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Comparison of actigraphic, polysomnographic, and subjective assessment of sleep parameters in sleep-disordered patients

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Abstract

Objective: Comparison of polysomnography (PSG)-derived sleep parameters (total sleep time, sleep efficiency, and number of awakenings) to those derived from actigraphy and subjective questionnaires.

Background: Actigraphy is commonly used to assist sleep specialists in the diagnosis of various sleep and circadian-rhythm disorders. However, few validation studies incorporate large sample sizes, typical sleep clinic patients, or comparisons with subjective reports of sleep parameters.

Methods: Clinical series with 100 consecutive sleep-disordered patients (69 men, 31 women, mean age of 49 ± 14.7 years) at a tertiary sleep disorders center. Sensitivity, specificity, and accuracy measures were obtained from epoch-by-epoch comparison of PSG and actigraphic data. Subjective sleep parameter data were derived from questionnaires given to subjects in the morning following their recording night.

Results: We found that total sleep time and sleep efficiency did not significantly differ between PSG data and the combined data obtained from actigraphy and subjective reports. Using a high-threshold (low-wake-sensitivity) actigraphic algorithm, the number of awakenings was not significantly different from those detected by PSG.

Conclusions: We recommend the use of subjective data as an adjunct to actigraphic data in estimating total sleep time and sleep efficiency in sleep-disordered patients, especially those with disorders of excessive somnolence.

Keywords: Actigraphy; Polysomnography; Subjective assessment; Awakenings; Total sleep time; Sleep efficiency

1. Introduction

Actigraphy, a method used to estimate sleep-wake schedules by measurement of activity, has been used by researchers to study sleep disturbances in a variety of populations, most frequently for the evaluation of insomnia, sleep state misperception and circadian rhythm disorders. The American Academy of Sleep Medicine recognizes it as a useful adjunct in the clinical assessment of sleep disorders [1]. An actigraph, worn on the wrist or ankle allows estimation of sleep and wakefulness based on motor activity. It provides a low-cost, non-invasive, objective, and longitudinal method for the diagnostic and post-treatment evaluation of patients with sleep disorders in the ambulatory setting.

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Prior studies have used a variety of methods and algorithms to validate actigraphy. Comparison of actigraphy with the 'gold standard' of polysomnography (PSG) has typically yielded agreement rates in the range of 78–95% [2]. However, systematic review of earlier studies revealed smaller sample sizes (mean $n = 42 \pm 25$) compared to the present study, and these studies were conducted on primarily normal subjects without sleep disorders [2]. Also, few studies have compared subjective sleep parameter values to the ones obtained from actigraphy and PSG. In the present study, PSG data in the form of sleep parameters such as number of awakenings, total sleep time, and sleep efficiency were compared to actigraphy as well as subjective data for 100 consecutive patients. We also performed an epoch-by-epoch comparison between PSG and actigraphic data to determine the sensitivity, specificity and accuracy of actigraphy.

2. Methods

2.1. Subjects

The subject population consisted of 100 consecutive patients who had an initial sleep study in our sleep laboratory. Of these 100 subjects, 69 were men and 31 were women with a mean age of 49 ± 14.7 years. Our university's panel on human subjects in medical research approved the study, and informed consent was obtained from every subject following full explanation of the study.

2.2. Procedures

Actigraphy and PSG were simultaneously performed for one night for each of the 100 consecutive subjects. Bedtimes and awakening times for the subjects were ad libitum; data collection commenced with lights out and was terminated at lights on.

2.2.1. Actigraphy

Model AW4 (Mini Mitter Co., Inc., Sunriver, OR) actigraphs were placed on the non-dominant wrists of subjects prior to lights out. These devices are accelerometers with a sensitivity of less than 0.01 g, and a sampling rate of 32 Hz. Actigraphic data during 30-s epochs were scored as sleep or wake by Actiware-Sleep® v. 2.53 analysis software (Mini Mitter Co., Inc.). This device uses a validated algorithm [3] in which activity counts recorded during the measured epoch are modified by the level of activity in the surrounding 2-min time period (i.e. ±2 min) to yield the final activity count for each epoch. The following equation is used:

$$A = 0.04E_{-4} + 0.04E_{-3} + 0.20E_{-2} + 0.20E_{-1} + 2E + 0.20E_{+1} + 0.20E_{+2} + 0.04E_{+3} + 0.04E_{+4}$$

where A = sum of activity counts for 30-s scored epoch and surrounding epochs; E = activity counts recorded during scored epoch; E_n = activity counts recorded during each previous ($_{-1}$, $_{-2}$, $_{-3}$, $_{-4}$) or following ($_{+1}$, $_{+2}$, $_{+3}$, $_{+4}$) successive epochs. If the summed activity count (A) is above a defined threshold (T), the epoch is scored as wake (i.e. $A > T$ = wake), otherwise, it is scored as sleep (i.e. $A \leq T$ = sleep). The high, medium, and low thresholds (T) are set at 80, 40, and 20 activity counts, respectively. The algorithm and threshold settings were not altered during the study or post hoc.

2.2.2. PSG

Concomitantly, PSGs with 30-s epochs were recorded for subjects using the Sandman NT® (Mallinckrodt Inc., Hazelwood, MO) system. Standard PSG recordings consisting of an EEG montage (C3-A2, C4-A1, 02-A1, 01-A2), chin EMG, ROC-A1, LOC-A2, snoring microphone, right and left anterior tibialis EMG, EKG, oronasal airflow, chest and abdominal impedance, and esophageal pressure manometry were conducted by experienced polysomnographic technologists. Separate polysomnographic technologists blindly scored the PSG recordings. A board-certified sleep specialist using ICSD criteria [4] gave a sleep diagnosis to each subject following review of the subject's sleep study.

The actigraphic and PSG data collection were synchronized for each subject. This was accomplished by having the PC clock at each recording station simultaneously start and control the actigraphic and PSG recordings. Agreement or disagreement between actigraphic and PSG data was assessed for each 30-s epoch. When actigraphic data agreed with PSG data, the epoch was scored as 'True sleep'

Table 1
Measures for actigraphic analysis[a]

Actigraphy	Polysomnography		
	Sleep	Wake	Total
Sleep	'True sleep' (TS)	'False wake' (FW)	TS + FW
Wake	'False sleep' (FS)	'True wake' (TW)	FS + TW
Total	TS + FS	FW + TW	TS + FS + TW + FW

[a] Sensitivity = TS/(TS + FS). Specificity = TW/(FW + TW). Accuracy = (TS + TW)/(TS + FS + TW + FW).

(TS) or 'True wake' (TW). When actigraphic data contradicted PSG data it was scored as 'False sleep' (FS) or 'False wake' (FW) (Table 1). Movement time was considered wake during the scoring of the PSG data, according to Rechtschaffen and Kales criteria [5]. For both actigraphic and PSG data, awakenings were defined as any interruption in sleep lasting for at least one 30-s epoch after sleep onset up to the time the subject had his or her final wake period in the morning. Total sleep time (TST) was defined as the total time the subject spent asleep, and sleep efficiency was calculated as the total sleep time divided by the total recording time and multiplied by 100.

2.3. Subjective questionnaire

The subjective sleep assessment questionnaire was given to each subject in the morning following the recording night. The questionnaire contained questions on subject estimates of sleep latency, number of awakenings, length of each awakening, total sleep time, and morning awakening time. The subjects were not allowed to have access to time information (i.e. clocks, watches) which would influence the accuracy of their estimates of sleep-wake parameters.

2.4. Analysis

Sensitivity, specificity, and accuracy were calculated using the following formulas for each subject:

- *Sensitivity* (ability to detect sleep via actigraphy when PSG scores it as sleep) = number of TS epochs/number of PSG-scored-sleep epochs
- *Specificity* (ability to detect wake via actigraphy when PSG scores it as wake) = number of TW epochs/number of PSG-scored-wake epochs
- *Accuracy* (ability to detect both sleep and wake compared to PSG) = number of (TS + TW) epochs/number of PSG-scored (sleep + wake) epochs [6]

These formulas (Table 1) have been described in earlier studies [6,9,16], and the frame of reference of the above definitions of 'sensitivity' and 'specificity' is the detection of sleep epochs. However, if the frame of reference is the detection of wake epochs, then sensitivity is equal to the 'specificity' as defined above and vice versa. In other words, if the frame of reference is the detection of wake epochs, then sensitivity is equal to TW/(FW + TW) which is defined as the 'specificity' in Table 1, and specificity is equal to TS/(TS + FS) which is defined as the 'sensitivity' in Table 1.

The number of awakenings, total sleep time (TST) and sleep efficiency (SE = [total sleep time/total recording time] × 100) were obtained from the PSGs for each subject. The Actiware-Sleep® analysis software calculated these three parameters for the actigraphic data. Finally, the subjects reported their estimated number of awakenings, total sleep time, and sleep efficiency by completing the sleep assessment questionnaire.

The data were analyzed using the SYSTAT® (Version 7.0, SPSS Inc., Chicago, IL) statistical package. Paired *t*-tests, non-parametric sign tests, and Pearson correlations (with Bonferroni probabilities) were used to individually compare sleep parameters (number of awakenings, TST, and SE) for actigraphic and subjective questionnaire data with those of the PSG data.

3. Results

The data for number of awakenings, total sleep time, and sleep efficiency as obtained from PSG, actigraphic (low-threshold algorithm), and subjective questionnaire data are depicted in Table 2. After review of these data, we observed that total sleep time and sleep efficiency were overestimated by actigraphy by means of 1.0–1.8 h and 12.1–29.1%, respectively, but to a lesser degree by the subjects (means of 0.3 h and 2.5%, respectively). Upon further analysis, total sleep time and sleep efficiency were overestimated in approximately three-quarter of the cases (75/100 and 77/100, respectively) by actigraphy, as opposed to half of the cases (49/100 and 45/100, respectively) by the subjects. We then selected the minimum value for each sleep parameter (TST, SE) for the actigraphic vs. subjective data of each subject and compared this value with that obtained from the PSG data. In performing this post hoc subanalysis, we found that TST and SE did not significantly differ between the PSG data and the combined data obtained from actigraphy and subjective reports, but the number of awakenings using the low-threshold algorithm was significantly different (Table 3).

Table 2
Comparison of means of sleep parameters between PSG, actigraphic, and questionnaire data for all subjects[a]

Sleep parameter	Mean ± SD	Mean difference from PSG
Awakenings (n)		
PSG	33.1 ± 20.0	–
Actigraphy		
Low threshold	39.5 ± 18.66*	6.3 ± 22.15
Medium threshold	36.6 ± 17.11	3.5 ± 21.02
High threshold	30.8 ± 14.04	− 2.1 ± 19.87
Questionnaire	3.4 ± 3.35*	− 29.8 ± 18.42
Total sleep time (h)		
PSG	5.5 ± 1.53	–
Actigraphy		
Low threshold	6.5 ± 1.05*	1.0 ± 1.47
Medium threshold	6.9 ± 1.00*	1.4 ± 1.45
High threshold	7.3 ± 0.98*	1.8 ± 1.47
Questionnaire	5.9 ± 1.77	0.3 ± 1.72
Sleep efficiency (%)		
PSG	68.4 ± 18.61	–
Actigraphy		
Low threshold	80.7 ± 9.30*	12.1 ± 17.70
Medium threshold	86.0 ± 7.30*	17.5 ± 17.22
High threshold	90.4 ± 5.26*	21.9 ± 17.42
Questionnaire	73.9 ± 19.22	2.5 ± 19.03

[a] Significance: $P < 0.05$.

Upon further analysis, the number of awakenings as calculated by the medium-threshold (medium-wake-sensitivity) and high-threshold (low-wake-sensitivity) actigraphic algorithm were in close agreement and *not* significantly different from that obtained by PSG (Table 2). Subjective reports markedly underestimated the number of awakenings compared to that obtained by PSG; the scored PSG data revealed more awakenings in 93 of the 100 subjects compared to their subjective reports. For these 93 cases, an average of 31 ± 20.2 more awakenings were observed in the PSG data compared to those reported by the subjects.

The sensitivity, specificity and accuracy calculated using the low-, medium-, and high-threshold Actiware-Sleep® algorithm for the epoch-by-epoch comparison data are shown in Table 4. The low-threshold algorithm provided the best overall accuracy and specificity, 0.77 and 0.48, respectively. The accuracy was dependent on the amount of sleep, as demonstrated in Fig. 1 and also Table 5, which lists the Pearson correlation coefficients with Bonferroni probabilities for epoch-by-epoch comparison of actigraphic (low-threshold algorithm) sensitivity, specificity, and accuracy measures vs. PSG data. The high-threshold algorithm yielded a higher sensitivity (0.98) compared with the low-threshold algorithm (0.92), but at the cost of lower accuracy and specificity, 0.76 and 0.28, respectively. The sensitivity and 1 − specificity data from each subject (irrespective of diagnosis) are plotted for the three different threshold algorithms in Fig. 2. Each point at a given threshold setting in this plot represents the decision criterion (true-positive vs. false-positive) for each subject; a separate ROC graph can be generated from each of these points. Each curve in this plot represents the locus of points for a particular discrimination capacity, in this case, a different threshold algorithm. The distribution of points is consistent with the above sensitivity and specificity data. Lastly, although the differences between the threshold algorithms in Fig. 2 appear minor; these algorithms were important

Table 3
Means (±standard deviations) by diagnoses for PSG using the minimum of actigraphy (low-threshold) or subjective report for each subject (post hoc analysis)[a]

Diagnosis	*n*	No. of Awakenings	TST (h)	SE (%)
OSAS	40			
PSG		31.8 ± 24.03	5.1 ± 1.37	66.1 ± 16.69
Actigraphy + Logs		10.7 ± 15.99*	5.7 ± 1.39	72.8 ± 16.92
OSAS + PLMD	26			
PSG		36.5 ± 17.40	5.8 ± 1.17	71.5 ± 16.50
Actigraphy + Logs		20.0 ± 24.26	5.7 ± 1.79	69.6 ± 19.03
UARS	10			
PSG		29.2 ± 11.81	5.7 ± 2.33	73.3 ± 28.23
Actigraphy + Logs		7.1 ± 12.35*	5.8 ± 1.32	70.8 ± 12.61
UARS + PLMD	9			
PSG		30.7 ± 15.55	6.8 ± 1.49	81.3 ± 14.57
Actigraphy + Logs		11.0 ± 17.21	5.6 ± 0.91	70.6 ± 10.55
Other	15			
PSG		29.4 ± 14.89	6.5 ± 1.74	77.7 ± 16.92
Actigraphy + Logs		7.6 ± 10.23*	6.3 ± 1.90	81.0 ± 8.62
Overall	100			
PSG		33.1 ± 20.00	5.5 ± 1.53	68.4 ± 18.61
Actigraphy + Logs		12.3 ± 18.02*	5.8 ± 1.53	72.8 ± 15.87

[a] TST, total sleep time; SE, sleep efficiency; OSAS, obstructive sleep apnea syndrome; UARS, upper airway resistance syndrome; PLMD, periodic limb movement disorder; Other, insomnia, narcolepsy, idiopathic hypersomnia, restless legs syndrome. Significance: $*P < 0.05$.

when comparing specific sleep parameters (e.g., number of awakenings) as discussed earlier.

4. Discussion

The results from our study were comparable with those obtained from an earlier independent study (sensitivity, 0.95; specificity, 0.36; accuracy, 0.80) using the same device on a group of 30 consecutive sleep-disordered patients [8]; however, these statistics were obtained in a different manner compared to that of our study. In other earlier studies, the overall agreement rates between actigraphy and PSG for sleep and wakefulness in normal subjects have been very high (>90%) [2]. The agreement rates in patients with sleep disorders such as OSAS and insomnia have been lower (78–85%) [2,9–13]. Hence, while actigraphy is an accurate measure of sleep patterns in normal individuals, the accuracy declines as the quality and quantity of sleep diminishes [14] (Fig. 1). Similarly, it has been reported in former studies that actigraphy is excellent at detecting sleep (sensitivity > 0.90) [2,9]. However, its ability to detect wakefulness is low (specificity = 0.35) [9]. This is especially true in the following situations: (a) subjects who are studied in a sleep laboratory for the first time (i.e. the 'first-night effect') experience lower sleep efficiencies, primarily due to the new environment and discomfort from recording instrumentation; (b) subjects with disturbed sleep who lie quietly in bed for long periods of time. Since normal individuals are typically asleep for most of the overnight testing duration, agreement rates between actigraphy and PSG tend to be high. Conversely, the agreement rates are lower for the subjects with disturbed sleep. Thus, Tyron's [6] method of reporting accuracy as well as sensitivity and specificity is a more appropriate way of depicting the validity of actigraphy.

This study found actigraphy to be excellent in

Table 4
Means (±standard deviations) of statistical measures by epoch-by-epoch comparison of actigraphy and PSG by diagnosis[a]

Diagnosis	*n*	Sensitivity	Specificity	Accuracy
OSAS	40			
Low threshold		0.94 ± 0.057	0.43 ± 0.147	0.76 ± 0.112
Medium threshold		0.97 ± 0.033	0.34 ± 0.138	0.74 ± 0.128
High threshold		0.99 ± 0.015	0.24 ± 0.118	0.73 ± 0.142
OSAS + PLMD	26			
Low threshold		0.90 ± 0.092	0.49 ± 0.159	0.78 ± 0.082
Medium threshold		0.95 ± 0.058	0.39 ± 0.148	0.79 ± 0.093
High threshold		0.98 ± 0.031	0.29 ± 0.139	0.78 ± 0.107
UARS	10			
Low threshold		0.94 ± 0.052	0.45 ± 0.200	0.74 ± 0.146
Medium threshold		0.97 ± 0.030	0.36 ± 0.194	0.72 ± 0.167
High threshold		0.99 ± 0.013	0.25 ± 0.163	0.70 ± 0.176
UARS + PLMD	9			
Low threshold		0.91 ± 0.050	0.63 ± 0.174	0.83 ± 0.070
Medium threshold		0.95 ± 0.036	0.52 ± 0.167	0.84 ± 0.083
High threshold		0.97 ± 0.020	0.40 ± 0.138	0.84 ± 0.099
Other	15			
Low threshold		0.93 ± 0.060	0.50 ± 0.202	0.79 ± 0.129
Medium threshold		0.96 ± 0.039	0.42 ± 0.166	0.79 ± 0.152
High threshold		0.98 ± 0.022	0.30 ± 0.136	0.77 ± 0.178
Overall	100			
Low threshold		0.92 ± 0.069	0.48 ± 0.175	0.77 ± 0.110
Medium threshold		0.96 ± 0.042	0.38 ± 0.163	0.77 ± 0.128
High threshold		0.98 ± 0.022	0.28 ± 0.142	0.76 ± 0.144

[a] OSAS, obstructive sleep apnea syndrome; UARS, upper airway resistance syndrome; PLMD, periodic limb movement disorder; Other, insomnia, narcolepsy, idiopathic hypersomnia, restless legs syndrome.

detecting sleep with a sensitivity of 0.92 with the low-threshold algorithm and 0.98 with the high-threshold algorithm. In concordance with previous studies, the specificity (i.e. actigraphy's ability to accurately detect wakefulness) was much lower (0.48). The accuracy (0.78) was compatible with the numbers reported by earlier studies studying sleep-disturbed patients [2,9–13].

Our data also indicated that actigraphy significantly overestimated total sleep time and sleep efficiency in our sleep-disordered population, who were predominantly afflicted with disorders of excessive somnolence. These findings are compatible with those reported in prior studies [12–16]. Although the subjective questionnaire data did not overestimate these parameters in our sleep-disordered population, the subjects were worse in recognizing their awakenings compared to the actigraphic or PSG data. This latter finding may be due to such factors as the subject's perception or recall of an awakening (versus our PSG and actigraphic definition of at least one 30-s

Table 5
Pearson correlation coefficients of statistical measures by epoch-by-epoch comparison of actigraphy (low-threshold algorithm) and PSG[a]

	No. of awakenings	TST	SE
Sensitivity	− 0.23	− 0.20	− 0.24
Specificity	− 0.04	0.30	0.40*
Accuracy	− 0.14	0.73*	0.80*

[a] Significance: $*P < 0.05$.

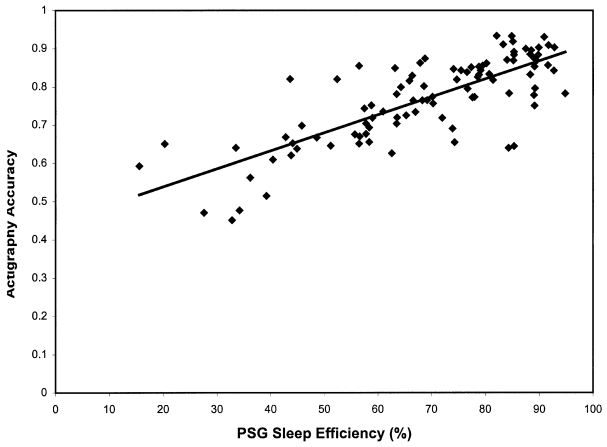

Fig. 1. Graph of actigraphy accuracy (low-threshold algorithm) vs. sleep efficiency by PSG for the 100 subjects. The least-squares fit for the linear trend is based on the equation, $y = 0.0047x + 0.444$. The Pearson correlation coefficient is 0.80 with a Bonferroni probability of $P < 0.00001$.

epoch), the depth and stage of sleep during which each awakening occurred, and the type of sleep disorder. When actigraphic data and subjective data were combined for total sleep time and sleep efficiency during a post hoc analysis, we found that the sleep parameters from these combined data were not significantly different from those of PSG data.

Thus, we recommend that clinicians should use subjective data (e.g. sleep logs) as an adjunct to actigraphic data when evaluating total sleep time and sleep efficiency. This may be especially important in patients with disorders of excessive somnolence (e.g. the obstructive sleep apnea syndrome, upper airway resistance syndrome, periodic limb movement disor-

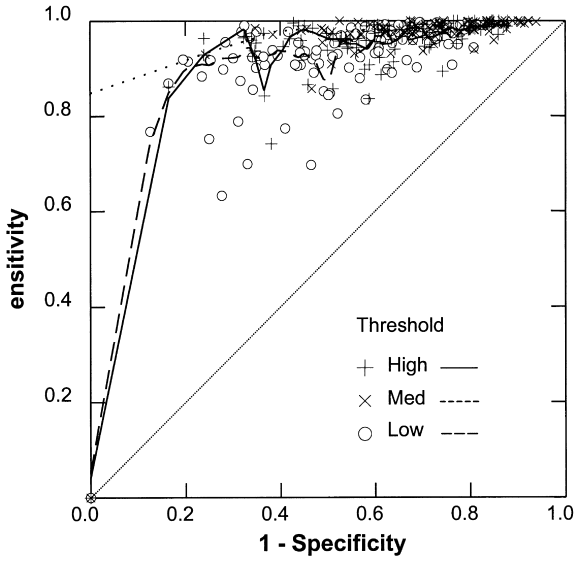

Fig. 2. Graph of sensitivity vs. 1 − specificity data from each of the 100 subjects, plotted for the low-, medium-, and high-threshold settings. The curves for each setting were generated by an iterative locally-weighted least squares smoother algorithm (SYSTAT®, v. 7.0, SPSS Inc., Chicago, IL) which does not presuppose the shape of the function [7].

der, idiopathic hypersomnia, narcolepsy). The post hoc method we used to combine actigraphic and subjective data is one approach for increasing accuracy in estimates of total sleep time and sleep efficiency by actigraphy, though additional validation of this method is necessary. Conversely, subjective data appear to be less sensitive than actigraphy for documenting sleep fragmentation, particularly in patients with insomnia [17]. Further work is recommended to refine the current actigraphic algorithms to achieve closer agreement with polysomnography, enabling the clinician to accurately assess sleep–wake patterns in a wide spectrum of sleep-disordered patients.

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