

Actigraphy, does it add value?

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Abstract

Actigraphy (activity-based monitoring) has become an essential tool in sleep research and sleep medicine. The validity and limitations of actigraphy in documenting sleep-wake patterns are discussed. Some normative data exists across groups. Actigraphy has been used in a variety of clinical sleep disorders such as circadian rhythm sleep disorders, both in terms of diagnosis and in follow-up as well as in intervention studies. Limitations of actigraphy exist. Controlling artifacts by using sleep logs and diaries will improve the efficacy. It is not sufficient as a stand-alone device to diagnose sleep-disordered breathing and any disorder which cause motion artefact limits its utility.

Keywords: Actigraphy, validity, circadian rhythm sleep disorders, intervention studies.

Introduction and background

Actigraphy is a term used to describe methods for measuring activity (movement) through small computerized wristwatch-like devices.¹ Wrist activity technology is based on the fact that during sleep there is little movement, whereas during wake there is increased movement.²

It was in the 1970s that Kupfer, Colburn and Kripke first used activity to differentiate wake from sleep and also published reliability data on the use of wrist actigraphy for the assessment of sleep.³⁻⁶ The early actigraphs were small, but analogue and needed manual scoring. Modern actigraphs have a movement detector (e.g. accelerometers) with sufficient memory to record continuously for 24-hours and up to several weeks. Since many models are water resistant, they rarely have to be removed. Generally modern actigraphs are the size of a wristwatch and collect digitized data (Figure 1). They are

generally worn on the non-dominant wrist, although in theory it is possible to be worn on the ankle. Physical movement is generally sampled several times per second and stored in 1-minute epochs (although sampling and epoch rates can be set). The digitized data are then translated into a numeric representation and stored until downloaded into a computer.²

The analogue electrical signal that is digitized varies with the actigraphy and can sometimes be chosen by the user. In a recent review⁷ Ancoli-Israel et al. described three ways that analogue signals could be digitized namely, time above threshold, zero crossing and digital integration (Figure 2).

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AW-2, AW-Spectrum, AW-Score

Figure 1: Example of modern day actigraphs
Reproduced from <http://www.actiwatch.respirionics.com/>.

Time above threshold counts the amount of time per epoch that the motion signal is above a given threshold, typically 0.1 to 0.2g. Two potential problems with this method are that the degree to which the signal is above threshold is ignored and the acceleration of the movement is not reflected. The zero-crossing method counts the number of times per epoch that the signal crosses zero. The problems with this method are once again neither the amplitude nor the acceleration is taken into account and high frequency artifacts may potentially be counted as movement. Digital integration samples the accelerometry output signal at a high rate and then, for each epoch, calculates the area under the curve. Amplitude and acceleration of the signal are reflected by this method, but not its duration and frequency. In studies comparing the three methodologies, digital integration was best for identifying movement amplitude, followed by time above threshold, and then followed by zero-crossing.⁸ Some newer devices utilize more than one method, thus reducing the deficits of utilizing only one method. Once the data are digitized, computer algorithms are used to

automatically score wake and sleep. They provide the user with summary statistics such as total sleep time, percent of time spent asleep, total wake time, percent of time spent awake, number of awakenings, time between awakenings and sleep onset latency.^{7,9,10} An example of an actogram report is shown (Figure 3). Different computer programs use different algorithms and there are no published articles comparing different algorithms. It is therefore important for the new user to understand that varying any part of the actigraph such as setting, recording mode and algorithm could change the final result.

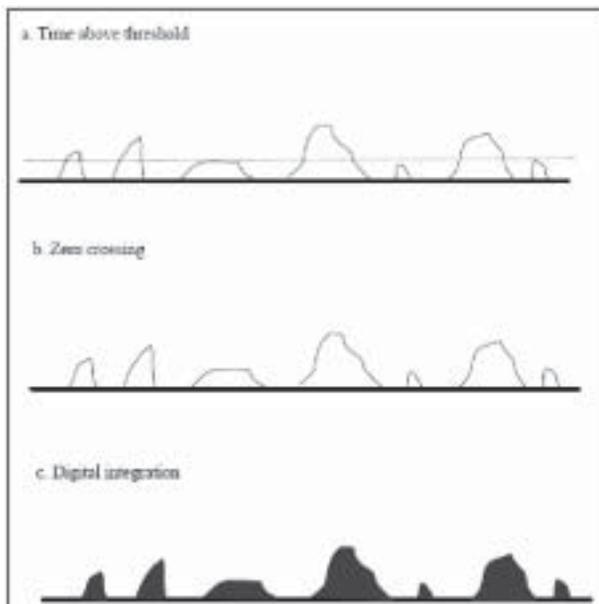
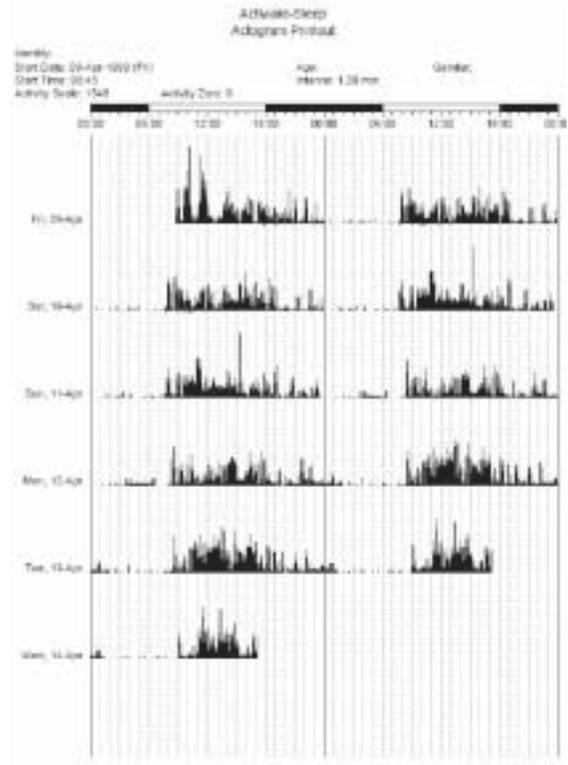


Figure 2: Three methods of deriving activity counts in actigraphy. **A,** Time above threshold, derives the amount of time per epoch that the activity is above some defined threshold (represented by a dashed line). **B,** Zero crossing counts the number of times the activity reaches zero (represented by the solid baseline). **C,** Digital integration calculates the area under the curves represented by black shadowing. Reproduced from Ancoli-Israel S, Cole R, Alessi CA et al: The role of actigraphy in the study of sleep and circadian rhythms. *Sleep* 2003; 26:342-92.



Date	30-Apr-1999 Fri	01-Apr-1999 Sat	02-Apr-1999 Sun	03-Apr-1999 Mon	04-Apr-1999 Tue
Bed time	22:21	22:28	23:28	20:50	20:13
Get up time	07:50	07:43	08:05	07:30	07:24
Time in bed	08:29	09:15	04:37	06:40	07:11
Sleep start	23:50	22:50	23:20	20:58	21:07
Sleep end	07:47	07:47	08:08	07:32	07:55
Assumed sleep	07:40	00:44	00:57	07:25	07:48
Actual sleep time	07:20	08:26	08:26	07:12	07:41
Actual sleep (%)	87.8	88.2	88.1	87.8	88.3
Actual wake time	00:10	00:39	00:27	00:11	00:07
Actual awake (%)	2.1	3.8	3.9	2.5	1.5
Sleep efficiency	86.7	91.3	89.2	85.9	86.8
Sleep latency	07:27	00:26	00:03	00:08	00:04
Wake bouts	10	10	14	8	8
Wake bouts	8	10	14	8	7
Mean sleep bout time	00:46:54	00:31:28	00:28:57	00:48:00	00:57:37
Mean wake bout time	00:07:07	00:07:28	00:07:30	00:07:22	00:07:00
Immobilize time	048.0	003.0	009.0	007.0	052.0
Immobilize time (%)	96.3	92.2	83.3	91.9	96.6
Moving time	20.8	41.8	00.0	26.0	10.0
Moving time (%)	4.3	7.8	12.9	3.5	3.4
1st immobility period	17	17	41	26	10
Mean length immobility	28.4	19.8	10.0	14.9	30.1
1 minute immobility	1	1	10	4	8
1 min immobility (%)	1.9	10.1	21.3	14.3	8.0
Total activity score	190	1793	2180	1130	873
Mean activity score	1.00	9.42	11.82	6.28	4.72
Mean score in active	27.85	42.73	23.98	20.58	22.89
Fragmentation index	10.2	21.8	34.8	22.4	3.6

Figure 3: An example of an actogram and sample report showing summary statistics. Reproduced from pmbcii.psy.cmu.edu/core_d/actigraphy_reports.html

Validity of actigraphy measures

There are many published reports on the validity of actigraphs in measuring sleep/wake. Some of these studies will be mentioned at a later section. A study on the sensitivity and specificity of reporting by Tyron¹¹ and more recently by Pollak and colleagues^{12,13} using “predicted value for sleep” (PVS) have shown that actigraphy is better at detecting sleep, than detecting wake during the sleep period. Most studies of actigraphy validity compare it to polysomnogram (PSG) which is the “gold standard” in studies involving sleep. Studies indicate that in normal sleep, actigraphy data correlate well with PSG data in the range of 0.89-0.98^{6,7,14,15}, but are somewhat lower (correlation coefficients between 0.78-0.88) in severely disturbed sleep. Actigraphy has also been compared with sleep logs and diaries and in certain circadian rhythm disorders has been comparable. Author’s of a study comparing actigraphy to the MSLT¹⁶ concluded that actigraphy during the day may yield a more accurate index of the effects of sleepiness. It is important to know very little-to-no evidence exists for the validity of many of the variables routinely computed for the output of actigraphy analysis software (e.g., sleep-onset latency, sleep bouts, wake bouts, motionless sleep, movement indices, circadian parameters).

Actigraphs as mentioned are usually worn on the non-dominant wrist. Two studies^{17,18} showed no difference between data collected from actigraphs placed at different locations, but other studies have established wrist placement as being superior¹⁹. There are some potential artifact problems. These include removal of device (non-compliance), from breathing movements, externally imposed movement from riding in vehicles⁷, forgetting to reattach the device¹, participating in quiet at-home activities (e.g. watching television), using medications that affect movement or sleep and sleeping with a bed partner. Controlling artifacts¹ by the use of sleep-wake logs or diaries or daily telephone calls is especially helpful. Some actigraphs have an event marker feature which allows the users to denote important events. Other actigraphs can record level of light and transpose it on the actigraph record. Some devices have external buttons to perform a “sound check” to ensure that the actigraph is working.

Advantages of actigraphy

One of the major advantages of actigraphy is that multiple nights (up to weeks) can be recorded together. It is simple to use in a non-laboratory setting and it is a simple efficient

means of evaluating sleep in situations where PSG is too cumbersome. It also appears to be useful in other populations where PSG difficult to obtain, such as nursing home patients, infants and young children.

What actigraphy actually measures

Actigraphy simply measures movement of a limb²⁰. It does not measure sleep as it is commonly defined and certainly does not measure the same parameters such as an electroencephalogram. It does not measure the subjective experience of sleep (as do sleep logs and questionnaires). For e.g., actigraphy generally underestimates sleep onset latency because many subjects are inactive and awake for a period of time (quiet wakefulness) prior to electroencephalographically defined sleep.

Clinical applications of actigraphy

The American Academy of Sleep Medicine in their recent updated recommendations²⁰ concluded that actigraphy is a valid way to assist in determining sleep patterns in normal, healthy adult populations. More specifically actigraphy is indicated to assist in the evaluation of patients with certain circadian rhythm sleep disorders. In the second edition of the International Classification of Sleep Disorders²¹ actigraphy is listed as a diagnostic tool for several specific sleep disorders. Some common important sleep disorders with evidence for actigraphic use will be discussed.

Insomnia

While there are quite a few studies using actigraphy to evaluate sleep in insomnia, there are hardly any that are validated with PSG. Chambers²² concluded that for insomnia patients, actigraphy is useful for the assessment of sleep variability or in the measurement of treatment effects. Wicklow²³ looked at intrusive thoughts in sleep-onset insomnia and found that certain categories of intrusive thoughts were associated with longer sleep-onset latencies measured by actigraphy but not by sleep logs.

Sleep-disordered breathing

Actigraphy cannot determine the presence or absence of abnormal breathing. There are no studies to date which propose the use of actigraphy alone in determining the presence of sleep apnoea. However patients with sleep

apnoea have more disrupted sleep and thus more body movements that can be detected by the actigraphy. Middelkoop and colleagues²⁴ in an epidemiological study consisting of actigraphy and airflow recording showed that patients with an apnea index of greater than 5 events per hour of sleep had higher movement and fragmentation indices compared to those with an apnea index of less than 5. Elbaz et al.²⁵ combined actigraphy with airflow, thoracic and abdominal movements and pulse oximetry. They found a modest increase in correlation with RDI estimates from traditional PSG when actigraphy was added to the airflow and thoracic and abdominal monitoring. However they did find that specificity and negative predictive value were substantially improved with the use of the actigraphy, but only for severe OSAS (RDI>30). In summary actigraphy while it may make a distinction between healthy individuals and those with moderate-severe OSA, it cannot determine the type of sleep-disordered breathing. Its real value in sleep apnoea is in combination with non-EEG stand alone devices.

Periodic Limb Movements in Sleep (PLMS)

The idea for using actigraphy in the detection and diagnosis of PLMS is appealing. Kazenwadel et al.²⁶ found high reliability between tibialis EMG and actigraphy for the number of leg movements per hour of sleep. In a study looking at actigraphy in the evaluation of the treatment efficacy for Syndrome Restless Leg (RLS)²⁷, Trenkwalder and coworkers studied the effects of L-Dopa therapy in uraemic and idiopathic restless legs syndrome and using actigraphy and PSG both at baseline and at the end of treatment period. They showed that, that treatment resulted in significant reductions in leg movements demonstrated by both PSG and actigraphy thereby confirming the usefulness of this device in evaluation of treatment efficacy. However, what limits the value of actigraphy in this group of patients is that actigraphy tends to underestimate the frequency of leg movements during sleep.⁷

Circadian Rhythm Sleep Disorders (CRSD)

Actigraphy allows the study of rhythms occurring over many days so it is well suited for the study of circadian rhythms. The latest practice parameters²⁰ published by the American Academy of Sleep Medicine in 2007 state that actigraphy is indicated in the evaluation of patients suspected of advanced sleep phase syndrome(ASPS), delayed sleep phase syndrome(DSPS), and shift work sleep disorder and

disorders such as jet lag and non-24-hour sleep/wake syndrome. There are many studies that have used actigraphy in the diagnosis of DSPS²⁸ or in the treatment effects of DSPS²⁹. Similarly there are good data for shift worker syndrome and jet lag.

Clinical intervention studies

Actigraphy is a very useful tool for intervention studies because it records for extended periods. With its ability to derive a large number of variables over a long period of time, it provides high statistical power for analysis of effects. It is of no surprise therefore that there are a growing number of studies which support the sensitivity of actigraphic measures used repeatedly during intervention studies. Some such studies have been discussed previously in this review. An example of such intervention studies would be along the lines of that performed by Vallieres and colleagues³⁰. In this study actigraphy and sleep logs were used in looking at different treatment effects on insomnia patients. Actigraphy performed better than sleep logs when compared to PSG and was sensitive in detecting the effects of treatment on several sleep parameters. The authors thus concluded that actigraphy was a useful device for measuring treatment response. Other studies indicate, that for some patients, actigraphy can be used as a screening device prior to PSG being ordered.

Paediatrics

There are an increasing numbers of studies that have used actigraphy in children. Actigraphy has been used successfully to characterize the sleep of infants, of developmental differences. It has been used in children with autism and to demonstrate differences in sleep between children with depression, abused children and unaffected children. An in depth review of the literature of this area is beyond the scope of this article.

Other groups

Actigraphy has been used to study sleep-wake patterns of older adults both in the community and in the nursing home. Sleep and circadian rhythm variables deduced from actigraphic recordings have been used as outcome measures in multiple studies of nursing home residents. It has also been used to differentiate different degrees of dementia in patients based on activity level. Actigraphy has also been

used to study circadian and 24 hour sleep-wake patterns in patients with schizophrenia and has also been used successfully in other mental illnesses such as depression. Studies on menopausal woman have shown that they experience more sleep disturbance. Studies on patients with cirrhosis suggest that they have decreased motor activity, more sleep fragmentation and dampened rhythms. Studies on patients with cancer demonstrate that those with more robust rhythms have less fatigue.

Summary and conclusions

Actigraphy is a cost-effective device that can record sleep in the natural environment. Although it inherently has some limitations, it clearly has advantages when PSG use is cumbersome or impractical in demented patients. While the role of actigraphy is still evolving, it has got increased usage especially in the field of Circadian disorders. It has also shown to be very useful in intervention and followup studies.

References

1. **Acebo C**, LeBourgeois MK. Actigraphy. *Respir Care Clin Am* 2006; 12(1): 23-30.
2. **Ancoli-Israel S**. In: Kryger MH, Roth T, Dement WC, editors. Principles and Practice of Sleep Medicine. Philadelphia: Elsevier Saunders, 2005: 1459-67.
3. **Kupfer DJ**, Weiss BL, Foster FG, Detre TP, Delgado J, McPartland RJ. Psychomotor activity in affective states. *Arch Gen Psychiatry* 1974; 30: 765-8.
4. **McPartland RJ**, Kupfer DJ, Foster FG. The movement-activated recording monitor: A third generation motor-activity monitoring system. *Behavior Research Methods & Instrumentation* 1976; 8: 357-60.
5. **Colburn TR**, Smith BM, Cuarini JJ, Simmons NM. An ambulatory activity monitor with solid state memory. *ISA Transactions* 1976; 15: 149-54.
6. **Kripke DF**, Mullaney DJ, Messin S, Wyborney VG. Wrist actigraphic measures of sleep and rhythms. *Electroencephalogr Clin Neurophysiol* 1978; 44: 674-6.
7. **Ancoli-Israel S**, Cole R, Alessi CA et al: The role of actigraphy in the study of sleep and circadian rhythms. *Sleep* 2003; 26:342-92.
8. **Gorny SW**, Spiro JR. Comparing different methodologies used in wrist actigraphy. *Sleep Review* 2001; Summer:40-2.
9. **Webster JB**, Kripke DF, Messin S, et al: An activity-based sleep monitor system for ambulatory use. *Sleep* 1982; 5: 389-99.
10. **Sadeh A**, Acebo C: The role of actigraphy in sleep medicine. *Sleep Med Rev* 2002; 6: 113-24.
11. **Tyron WW**. Activity and sleep. *Act Measure Psychol Med* 1991; 149-95.
12. **Pollak C**, Tyron WW, Nagaraja H, Dzwonczyk R. How accurately does wrist actigraphy identify states of sleep and wakefulness? *Sleep* 2001; 24(8): 957-65.
13. **Kushida CA**, Chang A, Gadkary C, Guilleminault C, Carrillo O, Dement WC. Comparison of actigraphic, polysomnographic and subjective assessment of sleep parameters in sleep-disordered patients. *Sleep Med* 2001; 398-96.
14. **Cole RJ**, Kripke DF, Gruen W, et al: Automatic sleep/wake identification from wrist activity. *Sleep* 1992; 15: 461-9.
15. **Jean-Louis G**, von Gizycki H, Zizi F, et al: Determination of sleep and wakefulness with the actigraphy data analysis software (ADAS). *Sleep* 1996; 19: 739-43.
16. **Roehrs T**, Turner L, Roth T. Effects of sleep loss on waking actigraphy. *Sleep* 2000; 23(6): 793-97.
17. **Jean-Louis G**, von Gizycki H, Zizi F, Spielman A, Hauri P, Taub H. The actigraphy data analysis software: I. A novel approach to scoring and interpreting sleep-wake activity. *Percept Mot Skills* 1997; 85(1): 207-216.
18. **Sadeh A**, Sharkey KM, Carskadon MA. Activity-based sleep-wake identification: An empirical test of methodological issues. *Sleep* 1994; 17: 201-7.
19. **Middelkoop HA**, Van Dam E, Smilde-van den Doel DA, Van Dijk G. 45-hour multiple-site actimetry in 20 healthy subjects: relations between body and limb movements and the effects of circadian sleep-wakefulness. *Sleep-Wake Research in the Netherlands* 1995; 681-4.
20. **Morgenthaler T**, Alessi C, Friedman L et al. Practice Parameters for the Use of Actigraphy in the Assessment of Sleep and Sleep Disorders: An update for 2007. *Sleep* 2007; 30: 519-29.
21. **American Academy of Sleep Medicine**. International classification of sleep disorders: Diagnostic and coding manual. 2nd ed. Westchester, IL: American Academy of Sleep Medicine; 2005.
22. **Chambers MJ**. Actigraphy and insomnia: A closer look Part I. *Sleep* 1994; 17(5): 405-8.
23. **Wicklow A**, Epsie CA. Intrusive thoughts and their relationship to actigraphic measurement of sleep: Towards a cognitive model of insomnia. *Behav Res Ther* 2000; 38: 679-93.
24. **Middelkoop HA**, Knuitingh NA, van Hilten JJ et al: Wrist actigraphic assessment of sleep in 116 community based subjects suspected of obstructive sleep apnoea syndrome. *Thorax* 1995; 50: 284-9.
25. **Elbaz M**, Roue GM, Lofaso F, Quera-Salva M. Utility of actigraphy in the diagnosis of obstructive sleep apnea. *Sleep* 2002; 25(5): 527-31.
26. **Kazenwadel J**, Pollmacher T, Trenkwalder C, et al: New actigraphic assessment method for periodic leg movements(PLM). *Sleep* 1995; 18: 689-97.

27. **Trenkwalder C**, Stiasny K, Pollmacher T et al. L-Dopa therapy of uremic and idiopathic restless legs syndrome: A double-blind, crossover trial. *Sleep* 1995; 18(8): 681-8.
28. **Quinto C**, Gellido C, Chokroverty S, Masdeu J. Posttraumatic delayed sleep phase syndrome. *Neurology* 2000; 54(1): 250-2.
29. **Okawa M**, Urata J, Uchiyama M et al. Melatonin treatment for circadian rhythm sleep disorders. *Psychiatry and Clinical Neurosciences* 1998; 52(2): 259-60.
30. **Vallieres A**, Morin CM. Actigraphy in the assessment of insomnia. *Sleep* 2003; 26: 902-6.