used 2 central, 2 frontal, and 2 occipital electroencephalograms; bilateral electrooculograms; bilateral submental electromyograms (chin and lower extremities); electrocardiogram; nasal flows from nasal cannula; oral flows from thermistor; abdominal effort piezo bands; pulse oximetry; and body position. An Alice 5 digital system (Respironics) was used to collect and store the PSG data.

Actigraphy

The Actiwatch Spectrum (Minimitter; Philips Respironics, Andover, MA) was used. Data were collected in 30-second epochs, which are the same as the PSG. The Actiwatch was programmed to start at 9 PM when participants arrived at the Sleep Center. All participants were instructed to wear the Actiwatch on the nondominant wrist. Data were downloaded from the actigraph to a laptop computer and scored using Actiware (version 6.0.8, Respironics). Each epoch is scored as either sleep or wake based on whether the accumulation of activity count is below (eg, sleep) or above the set threshold (eg, wake). The Actiware includes various default thresholds for activity count (eg, 40 for medium setting). The users can also change the number of immobile minutes required to detect sleep onset and mobile minutes required for sleep end and, therefore, tailor the definition for sleep onset and end. In default, sleep onset and sleep end are defined as 10 consecutive immobile minutes and 10 consecutive mobile minutes, respectively. Sleep variables derived from actigraphy vary as a function of the threshold for activity count and the immobile or mobile minutes used to define sleep onset or end. The commonly used default setting is a function of the medium threshold for activity count (40) and 10 immobile or mobile minutes for sleep onset or end. In this study, we tested combinations of 4 settings for sleep onset or end (5, 10, 15, and 20 immobile/mobile minutes for sleep onset/end) and 4 activity count thresholds (10, 20, 30, and 40) to determine which yielded the best agreement with PSG in estimating specific sleep parameters.

Statistical analysis

Data analyses were conducted using Stata 13.0 (StataCorp LP, College Station, TX) and SPSS 22.0 (SPSS Inc, Chicago, IL). Prior to data analysis, missing data and outliers were checked. Descriptive statistics (mean $\pm$ SD or percentage) were examined. Pearson correlation analysis was conducted to measure the strength of the relation between each

sleep variable measured by PSG and actigraphy. Paired t tests examine whether the mean difference in the pair of observations is different from 0. Independent, separate paired t test was conducted for each of the comparison (eg, comparison between PSG- derived TST and actigraphy-derived TST at one specific setting). For this study, a smaller difference between sleep parameters derived from PSG and actigraphy is desired. Bland-Altman plots were used to determine the agreement between these 2 measures (eg, TST measured by Actiwatch versus TST measured by PSG). The Bland-Altman analysis compares a measurement method (eg, actigraphy) to the gold standard (eg, PSG) in clinical practice.²⁹ The Bland-Altman plot demonstrates the mean bias (the average of differences between 2 methods) and 95% limits of agreement (mean bias $\pm$ 1.96 SD). The limits of agreement provide a reference interval, which can be interpreted as acceptable or not based on whether they are within a clinically acceptable range.²⁹ Pitman tests were also conducted to examine the difference in variance. The traditionally-used $P < .05$ (2-tailed) was considered statistical significance. Clinical significance was also taken into account when interpreting the results.

Results

Participant characteristics

Participants' mean age was 32.0 years (SD 4.1). Their mean gestational age was 32.3 weeks (SD 3.4). Their mean body mass index was 34.3 kg/m² (SD 7.0). The study participants included African Americans (38.5%), Hispanics (41.0%), and White women and women of other racial backgrounds (20.5%) who were combined into a "white and other" category. Detailed participant characteristics are in Table 1.

Comparisons of sleep parameters measured by PSG and actigraphy

When the 5 immobile/mobile minutes was used for sleep onset/end, an activity threshold of 10 produced estimations of TST, SE, and WASO closest to those produced by PSG (Table 2). The mean differences between PSG- and actigraphy-assessed TST, SE, and WASO were -8.8 minutes (SD 36.8), -2.0% (SD 8.2), and -1.1 minutes (SD 33.3), respectively.

When the 10 immobile/mobile minutes was used for sleep onset/end, an activity threshold of 10 produced estimations of TST, SE, and WASO closest to those produced by PSG (Table 3). The mean differences between PSG- and actigraphy-assessed TST, SE, and WASO were -1.9 minutes (SD 35.6), -0.4% (SD 7.9), and 7.4 minutes (SD 36.9), respectively. When the default setting was used (ie, 10 immobile/mobile minutes for sleep onset/end with an activity threshold of 40), all sleep parameters derived from actigraphy were statistically different from those derived from PSG.

When the 15 immobile/mobile minutes was used for sleep onset/end, an activity threshold of 20 produced estimations for TST and SE closest to those produced by PSG (Table 4). The mean differences between PSG- and actigraphy-assessed TST and SE were -5.9 minutes (SD 44.7) and -1.3% (SD 9.9), respectively. No activity threshold produced a close estimation of WASO.

When the 20 immobile/mobile minutes was used for sleep onset/end, an activity threshold of 30 produced estimations for TST and SE closest to those produced by PSG (Table 5). The

mean differences between PSG- and actigraphy-assessed TST and SE were -2.8 minutes (SD 47.7) and -0.6% (SD 10.6), respectively. No activity threshold produced a close estimation of WASO.

Bland-Altman plots for the combination of 10 immobile/mobile minutes for sleep onset/end with an activity threshold of 10

Taken together, both the 5 immobile/mobile minutes for sleep onset/end with an activity threshold of 10 (5-by-10) and the 10 im-mobile/mobile minutes for sleep onset/end with an activity threshold of 10 (10-by-10) seemed to provide sleep parameters which were similar to those produced by PSG. However, the 10-by-10 setting performed better in estimating TST and SE than the 5-by-10 setting because mean differences were smaller when the 10-by-10 setting was used. Therefore, Bland-Altman plots for TST, SE, and WASO were obtained for the 10-by-10 combination. The plots are shown in Fig. 1. On average, actigraphy overestimated TST by 1.9 minutes (95% CI = -13.6 to 12.8) and SE by 0.4% (95% CI = -3.0 to 2.2) but underestimated WASO by 7.4 minutes (95% CI = -4.7 to 19.6). Results of Pitman test of difference in variance suggested no difference between PSG- and actigraphy-measured TST, SE, and WASO (all $P > .05$). Limits of agreement for the 3 measures were as follows: TST, -73.2 to 69.5 minutes; SE, -16.3% to 15.4% ; and WASO, -66.4 to 81.2 minutes.

Sleep onset latency

When actigraphy-derived SOL was compared with PSG-derived SOL, the 15 immobile/mobile minutes for sleep onset/end yielded closest estimations regardless of the activity threshold (Table 4). The mean difference was around 4.4 minutes (SD 30.1). Although the 10 immobile/mobile minutes for sleep onset/end yielded significantly different estimation of SOL from the PSG, the mean difference between actigraphy- and PSG-derived SOL was only around 5 minutes. When the 10-by-10 setting was used, the mean difference was 4.6 minutes (SD 12.6). When the 5 and 20 immobile/mobile minutes for sleep onset/end were used, the differences between actigraphy- and PSG-derived SOL were approximately 12 and 8 minutes, respectively.

Discussion

This study is among the first that evaluated the agreement between actigraphy and the gold standard of PSG in pregnant women. Our data demonstrated that sleep parameters derived from the default scoring setting were significantly different from the ones obtained from PSG. These findings indicate that the default setting may not be appropriate to score actigraphy recordings in pregnant populations. In contrast, the 10-by-10 scoring setting showed no significant differences in the measurement of TST, SE, and WASO compared to PSG. Both the 10 and 15 immobile/mobile minutes for sleep onset/end yielded an accurate assessment of SOL.

In our sample, the default actigraph setting significantly overestimated TST and SE but underestimated WASO. These findings are consistent with the evidence from previous studies conducted in younger adults with type 1 diabetes,²³ patients with insomnia and

chronic obstructive lung disease,²⁵ and older women with insomnia.³⁰ When using actigraphy for sleep assessment, lack of movement or lying in bed awake motionless is likely coded as sleep.³¹ That could account for the poor ability of actigraphy to detect wakefulness, which has been reported previously.^{18,32} Both our data and current evidence^{23–25} suggest that the default setting is not optimal for sleep measurements, and different scoring settings are needed for different populations.

In this study, we found that the 10-by-10 scoring setting provided the greatest agreement and least bias in comparison with PSG for sleep measurements. When this setting was used, the bias for actigraphy in estimating TST, SE, and WASO was only 1.9 minutes, 0.4%, and 7.4 minutes, respectively. Our results regarding the use of a lower scoring setting were in accordance with previous studies performed in different populations. Specifically, Maglione et al²⁴ found that the 5-by-10 combination was the optimal scoring setting for TST, SE, and WASO in patients with Parkinson disease, who often suffer from recurrent sleep disturbances. Likewise, in younger adults with type 1 diabetes, the low threshold setting provided optimal results for TST, SE, and WASO.²³ Actiwatch is a sensitive accelerometer that can pick up the smallest wrist movement. During pregnancy, there is an increase in body movement during sleep.³³ When a period of time is scored as wake by PSG, a lower setting in actigraphy may score it as wake, whereas a higher setting may score it as sleep. During pregnancy, women typically experience a progressive increase in both the frequency and duration of nocturnal awakenings as pregnancy progresses due to general discomfort, urinary frequency, leg cramps, fetal movements, heartburn, backache, snoring, and leg cramps.^{34,35} Actigraphy likely overestimates TST and SE in conditions involving more wakefulness, as reported in previous studies.³⁶ Thus, lowering the immobile/mobile minutes for sleep onset/end and the activity threshold might be able to decrease overestimation of TST and SE by actigraphy.

In this study, both the 10 and 15 immobile/mobile minutes for sleep onset/end produced an accurate assessment of SOL regardless of the activity threshold. The difference between PSG- and actigraphy-assessed SOL was approximately 4 to 5 minutes. Current evidence has been inconsistent regarding the validity of actigraphy for the measurement of SOL. In patients with insomnia and chronic obstructive lung disease, the 10-by-10 combination provided optimal estimations for all sleep measures, including SOL; actigraphy underestimated SOL by 5.5 minutes ($P = .239$).²⁵ Likewise, Maglione and colleagues²⁴ reported that the 10 immobile/mobile minutes for sleep onset/end yielded a better estimation of SOL (only 0.65-minute difference, $P = .854$) than other settings in patients with Parkinson disease. Nevertheless, in adults with type 1 diabetes, none of the settings correctly identified SOL.²³ Estimation of SOL depends on accurate assessment of time in bed and detection of the wake/sleep transition.²⁴ In this study, we used the lights-off time recorded by the PSG technician as the time in bed. Therefore, the assessment of time in bed was presumably accurate. Sleep onset is a gradual rather than discrete process that entails a series of biobehavioral and psychological changes. Actigraphy and PSG focus on different phases of the sleep-onset process, which could result in a systematic difference.³⁷ Cole and colleagues indicated that actigraphy sleep-onset criteria were met prior to PSG-measured sleep-onset criteria.³⁸ Thus, the ability of actigraphy to detect the wake/sleep transition could have contributed to the bias. Additionally, the reliability of PSG-derived sleep scoring is not

perfect, particularly for stage 1 sleep,³⁷ which might also account for an important portion of the differences between actigraphy- and PSG-measured SOL.

A number of strengths and limitations of the present study warrant mention. One strength of our study is our sample, which is diverse in terms of ethnicity/race and socioeconomic status, including traditionally underrepresented populations such as African Americans in research studies. The substantial diversity of study participants further supports the generalizability of our findings. Data from both actigraph and PSG were obtained simultaneously on the same night. We also compared 4 different actigraph settings to PSG which is the gold standard to measure sleep objectively. However, findings from this study need to be interpreted in light of the limitations. We only had a 1-night PSG sleep recording in the sleep laboratory. A PSG recording in participants' natural home environment for a longer period would enable more accurate comparisons between sleep parameters derived from these 2 methods. However, in our experience, pregnant women are reluctant to undergo PSG. In this study, actigraph start and end times were established by the sleep technologist based on lights-off and lights-on times. Although this method improved accuracy in sleep scoring, it is not normally done with actigraph used at home. Our findings may not be generalized to free-living settings. Future studies are warranted to confirm these findings by using more commonly available information, such as participant self-reported start and end times. Another weakness is that, although desirable, it was not possible for the authors to perform sensitivity and specificity (epoch-by-epoch) analyses for technical reasons at this time. Further studies are needed which produce such analyses. This validation would quantify the strengths and weaknesses of actigraphy as a tool for measuring sleep in the pregnant population. Therefore, the results of our study are important but should be interpreted cautiously due to this weakness. But the evidence we have found supports the concept that there is agreement between actigraphy and PSG in measuring objective sleep. It is also important to mention that there are several commercial brands of actigraph available, and each yields different data based on distinct algorithms and software. The data in this article are only applicable to the Phillips Respironics brand. Additionally, we did not define acceptable limits of agreement a priori because of limited research in this area. Therefore, we were not able to determine whether those limits of agreement were optimal and acceptable for clinical or research purposes. Future studies need to replicate our results on larger scales.

In summary, the 10-by-10 scoring setting in actigraph provided the greatest agreement and least bias in comparison with PSG for sleep measurements. Findings from this study do not endorse using the default actigraph setting (the 10-by-40 scoring setting) to obtain sleep parameters in pregnant women. These findings have important implications for clinical practice and research. For instance, when the default setting was used, our participant TST was around 368 minutes as compared to the 335 minutes assessed by both PSG and the 10-by-10 setting. If less than 360 minutes of sleep was considered inadequate, using the default setting may have underestimated the sleep problems these pregnant women may have, which could have serious health consequences. Based on the overall findings, it is recommended that the 10-by-10 scoring setting, rather than the default setting, should be used in studies consisting of pregnant women, especially those during the second half of pregnancy.

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Abbreviations:

PSG	polysomnography
SE	sleep efficiency
SOL	sleep onset latency
TST	total sleep time
WASO	wake after sleep onset

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Fig. 1. Bland-Altman plots for sleep parameters. A, TST; Pitman test of difference in variance: $r = 0.12$, $n = 38$, $P = .49$. B, SE; Pitman test of difference in variance: $r = -0.06$, $n = 38$, $P = .73$. C, WASO; Pitman test of difference in variance: $r = 0.04$, $n = 38$, $P = .83$.

Table 1

Participant characteristics (n = 38)

Variables	$x \pm SD/n$ (%)
Age (y.)	32.0 $\pm$ 4.1
Marital status	
Married/common law	17 (44.7)
Single/divorce/separated	12 (55.3)
Race	
White & other	8 (21.1)
African American	14 (36.8)
Hispanic	16 (42.1)
Education	
Lower than 4 y college	20 (52.6)
4 y college or higher	18 (47.4)
Body mass index (kg/m ²)	34.0 $\pm$ 6.9
Gestational (wk)	32.2 $\pm$ 3.4
Parity	
Nulliparous	8 (21.1)
Multiparous	30 (78.9)

Comparison of sleep parameters assessed by PSG and actigraphy ($\bar{x} \pm SD$): 5 immobile/mobile minutes used for sleep onset/end

Table 2

Sleep parameter	PSG score	Activity count	Actigraphy score	Difference	r^*	P
TST (min)	334.7 $\pm$ 49.7	10	343.5 $\pm$ 43.8	-8.8 $\pm$ 36.8	0.70	.148
		20	369.1 $\pm$ 59.2	-34.4 $\pm$ 57.2	0.46	<.001
		30	371.5 $\pm$ 38.1	-36.9 $\pm$ 35.0	0.71	<.001
		40	379.5 $\pm$ 37.7	-44.8 $\pm$ 37.8	0.66	<.001
SE (%)	76.7 $\pm$ 10.0	10	78.6 $\pm$ 9.9	-2.0 $\pm$ 8.2	0.66	.149
		20	82.6 $\pm$ 8.7	-5.9 $\pm$ 8.1	0.63	<.001
		30	85.0 $\pm$ 8.2	-8.4 $\pm$ 7.8	0.64	<.001
		40	86.8 $\pm$ 7.9	-10.1 $\pm$ 8.4	0.57	<.001
WASO (min)	77.7 $\pm$ 37.9	10	77.8 $\pm$ 38.6	-1.1 $\pm$ 33.3	0.64	.984
		20	62.2 $\pm$ 35.4	15.5 $\pm$ 36.4	0.64	0.13
		30	49.8 $\pm$ 30.6	28.0 $\pm$ 30.3	0.64	<.001
		40	41.8 $\pm$ 27.8	35.9 $\pm$ 32.4	0.63	<.001
SOL (min)	23.6 $\pm$ 19.4	10	11.8 $\pm$ 13.7	11.8 $\pm$ 14.9	0.62	<.001
		20	11.8 $\pm$ 13.7	11.8 $\pm$ 15.0	0.51	<.001
		30	11.8 $\pm$ 13.7	11.8 $\pm$ 15.0	0.63	<.001
		40	11.7 $\pm$ 13.6	11.9 $\pm$ 15.1	0.55	<.001

Values in bold: not statistically different from and closest to the PSG value.

P value: based on paired t test.

* $P < .01$.

Table 3

Comparison of sleep parameters assessed by PSG and actigraphy ($\bar{x} \pm \text{SD}$): 10 immobile/mobile minutes used for sleep onset/end

Sleep parameter	PSG score	Activity count	Actigraphy score	Difference	* r	P
TST (min)	334.7 $\pm$ 49.7	10	336.5 $\pm$ 45.9	-1.9 $\pm$ 35.6	0.72	.750
		20	353.5 $\pm$ 43.2	-18.8 $\pm$ 35.2	0.72	.002
		30	362.3 $\pm$ 42.9	-27.6 $\pm$ 33.7	0.74	<.001
		40	368.5 $\pm$ 43.1	-33.8 $\pm$ 37.0	0.69	<.001
SE (%)	76.7 $\pm$ 10.0	10	77.1 $\pm$ 10.4	-0.4 $\pm$ 7.9	0.70	.744
		20	80.9 $\pm$ 9.6	-4.2 $\pm$ 7.9	0.68	.002
		30	82.4 $\pm$ 9.2	-5.8 $\pm$ 7.6	0.69	<.001
		40	84.2 $\pm$ 9.0	-7.6 $\pm$ 8.1	0.64	<.001
WASO (min)	77.7 $\pm$ 37.9	10	70.3 $\pm$ 36.8	7.4 $\pm$ 36.9	0.79	.222
		20	54.6 $\pm$ 30.8	23.1 $\pm$ 33.7	0.71	<.001
		30	48.0 $\pm$ 33.3	29.7 $\pm$ 36.9	0.78	<.001
		40	38.4 $\pm$ 25.7	39.3 $\pm$ 33.9	0.79	<.001
SOL (min)	23.6 $\pm$ 19.4	10	19.0 $\pm$ 19.2	4.6 $\pm$ 12.6	0.51	0.31
		20	18.1 $\pm$ 18.7	5.5 $\pm$ 14.5	0.53	0.26
		30	19.0 $\pm$ 19.1	4.6 $\pm$ 12.7	0.47	0.32
		40	19.2 $\pm$ 18.9	4.4 $\pm$ 12.5	0.49	0.38

Values in bold: not statistically different from and closest to the PSG value.

P value: based on paired t test.

* $P < .01$.

Table 4

Comparison of sleep parameters assessed by PSG and actigraphy ($\bar{x} \pm SD$): 15 immobile/mobile minutes used for sleep onset/end

Sleep parameter	PSG score	Activity count	Actigraphy score	Difference	r^*	P
TST (min)	334.7 $\pm$ 49.7	10	325.7 $\pm$ 58.4	9.0 $\pm$ 44.5	0.67	.220
		20	340.6 $\pm$ 58.2	-5.9 $\pm$ 44.7	0.67	.417
		30	348.4 $\pm$ 57.8	-13.7 $\pm$ 44.0	0.67	.063
		40	355.0 $\pm$ 59.1	-20.3 $\pm$ 47.6	0.63	.012
SE (%)	76.7 $\pm$ 10.0	10	74.5 $\pm$ 13.1	2.1 $\pm$ 9.9	0.66	.194
		20	77.9 $\pm$ 12.9	-1.3 $\pm$ 9.9	0.66	.440
		30	79.7 $\pm$ 12.7	-3.0 $\pm$ 9.8	0.65	.066
		40	81.1 $\pm$ 12.8	-4.5 $\pm$ 10.5	0.60	.012
WASO (min)	77.7 $\pm$ 37.9	10	63.8 $\pm$ 30.8	13.9 $\pm$ 33.7	0.69	.015
		20	48.9 $\pm$ 27.3	28.5 $\pm$ 33.0	0.69	<.001
		30	41.2 $\pm$ 25.4	36.5 $\pm$ 32.0	0.69	<.001
		40	34.5 $\pm$ 22.3	43.2 $\pm$ 33.6	0.69	<.001
SOL (min)	23.6 $\pm$ 19.4	10	28.0 $\pm$ 40.1	-4.4 $\pm$ 30.1	0.54	.376
		20	28.0 $\pm$ 40.1	-4.4 $\pm$ 30.1	0.53	.376
		30	28.0 $\pm$ 40.1	-4.4 $\pm$ 30.1	0.55	.376
		40	27.9 $\pm$ 39.8	-4.3 $\pm$ 29.8	0.49	.382

Values in bold: not statistically different from and closest to the PSG value.

P value: based on paired t test.

* $P < .01$.

Table 5

Comparison of sleep parameters assessed by PSG and actigraphy ($\bar{x} \pm SD$): 20 immobile/mobile minutes used for sleep onset/end

Sleep parameter	PSG score	Activity count	Actigraphy score	Difference	r^*	P
TST (min)	334.7 $\pm$ 49.7	10	314.0 $\pm$ 59.6	18.7 $\pm$ 48.9	0.61	.024
		20	330.0 $\pm$ 58.9	4.7 $\pm$ 48.6	0.61	.554
		30	337.5 $\pm$ 58.0	-2.8 $\pm$ 47.7	0.62	.716
		40	343.8 $\pm$ 59.5	-9.1 $\pm$ 51.3	0.57	.279
SE (%)	76.7 $\pm$ 10.0	10	72.2 $\pm$ 13.6	4.5 $\pm$ 10.8	0.62	.016
		20	75.5 $\pm$ 13.3	1.1 $\pm$ 10.8	0.60	.523
		30	77.2 $\pm$ 13.0	-0.6 $\pm$ 10.6	0.60	.741
		40	78.6 $\pm$ 13.2	-2.0 $\pm$ 11.3	0.55	.292
WASO (min)	77.7 $\pm$ 37.9	10	61.0 $\pm$ 30.0	16.7 $\pm$ 32.7	0.67	.003
		20	47.0 $\pm$ 26.9	30.7 $\pm$ 32.3	0.69	<.001
		30	39.5 $\pm$ 25.4	38.2 $\pm$ 31.6	0.69	<.001
		40	33.2 $\pm$ 22.1	44.5 $\pm$ 33.2	0.69	<.001
SOL (min)	23.6 $\pm$ 19.4	10	32.2 $\pm$ 39.5	-8.6 $\pm$ 30.1	0.56	.085
		20	31.4 $\pm$ 39.7	-7.8 $\pm$ 29.8	0.55	.117
		30	31.4 $\pm$ 39.8	-7.8 $\pm$ 29.8	0.56	.117
		40	31.3 $\pm$ 39.5	-7.7 $\pm$ 29.6	0.49	.118

Values in bold: statistically different from and closest to the PSG value.

P value: based on paired t test.

* $P < .01$.