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Original Article

The role of actigraphy in the assessment of primary insomnia: a retrospective study

Vincenzo Natale [a,*], Damien Léger [b], Monica Martoni [c], Virginie Bayon [b], Alex Erbacci [a]

[a] Department of Psychology, University of Bologna, Bologna, Italy
[b] Université Paris Descartes, Sorbonne Paris Cité, APHP, Hôtel-Dieu de Paris, Centre du sommeil et de la vigilance, Paris, France
[c] Department of Specialised, Experimental and Diagnostic Medicine, University of Bologna, Bologna, Italy

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ABSTRACT

Objective: The aim of our study was to evaluate quantitative actigraphic criteria obtained using the Actiwatch device (AW64; Cambridge Neurotechnology Ltd., Cambridge, UK) to differentiate participants with insomnia from normal sleepers.
Methods: In our retrospective study, we recovered 493 actigraphic records from two sleep measure databases of patients with insomnia ($n = 151$) and one of normal sleepers ($n = 342$). We considered the following actigraphic sleep parameters: time in bed (TIB), sleep-onset latency (SOL), total sleep time (TST), wake after sleep onset (WASO), sleep efficiency (SE), number of awakenings (NWAK), terminal wakefulness (TWAK), fragmentation index (FI), and mean motor activity (MA). We also considered two actigraphic circadian indexes: interdaily stability and intradaily variability. Using the Youden index, we calculated the quantitative actigraphic criteria that performed best for each actigraphic sleep parameter. Finally, we created receiver operating characteristic curves to test the accuracy of each criterion identified.
Results: All sleep parameters except TST and TWAK differentiated the two groups of participants, allowing calculation of quantitative actigraphic criteria. There were no differences in the circadian indices.
Conclusions: The quantitative actigraphic criteria obtained in our study were not the same as those obtained previously with a different device, suggesting the need to adopt shared technical solutions for actigraphy.

1. Introduction

Epidemiologic data indicate that insomnia is the most common sleep concern in the industrial world [1]. The *International Classification of Sleep Disorders*, Second Edition (ICSD-2) [2], identifies insomnia as one of eight major categories of sleep disorders and lists 12 specific insomnia disorders within this group. Insomnia can be defined as a subjective report of difficulty with sleep initiation, duration, consolidation, or quality occurring despite adequate opportunity for sleep resulting in daytime impairment. Routine clinical evaluation of a patient with insomnia essentially consists of carefully collecting the patient's sleep history, performing a clinical interview and standard questionnaires, and conducting a physical and mental status examination. Objective sleep assessment is only recommended in specific cases to provide supporting information [3,4].

One of the 12 specific types of insomnia is paradoxical insomnia, previously termed *sleep-state misperception*, i.e., a condition in which there is a complaint of insomnia without objective evidence of a sleep disorder. The computation of a misperception index has recently been proposed (objective total sleep time [TST] – subjective TST/objective TST), in which positive values correspond to underestimation of sleep time and negative values to overestimation [5]. Harvey and Tang [6] did not exclude the possibility that such an index could be added to the standard research assessment of insomnia, making objective sleep assessment a necessary part of the clinical evaluation of patients with insomnia [7,8].

However, objective sleep evaluation still creates pragmatic problems. The accepted gold standard for sleep assessment is polysomnography (PSG). This technique requires that participants either come to a sleep laboratory or be connected to portable PSG equipment at home, creating a considerable burden to participants and increasing study costs. Moreover, because of the high variability of insomniac sleep and problems related to the first-night effect, PSG is not indicated for routine evaluation of chronic insomnia [9]. A possible alternative to PSG could be actigraphy

* Corresponding author. Address: Department of Psychology, University of Bologna, Viale Berti Pichat, 540127 Bologna, Italy. Tel.: +39 051 2091846; fax: +39 051 243086.
E-mail address: vincenzo.natale@unibo.it (V. Natale).

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[10–12]. Actigraphy has several limitations and strengths compared to PSG. On the one hand, actigraphy measures motor activity, and hence only indirectly sleep; sleep-stage identification is not possible. On the other hand, actigraphy is less costly and less intrusive than PSG. Patients can be studied in their own home environment for multiple nights. It provides additional information about daily and circadian patterns of motor activity, and it is relatively easy to use in ambulatory settings [13].

One of the unresolved limits of actigraphy is the lack of quantitative criteria for the assessment of sleep quality. Vallières and Morin [14] showed that actigraphy is a reliable method for monitoring treatment response among patients with insomnia, i.e., for comparing pre- and posttreatment sleep quality. However, without standard quantitative criteria, it is difficult to use actigraphy for the diagnosis of primary insomnia. The best way to develop quantitative actigraphic criteria (QAC) would be to collect actigraphic data from a large sample of normal sleepers and to compare it with actigraphic data from patients with insomnia, enabling actigraphic cutoff values to be identified for assessment of sleep quality. Using the Basic Mini-Motion logger (Ambulatory Monitoring, Inc., Ardsley, NY), a recent study suggested preliminary QAC for the assessment of sleep quality in patients with primary insomnia [15]. The cutoff values were 12 min for sleep-onset latency (SOL), 16 movements for motor activity (mean number of movements within 1 min), 25 min for wake after sleep onset (WASO), and 92% for sleep efficiency (SE). However, these results were derived from a single limited sample using only one type of actigraph, and the study needs to be repeated in a larger sample and using different actigraph models.

Therefore, the aim of our study was to assess which QAC may be of use to differentiate participants with insomnia from participants with normal sleep using a different actigraph device (the Actiwatch – AW64; Cambridge Neurotechnology Ltd., Cambridge, UK) in a larger group of participants.

2. Methods

2.1. Population

We performed a retrospective study using actigraphic records from three anonymous databases. Informed consent was obtained for each database before original data collection. Actigraphic recordings of patients with insomnia came from the Centre du Sommeil et de la Vigilance, Hôtel-Dieu de Paris (database A) and the Service for Diagnosis and Treatment of Insomnia of the Department of Psychology, University of Bologna (database B). At the time of assessment, all participants underwent a 3-week sleep evaluation protocol; the actigraphy was performed during the second week of this protocol.

2.1.1. Inclusion criteria

We only included patients with a diagnosis of primary insomnia according to the qualitative criteria of the ICSD-2 and the research diagnostic criteria for primary insomnia [19] based on subjective complaints and clinical interviews according to the published recommendations for a standard research assessment of insomnia [3].

Patients must have complained of nocturnal sleep difficulties for at least three nights a week and for at least 6 months, with associated impact on daytime activities. The diagnosis of primary insomnia was confirmed in the two clinical centers under the supervision of accredited sleep specialists using semistructured interviews.

2.1.2. Exclusion criteria

Based on these interviews, participants with other sleep diagnoses, such as narcolepsy, sleep apnea, restless legs syndrome, or periodic limb movement disorder (PLMD), were excluded. Patients with psychiatric disorders or those who were using psychoactive medications or other drugs that can affect sleep (e.g., corticosteroids, β blockers) also were excluded. During the clinical assessments, patients were systematically assessed for significant symptoms of depression or anxiety using the Beck Depression Inventory [20] and the State-Trait Anxiety Inventory [21]. Patients with a Beck Depression Inventory score of 20 or higher or a State-Trait Anxiety Inventory score of 40 or higher were not considered as having primary insomnia.

Thus the final sample consisted of 151 patients with primary insomnia (55 men and 96 women), aged 42.67 ± 14.81 years (range, 15–76 years). Database C (control group) was compiled at the Laboratory of Applied Chronopsychology of the Department of Psychology, University of Bologna, Italy, using a series of previous studies [17,22–24] involving healthy participants. We retrospectively included 342 participants (142 men and 200 women) aged 31.81 ± 17.22 years (range, 15–82 years) from this database. None of the participants worked flexible time schedules or night shifts and none had complained of sleep disturbance or daytime symptoms due to unsatisfactory sleep. The exclusion criteria used in our previous studies [17,22–24] included sleep disorders, mental disorders, serious or acute illness, use of psychoactive medication, and disabilities interfering with or restricting mobility [3]. For inclusion in these previous studies [17,22–24], participants had to complete the 12-item General Health Questionnaire [25], the Sleep Disorders Questionnaire [26], and the Profile of Mood States [27]; participants who did not report any sleep disorder in the Sleep Disorders Questionnaire were included if they had a General Health Questionnaire score of four or less and a Profile of Mood States score of 250 or less.

2.2. Actigraphy

2.2.1. Hardware

The Actiwatch (AW64, Cambridge Neurotechnology Ltd., Cambridge, UK) device was used. The device hardware consists of a piezoelectric accelerometer with a sensitivity of $\geqslant$0.05 g. The sampling frequency is 32 Hz. Filters are set to 3–11 Hz by default. The Actiwatch weighs 16 g and has a nonvolatile memory of 64 Kb. Actigraphs were initialized by Actiwatch Activity and Sleep Analysis, version 5.32 (Cambridge Neurotechnology Ltd., Cambridge, UK) to collect data in 1-min epochs in accordance with the 2002 practice parameters for the use of actigraphy [10].

2.2.2. Software

Actigraph data files were analyzed by Actiwatch Activity and Sleep Analysis, version 5.32 (Cambridge Neurotechnology Ltd., Cambridge, UK). This software identified each epoch as sleep or wake using the mathematical model developed and validated by Oakley [16]. Sleep was scored when the total activity count (A) was equal to or less than the activity threshold setting according to the following formula: $A = an2(1/25) + an1(1/5) + a + a1(1/5) + a2(1/25)$, in which an2 and an1 were the activity counts from the prior 2 min and a1 and a2 were the subsequent 2 min.

2.2.3. Sensitivity threshold

The clinician could set the wake sensitivity threshold as high (20 counts per epoch), medium (40 counts per epoch), low (80 counts per epoch), or auto (mean score in active period*0.888/epoch length) before sleep scoring. No specific recommendations were provided by the manufacturer on how to use these thresholds. Thus to explore which threshold best discriminates patients with primary insomnia from normal sleepers, we considered all four AW64 wake sensitivity settings.

2.2.4. Recordings

All participants wore the actigraph on the nondominant wrist for at least seven consecutive nights [28]. Participants were instructed to push the event-marker button on the device to mark occurrences such as time in and out of bed. During the recorded period, participants had to complete a sleep diary every day within 30 min of the last morning awakening.

2.2.5. Scoring

Automatic scoring using the event-marker points was checked by an experienced scorer with the help of information present in the sleep diary to determine the participants' time in bed (TIB). If participants forgot to push the event-marker button, the scorer only referred to the sleep diary information and vice versa. If both types of information were lacking, the night was excluded from the analyses.

2.3. Sleep measures

We considered the following sleep measures: (1) the time when the participant went to bed and switched off the light (bedtime) and the time when the participant last woke up in the morning (get up time); and (2) TIB was the time expressed in minutes between bedtime and get up time. Actiwatch Activity and Sleep Analysis software calculated sleep start independently of the sleep–wake discrimination algorithm based only on the presence of movement or no movement. Sleep start was defined using the first immobile block at least 10 min after bedtime with no more than one epoch of movement. The first epoch of this block was classified as sleep start. Therefore, this sleep parameter was not influenced by the wake sensitivity threshold.

SOL corresponds to the interval in minutes between bedtime and sleep start. For sleep end, the algorithm is used to search for a 10-min period of activity around get up time and then works backwards to locate the last epoch of immobility before the start of such a sequence and classifies that as sleep end. Terminal wakefulness (TWAK) is the amount of wake time, in minutes, between the sleep end and the Get up Time. TST corresponds to the sum in minutes of all sleep epochs between sleep-onset time and sleep end. WASO is the sum in minutes of all wake epochs between sleep start and sleep end. SE percentage (SE%) is the ratio of the TST to the TIB multiplied by 100. The number of sleep interruptions, i.e., the number of awakenings (NWAK), also was computed.

One of the recommendations for future research proposed by the Standards of Practice Committee of the American Academy of Sleep Medicine was to analyze specific actigraphic parameters for which there are no correlated PSG values and usually are not considered during sleep evaluation. Therefore, we considered the mean motor activity (MA) (mean number of movements within one epoch) during sleep and the fragmentation index (FI). The FI is suggested to be an indicator of restlessness and corresponds to the sum of the percentage of moving epochs within the sleep period and the percentage of immobility phases of 1 min out of all immobility phases.

Finally, we also considered two circadian sleep-wake rhythm parameters present in the output of Actiwatch Activity and Sleep Analysis software: interdaily stability (IS) and intradaily variability (IV). IS quantifies the strength of coupling of the sleep–wake cycle to the 24-h regularity in the environment. A low IS is indicative of a weak circadian rhythm. The IV quantifies the fragmentation of periods of rest and activity. A high IV is indicative of many transitions between period of rest and activity [29].

2.4. Statistical analyses

Sex distribution was similar in the two samples ($\chi^2 = 1.13$; $P = .28$). In contrast, mean age was different ($F_{[1,450]} = 42.34$; $P < .0001$). Therefore, we systematically inserted age as a covariate in the analyses. For each sleep measure, independent analyses of covariates (age as covariate) were performed to compare the insomnia group to the control group. For sleep parameters influenced by the wake sensitivity threshold, analyses were repeated for each sensitivity level. In view of the large size of the sample, we decided to set the cutoff value for significant results at $P < .00005$ [30].

The sleep parameters that were significantly different in the insomnia and control groups were further analyzed. Various cutoff values for each parameter were tested regarding sensitivity and specificity. Sensitivity was the proportion of accurately classified individuals who reported insomnia. Specificity was the proportion of accurately classified individuals who reported having no sleep problems. The Youden index (i.e., the highest value obtained when calculating sensitivity + specificity-1) was used to determine optimal cutoff values [31]. For each QAC, we generated a receiver operating characteristic [32] curve. Values for the area under the receiver operating characteristic curve (AUC), which graphically depicted the relation between sensitivity and specificity, were used as figures of merit.

For each QAC, positive (the probability that someone who tested positive with the actigraph really had insomnia) and negative (the probability that someone who tested negative with the actigraph was actually a normal sleeper) predictive values also were computed. All statistical analyses were performed using SPSS 18.0 (SPSS, Inc. Chicago, IL).

3. Results

Sleep measure results for the two groups are shown in Table 1. In the first section, results of sleep measures based directly on motor activity are shown; in the other four sections, data relative to sleep measures scored according to the algorithm for each of the four wake sensitivity thresholds (low, medium, high, and auto) are presented. Patients with insomnia tended to go to bed earlier and wake up later than control participants. Hence the insomnia group stayed in bed (TIB) significantly longer (approximately 40 min longer) than the control group. The insomnia group had significantly higher values for SOL, MA, and FI than the control group. The insomnia group significantly differed from the control group for WASO, NWAK, and SE%. The insomnia group achieved the same number of hours of sleep (TST) as the control group, except when the auto wake sensitivity threshold was used.

To distinguish the insomnia group from the control group, all the wake thresholds were similarly performed. However, in the control group only the SE% derived with a low wake threshold was higher than the cutoff value for adequate sleep (85%) provided in the literature [4]. Therefore, we only further analyzed the sleep parameters derived using the low wake sensitivity threshold. According to the Youden index, the following cutoff values should be optimal: SOL of 14 min, MA of 21 min, FI of 35 min, Low_WASO of 40 min, Low_NWAK of 22 min, and Low_SE% of 87%.

The performance varied across actigraphic sleep parameters with the AUC ranging from .60 to .74. Low_WASO, Low_SE%, and MA had AUCs higher than .70 (fair accuracy). However, the parameter that seemed to perform best was the Low_WASO, with higher sensitivity and negative predictive value (Table 2).

4. Discussion

The aim of our study was to evaluate if the QAC previously obtained using the Basic Mini-Motionlogger actigraph [15] could be

Table 1
Sleep measures (means and standard deviation) for insomnia and control group. The Table is divided into 2 sections.

	Control group	Insomnia group	*F*	*P* value
Bed time[a]	24:11 ± 1:19	23:50 ± 1:12	1.62	n.s.
Get up time	07:53 ± 1:16	08:15 ± 1:25	30.01	<.00001
TIB	462.91 ± 48.98	505.54 ± 64.07	93.73	<.00001
SOL	9.27 ± 7.48	16.05 ± 14.71	33.57	<.00001
MA	16.97 ± 6.78	27.30 ± 17.69	45.10	<.00001
FI	28.98 ± 8.97	37.33 ± 16.88	37.49	<.00001
IS	.53 ± .12	.51 ± .13	13.06	n.s.
IV	.85 ± .21	.81 ± .24	.29	n.s.
Low_TST[b]	413.84 ± 45.59	425.49 ± 69.72	14.49	n.s.
Low_NWAK	23.52 ± 11.20	26.56 ± 9.74	23.13	<.00001
Low_WASO	35.79 ± 14.21	57.72 ± 32.08	115.04	<.00001
Low_TWAK	3.88 ± 3.24	6.28 ± 6.67	14.08	n.s.
Low_SE	89.46 ± 3.75	84.18 ± 8.63	72.84	<.00001
Medium_TST	389.86 ± 48.82	396.24 ± 70.93	6.03	n.s.
Medium_NWAK	28.91 ± 10.51	31.56 ± 8.87	20.58	<.00001
Medium_WASO	58.62 ± 20.88	87.12 ± 39.77	115.08	<.00001
Medium_TWAK	3.86 ± 3.23	6.12 ± 6.11	13.44	n.s.
Medium_SE	84.57 ± 4.88	78.35 ± 10.01	71.55	<.00001
High_TST	363.73 ± 48.70	364.68 ± 71.53	2.27	n.s.
High_NWAK	30.45 ± 9.54	32.40 ± 7.97	15.01	n.s.
High_WASO	84.88 ± 26.48	118.75 ± 45.92	115.79	<.00001
High_TWAK	3.99 ± 4.16	6.06 ± 6.09	8.24	n.s.
High_SE	78.91 ± 5.76	72.12 ± 10.99	68.76	<.00001
Auto_TST	414.68 ± 53.10	433.34 ± 66.85	24.84	<.00001
Auto_NWAK	21.94 ± 9.06	24.25 ± 8.14	19.94	<.00001
Auto_WASO	32.62 ± 12.09	50.04 ± 25.08	101.74	<.00001
Auto_TWAK	3.87 ± 3.24	6.09 ± 6.10	12.63	n.s.
Auto_SE	90.13 ± 3.14	85.61 ± 7.09	69.84	<.00001

Abbreviations: n.s., not significant; TIB, time in bed (min); SOL, sleep-onset latency (min); MA, mean motor activity (number of movements in 1 epoch); FI, fragmentation index; IS, interdaily stability; IV, intradaily variability; NWAK, number of awakenings; WASO, wake after sleep onset (min); TWAK, the time (min) between sleep end and get up time; SE, sleep efficiency.

[a] In the first section, sleep parameters derived from any sleep algorithm are grouped: bedtime refers to the moment at which subjects go to bed and switch off the light, and get up time refers to the moment at which subjects wake up for the last time in the morning.

[b] In the second section, sleep measures for each wake sensitivity threshold (low, medium, high, and auto) are reported.

replicated with a different actigraph device (the Actiwatch) in a larger group of participants. Our study enabled us to confirm that actigraphy is a satisfactory tool for objectively distinguishing patients with primary insomnia from normal sleepers. However, the QAC differed from those found in previous research [15] (see Table 2). Therefore, we may conclude that QAC are strongly linked to the type of actigraphic device. This conclusion is in line with a recent review on the role of actigraphy in sleep medicine [13], and we believe that this finding could present a problem for the routine clinical use of actigraphy. We conceive two possible solutions to this potential problem: (1) the companies involved should reach an agreement on a standard solution for the accelerometer and algorithms used; and (2) the companies should promote basic research to define the QAC for their specific actigraph device.

In both studies, patients with insomnia had lower SE than the control participants. In the earlier study, patients with primary insomnia had a similar TIB but a lower TST than control participants; conversely, participants with insomnia had a similar TST but a higher TIB in our study. This result was unexpected as it appears more logical that participants with insomnia would have a shorter TST than those with no complaint of insomnia. The findings may be partly explained by the study inclusion criteria. The qualitative criteria of the ICSD-2 and the research diagnostic criteria for primary insomnia [19] do not include limited TST in their definition. In our group, we did not include those with a suspicion of depression or anxiety. Nevertheless, there are no specific data to indicate how anxiety or depression may impact on TST in patients with insomnia. It also is plausible that TIB, and thus indirectly TST, could reflect characteristics of the study sample, whereas SE more adequately reflects sleep quality irrespective of cultural, biologic, or geographic confounding factors. Therefore, it is possible to conclude that global sleep quality (SE) more typically reflects insomnia than sleep quantity (TST). Considering the actigraphic indices with AUCs larger than .70 (fair accuracy), we can conclude that motor activity (MA), wake after sleep onset (Low_WASO), and sleep efficiency (Low_SE%) are reliable actigraphic indices for discriminating patients with primary insomnia from normal sleepers using the Actiwatch AW64.

Interestingly, the SOL of participants with insomnia was relatively short (16.05 ± 14.71 min), though it was still significantly longer than that of the control group (9.27 ± 7.48 min). Clinical standards [3,4] define sleep initiating insomnia as an SOL longer than 30 min at least three times a week for at least 1 month. We found a cutoff SOL of 12 min in our earlier study [15], but recognize that we did not only include participants with sleep initiating insomnia, but also those with sleep maintenance or with early morning awakening insomnia. Our study confirms once more that SOL may be objectively shorter than the values subjectively reported by patients.

All wake sensitivity thresholds significantly differentiated sleep of participants with insomnia from that of the control group. Moreover, the overall performance of low wake sensitivity for our control group seemed similar to that of normal sleepers (i.e., SE >85%). These data correlate with previously published results [17,18] and highlight the importance of indicating which wake sensitivity threshold is selected when using the AW64.

There were no significant differences between the groups in the indices of circadian rhythm (IS and IV). Thus it is possible to hypothesize that altered circadian rhythm is not a systematic feature in patients with primary insomnia. Conversely, both MA and FI showed adequate specificity (.79 and .78, respectively)

Table 2
For each sleep measure the value of the area under the cutoff value and receiver operating characteristic curve with associated sensitivity and specificity and positive and negative predictive values are indicated. In the first section, sleep parameters derived from motor activity are shown; in the second section, sleep parameters derived from the sleep algorithm set on low sensitivity are reported. In this research the actigraph, Actiwatch (AW64; Cambridge Neurotechnology Ltd., Cambridge, UK), was used. In previous research [15] the Basic Mini-Motionlogger (Ambulatory Monitoring, Inc., Ardsley, NY) was used.

	Previously proposed cutoff value [15]	Cutoff value	Area under ROC curve	Sensitivity	Specificity	Positive predictive value	Negative predictive value
SOL	12	14	.64	.42	.82	.50	.76
MA	16	21	.71	.54	.79	.53	.79
FI		35	.67	.46	.78	.48	.76
Low_WASO	25	40	.74	.68	.68	.49	.83
Low_NWAK		22	.60	.68	.55	.40	.79
Low_SE	92%	87%	.72	.50	.74	.47	.77

Abbreviations: ROC, receiver operating characteristic curve; SOL, sleep-onset latency; MA, mean motor activity (number of movements in 1 epoch); FI, fragmentation index; WASO, wake after sleep onset (min); NWAK, number of awakenings; SE, sleep efficiency.

and medium sensitivity (.54 and .46) for detecting primary insomnia. Thus the difference between patients with insomnia and good sleepers makes MA and FI adequate actigraphic indices to assess primary insomnia.

Despite the large sample size of our study, there are some methodologic limitations. First, we acknowledge that insomnia was only diagnosed by interview and not by PSG, which is considered the gold standard in the evaluation of sleep disorders. However, participants were carefully interviewed by sleep specialists and the questionnaires included questions designed to exclude participants with narcolepsy, sleep apnea, restless legs syndrome, PLMD, psychiatric disorders, sleep-disruptive medical conditions, and use of psychoactive medications or other drugs affecting sleep. Nevertheless, we recognize that PSG may have detected nonclinical cases of sleep apnea or PLMD.

Second, we retrieved actigraphic data from databases that had used different questionnaires for the two groups of participants: insomnia and normal sleepers. However, the sleep diary used with the actigraphy was the same in the two groups. Third, patient data were derived from two different database sources, and it is possible that the assessment of insomnia slightly differed from one center to the other. However, the definition of insomnia used was the same, based on the ICSD-2 criteria. It also is more interesting to use data from different countries, and we consider this a strength in our study.

In conclusion, our study confirms that actigraphy can differentiate participants with primary insomnia from normal sleepers in a large group of participants from two countries on most sleep parameters except TST and TWAK. However, the quantitative actigraphic criteria obtained with the Actiwatch in our study were not the same as those previously obtained with a different device, suggesting the need to adopt shared technical solutions for the development of this important sleep tool.

Conflict of interest

The ICMJE Uniform Disclosure Form for Potential Conflicts of Interest associated with this article can be viewed by clicking on the following link: http://dx.doi.org/10.1016/j.sleep.2013.08.792.

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