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The Role of Actigraphy in the Study of Sleep and Circadian Rhythms

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1.0 BACKGROUND

ACTIGRAPHY HAS BEEN USED TO STUDY SLEEP/WAKE PATTERNS FOR OVER 20 YEARS. The advantage of actigraphy over traditional polysomnography (PSG) is that actigraphy can conveniently record continuously for 24-hours a day for days, weeks or even longer. In 1995, Sadeh et al.,[1] under the auspices of the American Sleep Disorders Association (now called the American Academy of Sleep Medicine, AASM), reviewed the current knowledge about the role of actigraphy in the evaluation of sleep disorders. They concluded that actigraphy does provide useful information and that it may be a "cost-effective method for assessing specific sleep disorders...[but that] methodological issues have not been systematically addressed in clinical research and practice." Based on that task force's report, the AASM Standards of Practice Committee concluded that actigraphy was not indicated for routine diagnosis or for assessment of severity or management of sleep disorders, but might be a useful adjunct for diagnosing insomnia, circadian rhythm disorders or excessive sleepiness.[2] Since that time, actigraph technology has improved, and many more studies have been conducted. Several review papers have concluded that wrist actigraphy can usefully approximate sleep versus wake state during 24 hours and have noted that actigraphy has been used for monitoring insomnia, circadian sleep/wake disturbances, and periodic limb movement disorder.[3,4] This paper begins where the 1995 paper left off. Under the auspices of the AASM, a new task force was established to review the current state of the art of this technology.

Actigraphs are devices generally placed on the wrist (although they can also be placed on the ankle or trunk) to record movement. Collected data are downloaded to a computer for display and analysis of activity/inactivity that in turn can be further analyzed to estimate wake/sleep. The latter technology is based on the observation that there is less movement during sleep and more movement during wake. As described in Ancoli-Israel,[5] the first actigraphs were developed in the early 1970's.[6-8] Kripke and colleagues were some of the first investigators to publish reliability data on the use of wrist actigraphy for the assessment of sleep.[9-11] Over the years, additional types of actigraphs were developed leading to the digital types used today.

Actigraphs today have movement detectors (e.g., accelerometers) and sufficient memory to record for up to several weeks. Movement is sampled several times per second and stored for later analysis. Computer programs are used to derive levels of activity/inactivity, rhythm parameters (such as amplitude or acrophase) and sleep/wake parameters (such as total sleep time, percent of time spent asleep, total wake time, percent of time spent awake and number of awakenings).

2.0 OBJECTIVES

This paper reviews four major areas in which actigraphy is used for the measurement of sleep or rhythms. The first area of review covers the more recent papers on the technology and validity of actigraphy. Sadeh et al. concluded that the validation studies for normal subjects showed greater than 90% agreement and were very promising.[1] Actigraphs and computer programs using different algorithms to process the data have been commercially available for quite some time. Actigraphs differ in how they detect and record movements and they use different methodologies for computing activity levels. The output of the analysis programs has been compared to the results of PSG and sleep diaries. This section reviews the results and evaluates the conclusions of these types of studies.

The second area of review is of those studies examining actigraphy in populations with sleep disorders. Actigraphy is being used more often in studies of sleep disorders, either as an alternative to PSG, as an addition to partial unattended monitoring devices or for follow-up. This is especially common in patients with complaints of insomnia.

In addition to gaining information about sleep, data collected over long periods can be used to determine activity circadian rhythm cycles. Actigraphy is particularly useful for recording rhythms, as it is very difficult to record PSG for 24-hours and almost impossible to record for more than 24-hours. The use of actigraphy in studies of circadian rhythms comprises the third area of review.

The fourth area of review is those studies in which actigraphy was used as a treatment outcome measure or to examine the relationship between sleep/activity patterns and demographic or clinical variables. Since actigraphy is easier to use, less invasive and substantially less expensive than PSG, actigraphy is often used in lieu of PSG in both clinical trials where it is necessary to determine the effect of a treatment on sleep and in studies requiring multiple measurements.

3.0 METHODS

As with the first review in 1995, the Standards of Practice Committee of the American Academy of Sleep Medicine commissioned this updated review. A Medline literature search was conducted from the year 1995 to April 2002. Key words for the Medline search included actigraphy, actigraph, actigraphic recording, actimeter, actometer, wrist actigraph, actigraph recording, wrist activity, rest activity, activity, and sleep-wake activity, each paired with sleep, sleep disorders and sleep disorders-circadian. Articles published prior to the original American Academy of

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Sleep Medicine's (AASM) Practice Parameters for the Use of Actigraphy in the Clinical Assessment of Sleep Disorders[1] in 1995 were not included in the current update, and only articles written in English were included.

A total of 171 articles were identified as potentially relevant based on these Medline searches. All of these were obtained in full length and examined. Upon review of these articles, approximately 30 additional references were discovered by perling (i.e., checking the reference sections for articles otherwise missed). These were references located in publications not typically found through Medline. In an attempt to include all articles matching the stated criteria, task force members also added any articles they discovered through their personal review of the literature. All new articles published up to the point of the final draft of this manuscript (July 2002) were reviewed.

Only papers where actigraphs were used to measure some aspect of sleep/wake activity or circadian rhythms were included. Papers that only measured activity (without any reference to sleep) or that made measurements only in the daytime were excluded. Only papers published in English, in peer-reviewed journals, were included. Case studies and review articles were included in the narrative, but not in the evidence tables. No conference abstracts, even if published, were included. Papers were categorized into four sections: Technology, Sleep Disorders, Circadian Rhythms, and Other Clinical Research.

Within each category, task force members were assigned to read each paper, summarize the relevant points for the evidence tables and rate the study according to the evidence levels shown in Table 1. Abbreviations used in the evidence tables are described in Appendix A.

Table 1—Levels of Evidence for Actigraphy

Level[1]	Grade[2]	Criteria
1	A	Blind, prospective comparison of results obtained by actigraphy to those obtained by a reference standard[3] on an appropriate spectrum of subjects *and* number of patients.
2	B	Blind, prospective comparison of results obtained by actigraphy to those obtained by a reference standard[3] on a limited spectrum of subjects *or* number of patients.
3	C	Comparison of results obtained by actigraphy to those obtained by a reference standard[3], but not blind, not prospective or otherwise methodologically limited.
4	C	a - Adequate comparison of results obtained by actigraphy to those obtained by a non-standard reference[3]; *or* b - Actigraphy not compared to any reference, but actigraph results demonstrated ability to detect significant difference between groups or conditions in well-designed trial.
5	D	Actigraphy not adequately compared to any reference, and *either* a - Actigraph not used in a well-designed trial, *or* b - Actigraph used in such a trial but did not demonstrate ability to detect significant difference between groups or conditions.

[1] Level refers to level of evidence.
[2] Grade refers to grade of recommendation.
[3] Reference standards for actigraphic evaluation of sleep and circadian rhythms may include, as appropriate, polysomnography, oximetry, melatonin rhythms, core body temperature rhythms, and/or other generally accepted "gold standards," applied in an acceptable manner. Non-standard references include such items as sleep logs, spousal reports, other experimental monitors, etc.

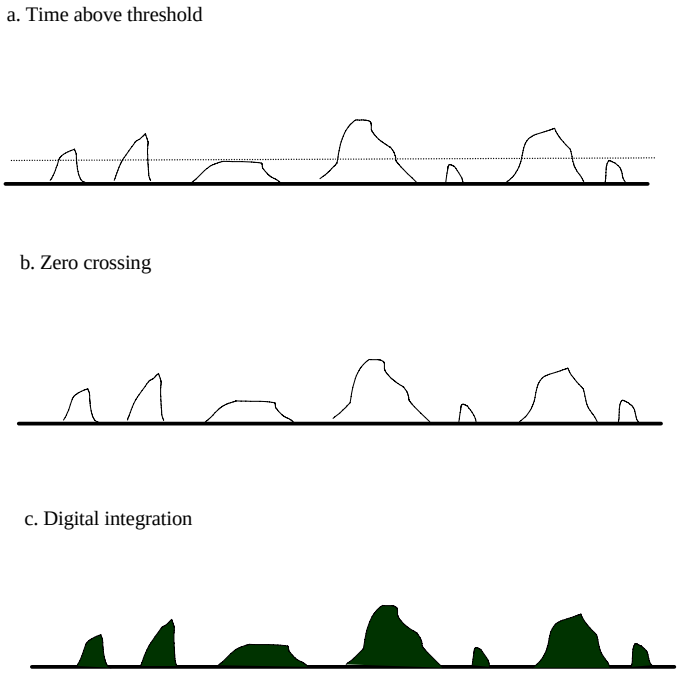


Figure 1—Three different methods for deriving activity counts in actigraphy. Panel A, time above threshold, derives the amount of time per epoch that the activity is above some defined threshold (represented by a dashed line). Panel B, zero crossings, counts the number of times the activity reaches zero (represented by the solid baseline) during the epoch. Panel C, digital integration, calculates the area under the curves represented by black shading. (Based on Gorny and Spiro (15))

4.0 TECHNOLOGY

The technology section (see Table 2) includes studies that compared functional differences between actigraphic devices, data acquisition strategies, and software programs. The question asked was, "How well did the devices and the computer programs that process data, assess states of sleep/wake and related phenomena?"

4.1 Data Acquisition

Mechanically, the first generation actigraphs were threshold-motion detectors, which were nonlinear and failed to be sensitive enough to detect small movements.[12] They also tended to saturate with modest levels of movement. Some of the newer actigraphs detect motion with linear accelerometers in a single axis or multiple axes.[12] Most single axis acceleration devices in use today use .25 to 2-3Hz bandpass filtering before data are stored, essentially eliminating very slow movements of less than .25 Hz and movements faster than 2-3 Hz. This is consistent with the early recommendations of Redmond and Hegge who noted that voluntary human movement rarely exceeds 3-4 Hz, and that involuntary movements such as tremor and shivering exceed 5Hz.[13] However, van Someren et al. suggested using 0.5-11Hz bandpass filters that would reduce gravitational artifacts while picking up some of the faster movements that occur in younger subjects.[14]

After motion is transduced into an analog electrical form, it is digitized and stored. Some aspects of these processes are programmable by the user, such as the length of the epoch over which activity counts are accumulated and stored. Other aspects of the digitizing are built into the device. One key component is how the analog signal is digitized: time above threshold, zero crossings, or integration (see Figure 1).

The "time above threshold" strategy cumulatively counts the amount of time per epoch that the level of the signal produced in response to motion is above some threshold (commonly 0.1 to 0.2 g). Two potential problems with this strategy are that the degree to which the amplitude is above threshold is ignored and that the acceleration of the movement is not reflected.

The "zero-crossing method" counts the number of times per epoch that the activity signal level crosses zero (or very near zero). Three potential problems with this approach are that the amplitude of the movement is ignored, the acceleration of movements is not registered, and high frequency artifacts may potentially be counted as considerable movement.

"Digital integration" involves sampling the accelerometry output signal at a high rate, then calculating the area under the curve for each epoch. Rectifying the analog signal doubles the amount of data available for analysis. Digital integration reflects acceleration and amplitude of movement, however duration and frequency of movements are not shown.

In direct comparisons of these three methods of deriving activity counts, using the same movement input, digital integration was found to be better for identifying movement amplitude than time above threshold and both digital integration and time above threshold were better than zero crossing.[15] Some devices simultaneously utilize more than one method of acquiring data thus increasing the benefits and reducing the deficits of utilizing only one method.

Many investigators have begun to report actigraphy data simply as activity counts. However, different devices, different data collection strategies,[12] and different scoring algorithms produce very different counts for the same activity.[15] These differences have made direct comparisons between laboratories and clinics difficult and contentious. Although *relative* changes in activity can be meaningful, more direct comparisons following computer processing of the data (such as sleep/wake scoring) are more meaningful.

4.2 Data Processing

Actigraphy data today are generally processed by computers, after the data are downloaded from the actigraphs, rather than by hand or eye. While most programs are designed to work with a specific device, some are intended to work with data produced by several, if not all, devices. Different programs often use different algorithms. However, there are no published articles comparing the different algorithms. Rather, published articles present information about the accuracy and/or usefulness of the outputs of specific computer programs. Before choosing an actigraph to use, two questions need to be asked and answered satisfactorily about such programs and the device(s) they work with:

1. Is the output reliable, that is, how well does the same input result in the same output?
2. Is the output valid, that is, how well does the output actually measure what it is purported to measure?

There are only a few published reports of direct studies of reliability between actigraphs and PSG. In general, when tested, actigraphy devices have been found to be reliable. Jean-Louis et al. compared new and old instruments of the same make and model in healthy adults and found no differences when the devices were worn on the same wrist (evidence level 3C).[16] In a second study when healthy adults wore two actigraphs, one on each wrist or two on the same wrist, correlations of activity counts were 0.80 to 0.96; when these data were converted to sleep/wake scores the agreement rates between pairs of devices ranged from 93% to 99% (evidence level 1A).[17] The correlations between devices for data collected just at night were between 0.60 and 0.96 and the sleep/wake scoring agreements again were between 93% and 99%.[17] Pollak and colleagues had their subjects wear actigraphs from two different manufacturers and found that there were differences between them (evidence level 3C).[18]

There are many published reports on the validity of actigraphs for measuring sleep/wake. Many of these are reviewed in other sections of this report. When comparing actigraphic to other biological variables, their similarity needs to be taken into account. If the actigraphic and other variables are judged to have equal standing, a measure of correlation is appropriate, but if one of the variables is invested with definitive importance ("gold standard"), different measures are needed to quantify how close actigraphy approaches the gold standard. For studies of sleep, PSG is considered definitive. Most tests of actigraph validity, therefore, involve comparing actigraphy with PSG. Comparison by correlation provides information about the relative, but not the absolute performance of actigraphy. For example, a high correlation on total sleep time would mean that individuals who sleep longer by PSG criteria also sleep longer by actigraph criteria, and vice versa, but this could be true even if actigraphy systematically over-estimated total sleep time. Therefore, it is possible for the correlation between actigraph and PSG sleep results to be high, even when the epoch-by-epoch agreement is relatively low. Correlations provide an incomplete picture, especially if most of the data come from the sleep period.[19]

An alternate approach is Tryon's method of calculating and reporting sensitivity, specificity, and overall accuracy or agreement (true sleep epochs + true wake epochs/all epochs) separately.[20] Sensitivity for sleep is the proportion of PSG sleep epochs also identified as sleep by actigraphy. Specificity for sleep is the proportion of non-sleep (wake) epochs correctly identified by actigraphy. Sensitivity and specificity for wakefulness are similarly defined. Agreement is the proportion of PSG epochs correctly identified by actigraphy. Sensitivity, specificity and agreement therefore assess actigraphic recorders using an established standard. Data collected using this scheme have shown that actigraphy is more likely to detect sleep (sensitivity) but less reliable at detecting wake (specificity) (evidence level 1A and 3C).[19,21]

More recently, Pollak and colleagues have suggested different ways to compute the performance of an actigraph's ability to detect sleep and wake.[21] They use "predicted value for sleep" (PVS) which is the proportion of actigraphic sleep epochs that are also classified as sleep by PSG, and use "predicted value for wakefulness" (PVW) which is the proportion of actigraphic wake epochs that are also classified as wakefulness by PSG. PVS answers the question, "What percentage of the epochs that the actigraph scores as sleep are true (PSG) sleep?" This is not the same as sensitivity for sleep, which answers the question, "What percentage of true (PSG) sleep epochs are detected by the actigraph?" Pollak and colleagues also report agreement rates but correctly point out that this measure is actually not very useful because it confounds PVS with PVW. For example, a high PVS but a poor PVW during the sleep period would yield a high agreement rate since most of the epochs would be sleep. This high agreement rate gives a false sense of validity since much of wake after sleep onset (WASO) could be mis-scored by actigraphy because of the low PVW. In fact, it has generally been shown that actigraphy is better at detecting sleep (high PVS) than at detecting wake (PVW) during the sleep period (evidence level 1A and 3C).[19,21] Results of future studies are likely to result in more useful measures if predictive values are reported in addition to sensitivity, specificity and agreement. It is worth noting that all of these measures vary with the proportion of recorded PSG epochs that represent sleep (base rate of sleep). During the sleep period, even malfunctioning recorders that are not being worn or are insensitive to movement will appear to accurately identify sleep if the low activity counts recorded by them are interpreted by scoring algorithms as "sleep".

4.3 Comparisons to PSG

As PSGs are still considered the gold standard, most studies have compared actigraphy to PSG. A technical difficulty in doing these comparisons is accurately time-locking the epochs of the actigraph with those of the PSG.[21] If they gradually drift apart, over time different segments of sleep or wake may be compared with each other, rendering the results meaningless. A related problem is how to compare the often-used 1-minute epoch of actigraphy with the standard 30-second epoch of PSG.

In these comparisons, low threshold actigraph algorithms (e.g., defining wake as occurring even when a small number of activity counts accumulated during the epoch) yielded the best accuracy rate and PVS, however, as sleep efficiency diminished, accuracy rate diminished (evidence level 1A).[19] Actigraph PVW was best with high threshold algorithms (e.g., defining wake as occurring when a large number of activity counts, such as 100, accumulated during the epoch) compared to low threshold algorithms but at a cost of lower accuracy and PVS.[19] One computer program, Actigraph Data Analysis Software (ADAS), which converts raw actigraph data into information about sleep/wake, has been shown to be valid when compared to PSG (evidence level 2B),[22] even when raw data were derived from different devices and in patients with insomnia (evidence level 3C).[16]

Other studies have also shown that actigraphy was highly correlated with PSG for differentiating sleep from wake (evidence level 2B and 3C respectively),[22,23] with reported correlations for total sleep time (TST) being 0.97.[22] Comparisons showed 91%-93% overall agreement in adults (age 20-30 years) (evidence level 2B),[24] and 91.4%-96.5%

minute-by-minute agreement rates in adolescents (age 10-16 years) and adults (age 20-30 years) (evidence level 1A).[17] In healthy adults, actigraphy was valid for assessing sleep durations and sleep/wake activity, but less reliable for more specific measures such as sleep offset or sleep efficiency (evidence level 3C).[25] There was also no first night effect in healthy adults (evidence level 3C).[16] In nursing home populations, Ancoli-Israel et al. reported correlations between actigraphy and PSG for TST of 0.81 - 0.91 and for percent sleep of 0.61 - 0.78 (evidence level 3C).[26]

There are discrepant reports about the validity of actigraphy for other sleep variables. One study of four adults found good correlations for sleep onset latencies, wake time after sleep onset, sleep efficiency, and total sleep time (evidence level 3C),[27] while two other studies of healthy adults found poorer relationships for sleep onset latency and wake time after sleep onset with quiet wake being frequently misidentified as sleep (evidence level 2B and 3C respectively).[22,23] Early actigraph validation research found that the correlation between actigraphy and PSG for sleep onset latency was only 0.53 when sleep onset was defined as the first minute of actigraph-estimated sleep, but jumped to 0.94 when sleep onset was defined as the beginning of the first period containing 20 minutes of actigraph-identified sleep with no more than one minute of wake intervening.[28] However, subsequent research has continued to use the first-minute definition. This may account for some of the observed error in actigraphic scoring not only of sleep onset latency, but also of variables that depend upon it, such as sleep efficiency and wake time after sleep onset. A study of healthy adults on a shiftwork schedule found poor relationships with sleep efficiency and less reliability for determining sleep offset compared to PSG (evidence level 3C).[25] Yet others found that actigraphy overestimated sleep efficiency and total sleep time in patients with sleep disorders (evidence level 1A).[19] To summarize, when compared to PSG, actigraphy was found to be valid and reliable for detecting sleep in normal, healthy adult populations but less reliable for detecting sleep as sleep became more disturbed (evidence level 2B).[22]

4.4 Comparisons to Observations, Sleep Logs, and Diaries

Actigraphy has also been compared to both direct observations of sleep and to sleep logs and diaries. In a study of the effects of circadian rhythms entrainment (entrained vs. free-running) on sleep by Lockley et al., sleep logs and actigraphy yielded similar data for sleep timing, sleep duration, sleep onset and sleep offset but not for sleep latency, number and duration of night awakenings or number of naps (evidence level 1A).[29] Nurses' observations of sleep in psychiatric patients were similar to actigraph data but sleep logs kept by patients in the morning were not found to be satisfactory (evidence level 4C-a).[30] Observations of nursing home residents by research staff yielded a PVS of 87% and PVW of 90% when compared to actigraphy (evidence level 3C).[26]

Monk et al. compared both actigraphs and sleep diaries to PSG during space flight (evidence level 3C).[31] Predicted values of actigraphy were clearly superior to those of diaries for sleep onset and offset, sleep duration, and sleep efficiency. The authors concluded that in general, actigraphy is a simple, efficient means of evaluating sleep in situations, such as space, when PSG is too cumbersome for routine use.[31] Dijk et al. measured wrist activity continuously in five astronauts during 10 to 16 days of space flight, and performed sleep PSG on four of those days (evidence level 3C).[32] They found that actigraphically estimated sleep duration was significantly longer on PSG-recording nights than non-PSG nights. They concluded that astronauts probably adhered more closely to their scheduled bedtime when their work duties included PSG sleep recording.

Actigraphy appears to be useful in other populations where PSG might be difficult to obtain, such as in nursing home patients as mentioned above,[26] or in infants and young children. In general, Sadeh concluded that with infants, actigraphy should be paired with parental sleep logs for screening infant sleep problems, although actigraphy appeared to be a more consistent measure than parents' sleep logs of the child's sleep/wake (evidence levels 4C-a).[33,34] The agreement rates between the logs and actigraphy declined over time apparently because the parents increasingly tended to omit items from the logs. Thus, for determining if a child's night awakenings decline during treatment, actigraphy appears to be more accurate (evidence level 4C-a).[35]

In a study of children and adolescents, Sadeh found that a minimum of seven nights of actigraphy were needed to get five nights of useful data for sleep onset and number of minutes of wake (evidence level 4C-a).[33] In another study of children and teenagers, Acebo et al. reported good agreement between observations and actigraphy for sleep onset, number of minutes awake, and sleep efficiency (evidence level 4C-a).[36] Acebo et al. also found that, in children, more than seven nights of data collection were needed to get useful data for sleep efficiency, sleep period and number of minutes of sleep.[36]

4.5 Comparisons to MSLT

In a study of the effects of diphenhydramine vs. placebo on daytime sleepiness, Roehrs et al. showed that MSLT was more sensitive than actigraphy to sleep loss (evidence level 2B).[37] Yet, their data showed that actigraphy during the day reflected prior sleep loss with more epochs of inactivity, suggesting more daytime sleep. Since actigraphy is not restricted to use in a laboratory as is the MSLT, the authors concluded that actigraphy during the day may yield a more accurate index of the effects of sleepiness.

4.6 Comparisons to EMG

Since the actigraph records movements, placement on the foot can be used to record movements that are most typical of periodic limb movement disorder (PLMD). In a study of PLMD, Kazenwadel et al. found actigraphy recorded on the foot to be comparable to surface EMG anterior tibialis measurements during PSG (evidence level 1A).[38] The correlations between leg kicks determined by activity counts and tibialis EMG measurements remained high both on and off medication. The authors concluded that measurement of PLMD by actigraphy was possible if 0.5-second epochs were used. However, considerable manual adjustment and editing of computerized data were necessary to avoid underestimating the number of leg kicks. These results were in disagreement with those of Sforza et al., who also compared actigraphy recorded from the foot to PSG-recorded anterior tibialis EMG (evidence level 5D-b).[39] However, the Sforza et al. study had a very small sample size for a validity study, and only two out of 35 patients had PLMD. (For additional discussion on the use of actigraphy in PLMS see also section 5.5, Restless Legs Syndrome/Periodic Limb Movement Disorder)

4.7 Actigraph Placement

Two studies found no difference between data collected from actigraphs placed on different locations (e.g., dominant wrist, non dominant wrist, ankle, or trunk) (evidence level 3C and 1A respectively).[16,17] However, in a series of two studies by Middelkoop et al., other results were found. In one study, wrist placement was shown to detect more movements than ankle placement which in turn detected more movements than trunk placement in the first study (evidence level 4C-a).[40] In a second study of healthy adults, wrist placement was again superior to both ankle and trunk placement, however, dominant wrist placement was better than all other placements at detecting wake (evidence level 4C-b}.[41] Violani et al. found that the right wrist recorded more activity than the left wrist both early and late in the sleep period but no differences were found between ankle placements (evidence level 4C-a).[42] Middelkoop and colleagues concluded that more studies which compare different placements of actigraphy concomitant with PSG recordings were needed.[41]

4.8 Artifacts in Actigraphic Recordings

There are some potential artifact problems when using actigraphy for

sleep/wake determinations. For example, artifacts can come from noncompliance (not wearing the recorder), from breathing movements, from postural blocking of arm movements, or from externally imposed movement from riding in vehicles.[21] Many investigators routinely have volunteers who wear actigraphs keep concomitant logs of sleep times and actigraph removal, and use these data to help with artifact rejection.[43,44]

4.9 Summary

Recent research has refined the ability of actigraphs to study sleep/wake. Although there are still some technical differences in the mechanical aspects of how actigraphs accumulate data on movements, how these data are processed, and the nature of the algorithms used to process these data, both the actigraphs themselves and the algorithms that process the data from actigraphs have improved since the last task-force report published in 1995.[1] For example, a method using dichotomous indices of activity has been developed to compare activity in-bed to out-of-bed that, among other things, might be useful for studying circadian phase shifts.[45] However, no head-to-head comparisons have been made between actigraphs and no conclusions can be drawn about which method is more valid vs. PSG.

Actigraphy is useful in populations where PSG would be difficult to record, such as in demented patients,[26] and in astronauts in space.[31] There does not seem to be a first night effect with non-sleep disordered patients (evidence level 3C),[16] which is of particular benefit when only one night of recording is possible. If more nights are needed, the actigraph also has the advantage of being easy to record for multiple nights. There may be advantages of using combined data from actigraphy and a subjective questionnaire with sleep-disordered patients, especially if they are excessively somnolent (evidence level 1A).[19] For studies of rhythms or for studies where time of lights out is important, an actigraph that also records light exposure would be beneficial.[5,46]

Yet, regardless of the technology, research studies must demonstrate that actigraphy serves the needs of sleep/wake researchers and clinicians. Given the expanded use of actigraphy, the time has arrived for standards to be established, similar to those developed for polysomnography in 1968 by Rechtshaffen and Kales.[47] Such standards might include device standards (e.g., digital integration is best) and/or counts defined with standardized units of measurements (e.g., g-force units) so data from different machines and algorithms could be compared and comparisons could be made to other acceleration measures. In addition, bench-test minimal standards for computer programs used with actigraphy need to be developed.

Ultimately, field tests are needed to determine what actigraphy is capable of doing and how well it can do it. Data showing that actigraphy is reliable and valid are necessary as are data demonstrating the best procedures for getting the best measurements for sleep/wake evaluations (e.g., best location on the body to place the device, how to analyze raw data) and evaluating potential problems. Published reports using actigraphy must contain complete reporting of sensitivity, specificity, scoring algorithm, and filters, as well as reliability, validity, ruggedness, and artifact rejection for the device and computer program used.[18] On the other hand, technical standards may not be as important as simply demonstrating validity and reliability for determination of sleep/wake status of all actigraphic measurements with any given apparatus and scoring algorithm.

5.0 ACTIGRAPHIC ASSESSMENT OF CLINICAL SLEEP DISORDERS

One possible application of actigraphy in sleep medicine has been the diagnosis and assessment of clinical sleep disorders (see Table 3). Compared to traditional polysomnography, the actigraph is relatively unobtrusive and can record for multiple days and nights. This may be useful in the assessment of insomnia patients, whose sleep has been shown to be quite variable from night to night.[48] Moreover, actigraphy makes home recording more accessible, permitting the evaluation of patients in their natural sleeping environment and eliminating laboratory effects that may alter a patient's typical sleep patterns.

The convenience of using actigraphy to evaluate disordered sleep, however, must be weighed against its reliability and validity as compared to the traditional gold standard for sleep assessment, polysomnography. In addition, a determination of actigraphy's potential usefulness must take into consideration how it compares to alternative methods that may be equally or less expensive, such as self-report. Although it might be expected that the objective and unbiased nature of data produced by the actigraph would necessarily be more accurate than those yielded by subjective assessment techniques such as sleep logs, this assumption must be confirmed empirically.

5.1 Insomnia

Chambers, in an analysis of previously published data,[49] found that when total sleep time estimates from actigraphs and sleep logs were compared to polysomnography for a group of insomnia patients, there was no significant difference in the mean absolute error for the two techniques (evidence level 4C-b).[50] Moreover, sleep log estimates of total sleep time had a significantly higher correlation with PSG than did those from actigraphy, suggesting that for insomnia patients as a group, sleep log error, at least with respect to the estimation of total sleep time, is more systematic and predictable for sleep logs than for actigraphy. However, this same analysis did reveal a substantial within-subjects, or night-to-night correlation ($r = 0.81$) between actigraph and PSG total sleep time. Such a finding indicates that those factors contributing to actigraph error for a given patient (e.g., periodic leg movements, minimal activity during extended periods of nocturnal wakefulness) tend to be consistent from night to night. Therefore, at least for insomnia patients, actigraphy may be useful in the assessment of sleep variability or in the measurement of treatment effects.

A number of recent studies have employed actigraphy in the evaluation of sleep of the patient with insomnia; however, few of these studies have validated the actigraphy findings with PSG data. Guilleminault and colleagues in a study of non-drug treatments for insomnia, evaluated potential subjects using a sleep questionnaire, one week of sleep diaries, and four days of actigraph monitoring (evidence level 4C-b).[51] These subjects also underwent one night of laboratory polysomnography, but simultaneous recording with an actigraph was not performed, so direct validation of the actigraphy with PSG findings was not possible. However, baseline data from this study did show that actigraphy consistently produced higher estimates of total sleep time and the number of awakenings and lower estimates of sleep onset latency than those yielded by sleep logs. The differences between actigraph and sleep log data were attenuated somewhat in the post-treatment recordings, with greater treatment-related improvement seen in sleep log variables than in actigraph variables.

Wilson et al., in a study of insomnia patients with musculoskeletal pain, found a similar discrepancy between the sleep estimates reported on sleep logs and those determined by the actigraph, with a much larger disagreement in the number of awakenings during the night (evidence level 5D-b).[52] These researchers found relatively low correlations among patients ($r = 0.34$ to 0.42) between the two measures for estimates of total sleep time and number of awakenings, and no significant correlation for sleep efficiency. Consistent with the analysis of Chambers (evidence level 4C-b),[50] the highest correlation found in this study was for night-to-night actigraphic estimates of total sleep time. However, actigraph sleep variables consistently failed to produce significant correlations with clinical assessment measures such as pain severity estimates or scores on the Pittsburgh Sleep Quality Index. Two other studies also failed to find correlations between actigraph sleep variables and global subjective reports of well-being, sleep behaviors, and health-related symptoms (evidence level for both 5D-b).[53,54]

Wicklow and Espie examined the relationship between cognitive intrusions prior to sleep onset and sleep-related variables as measured by actigraphy and sleep logs (evidence level 4C-a).[55] Their findings indicated that the presence of certain categories of intrusive thoughts was

associated with longer sleep-onset latencies, but only as measured by actigraphy, not sleep logs. These researchers also found that actigraphic TST was greater and sleep latency was less than that indicated by sleep logs. However, there were significant correlations ($r = .419$ for sleep latency, $r = .526$ for TST, both $p < .001$) between the two methods for these variables.

5.2 Insomnia Secondary to Circadian Rhythm Disturbance

Other researchers have utilized actigraphy to assess insomnia complaints secondary to a circadian rhythm disturbance. Kerkhof and van Vianen divided a group of chronic insomniacs into early- and late-sleep phase groups, based on oral body temperature data, and found greater nocturnal motor activity, as measured by actigraph, in the early phase group (evidence level 4C-b).[56] This finding was consistent with the subjective assessments of these subjects, who reported spending more time awake during the night than the late phase group. Several studies have used actigraphy to assist in the diagnosis of delayed sleep phase syndrome (DSPS) and to assess effects of DSPS treatments.[44,45,57-61] DSPS is characterized by a consistent pattern of late sleep onset and offset, often making diagnosis by PSG impractical. Although sleep logs are often used to diagnose DSPS, actigraphy can potentially offer objective evidence about rest-activity patterns that either corroborates logs or calls them into question. Dagan et al. used 4-7 days of actigraphy at home in conjunction with a comprehensive clinical assessment to diagnose dozens of subjects with DSPS, but they offered no independent evidence of the validity of this method (evidence level 5D-a).[57] Similarly, Quinto et al. reported that actigraphy "confirmed" sleep logs in a case of DSPS.[59] Minors et al. reported that there were significant differences in wrist activity patterns that distinguished people with DSPS from normal sleepers (evidence level 4C-b).[45] Nagtegaal et al., in two separate studies, provided evidence that wrist activity patterns in DSPS were consistent with a "gold-standard" biological marker of circadian rhythm disturbance. In the first study (a case report), they found that the late time of day of low activity corresponded with a late period of high melatonin secretion in a case of DSPS.[60] In the second study (a randomized, placebo-controlled trial), they found that actigraphy detected a 38-minute advance in sleep-onset time with melatonin treatment, paralleling advances in dim-light melatonin onset. Sleep log variables, however, failed to detect this phase shift (evidence level 1A).[61] Cole et al. also provided objective evidence that actigraphy can detect circadian rhythm disturbance in DSPS (evidence level 2B).[44] They reported that the circadian phase of melatonin secretion was significantly delayed, compared to normal, historical controls, in 45 DSPS volunteers whose delayed sleep was identified both by actigraphy and sleep logs. Additional information on the use of actigraphy in circadian rhythms can be found in section 6.0.

5.3 Disturbed Sleep in Children

Actigraphy has also been used to assess disturbed sleep in children. Franck et al. compared sleep, recorded by actigraph, of HIV-infected children to that of normal controls and confirmed that sleep-related complaints, as reported by parents, were greater in the patient group (evidence level 4C-b).[62] Actigraph estimates of sleep efficiency, WASO, and number of awakenings were significantly different between the two groups, while differences in TST and SOL failed to reach significance. Within the patient group, the only significant correlation between actigraph data and subjective reports was for night waking. Another study examined autistic children with and without parent-reported sleep problems and found an earlier sleep offset time for the sleep problem group but no other significant differences in actigraphically measured sleep variables (evidence level 5D-b).[63] Sadeh et al. using actigraphy, reported that newborns slept twice as much during night time hours than during the day and that later gestational age was correlated with an increased percentage of quiet sleep time (evidence level 4C-b).[64] In a case report, Etzioni et al., using wrist actigraphy, found that 3mg of melatonin administered in the evening for two weeks restored sleep continuity in a child with a germ cell tumor involving the pineal region.[65]

Some studies have used actigraphy to examine developmental differences in sleep patterns. Sadeh et al. recorded the sleep of school-age children for 4 to 5 nights and found that older subjects had delayed sleep-onset times, shorter sleep periods, and shorter sleep times than younger subjects (evidence level 4C-b).[66] They also found that increased reported daytime sleepiness was associated with greater age and shorter sleep periods, as measured by the actigraphy. Aronen et al. demonstrated that actigraphically measured TST was negatively correlated with teacher-reported behavioral symptoms in young children (evidence level 4C-b).[67] Kramer et al., although not specifically studying children, did show apparent developmental differences in sleep between young and elderly adult subjects (evidence level 4C-b).[68] They found the elderly subjects, whose average age was 65 years, to have less variability for time in bed, advanced sleep phase, and more nocturnal awakenings than the younger subjects (mean age = 20.6 years).

5.4 Sleep-Related Breathing Disorders

Several study protocols have attempted to detect the presence of obstructive sleep apnea from actigraphic data. This work has generally relied on the fact that compared to normal sleepers, apnea patients have more fragmented sleep and that this fragmentation is manifested in body movements that can be detected by the actigraph. Middelkoop et al. found that the average duration of periods with no movement (i.e., no activity), as measured by the actigraph, differed significantly among three subject groups of varying apnea severity (evidence level 4C-b).[69] No other actigraph or sleep log variable correlated significantly with the apnea index. However, the proportion of variance accounted for by this variable was small (11%), and the sensitivity of this measure to detect subjects with an apnea index greater than 5 was 5% while the specificity was 100%.

Drinnan et al. attempted to determine whether the specific placement of the actigraph might affect its accuracy in the identification of arousals associated with sleep-disordered breathing (evidence level 5D-b).[70] Their data revealed that a left tibia placement resulted in the most favorable relationship between actigraph-measured movement and EEG arousals, with placement on the right tibia, left ankle, and left wrist faring somewhat worse. Still, none of the placements yielded statistically significant correlations with EEG arousals, and none were adequate in predicting the degree of sleep disordered breathing present. As with the Middelkoop et al. study (evidence level 4C-b),[69] however, the relatively low severity of sleep apnea among patients in this study (mean apnea-hypopnea index or AHI = 18.9) may have limited the power of the technique to differentiate between groups.

Kushida et al. compared PSG, actigraphy and subjective reports in a study of 100 sleep clinic patients, the majority of whom had a diagnosis of obstructive sleep apnea syndrome or upper airway resistance syndrome (evidence level 2B).[19] Consistent with previous studies, they found that the actigraph was considerably better at detecting sleep than detecting wakefulness, with a sensitivity of 98% for sleep detection and a specificity of 48% for wake detection using a high-threshold algorithm. This algorithm compared PSG and actigraphic data in 30-second epochs, modifying the activity counts during the epoch by the level of activity in the surrounding 2-minute time period. When compared to PSG, the actigraph was much more prone to overestimate total sleep time and sleep efficiency than was subjective patient report. However, the actigraph's estimates of number of nocturnal awakenings did not differ significantly from PSG data while self-report did, suggesting actigraphy was more accurate than the patient's subjective reports.

Elbaz et al. reported on an inventive use of actigraphy in the diagnosis of sleep-disordered breathing that combines the actigraph with what they termed "simplified polysomnography," consisting of airflow, thoracic and abdominal movements, and pulse oximetry (evidence level 3C).[71] They reasoned that the addition of actigraphy could improve the estimation of the RDI from that of simplified polysomnography alone by

supplying a more precise value for TST than the traditionally used TIB. However, the actual increase in correlation with RDI estimates from traditional polysomnography was somewhat modest, from r = .94 for simplified polysomnography alone to r = .976 for simplified polysomnography plus actigraphy. The authors did find that specificity and negative predictive value were substantially improved with use of the actigraph, but only for severe OSAS (RDI > 30).

5.5 Restless Legs Syndrome/Periodic Limb Movement Disorder

One of the more natural applications of actigraphy has been in the identification and assessment of periodic leg movement disorder (PLMD). Sforza et al. conducted a study of 35 patients with varying diagnoses to determine if actigraphy could reliably detect leg movements during sleep (evidence level 5D-b).[39] Subjects were simultaneously recorded using PSG and actigraphy placed on the upper part of the right foot. PSG-recorded EMG tibialis activity was visually scored and classified in 8 levels based on duration and amplitude. Actigraphic data were collected in 5-second epochs and compared directly to EMG activity of similar-length epochs. The results of this analysis revealed that although there was a high correlation between the two collection methods, actigraphy substantially underestimated the number of movements yielded by the EMG. However, this failure may be attributable to the low sensitivity of the actigraph used, which is only able to detect accelerations greater than 0.1 g. In contrast, Pollak used actigraphs that were sensitive to 0.033 and 0.024 g, respectively (evidence level 4C).[18] For Sforza, agreement was greater for the activity events with greater duration and amplitude. Because of the actigraph's failure to detect many events of lesser duration or amplitude, this study's authors concluded that the device "cannot be regarded as a good method to estimate motor activity during sleep" (p. 158). However, other authors did note that the actigraph had adequate night-to-night reliability and suggested that it might be useful in the assessment of treatment effects in patients with PLMD or restless legs syndrome (RLS) (evidence level 4 C-b and 5 D-b, respectively).[50,52]

Two recent studies have employed actigraphy in the evaluation of treatment efficacy for RLS.[72,73] Trenkwalder et al. in a placebo-controlled crossover design, studied the effects of L-dopa therapy for idiopathic and uremic restless legs syndrome, using both PSG and actigraphy at baseline and at the end of each treatment period (evidence level 1A).[72] Their data revealed that treatment resulted in a significant reduction of leg movements, measured by both PSG and actigraph, for both patient types. Both PSG and actigraphic data also showed that this improvement was limited to the first 4 hours of recording time. Parallel to these objective indices, subjective measures such as sleep diaries and quality of life ratings showed similar improvement in response to treatment. Furthermore, because actigraphy was continued for two additional nights after the PSG study, the authors were able to confirm the stability of this treatment effect.

Collado-Seidel et al. conducted a similar study of L-dopa and slow-release L-dopa efficacy, but without the use of polysomnography (evidence level 4C-b).[73] Like Trenkwalder et al.,[72] these researchers found significant treatment-related effects for most actigraphic variables, including movements per hour and number of movement episodes. Only the change in the time without movements in the first half of the night failed to reach significance. Subjective improvements were also seen with patients reporting increases in sleep quality and overall well-being and decreases in number of awakenings, time awake, and reports of daytime fatigue.

5.6 Other Sleep Disorders

Various case reports have employed actigraphy in the assessment of other sleep disorders, including fatal familial insomnia,[74] non-24-hour sleep-wake syndrome,[75,76] REM sleep behavior disorder,[77] and posttraumatic delayed sleep phase syndrome.[59] In each of these reports, the actigraph provided data relevant to the patients' sleep/wake patterns, in many cases over a substantial period of time. However, these case studies did not compare the actigraphy data to PSG, nor did they indicate whether the actigraph alone was sufficient to diagnose the conditions.

5.7 Summary

Recent literature suggested that actigraphy might have some value in the assessment of sleep disorders. For insomnia, actigraphy may be most valuable in assessing treatment effects or night-to-night variations in subjects' sleep. It has been demonstrated that actigraphy has the ability to detect sleep phase alterations associated with circadian rhythm disturbances. Additionally, actigraphy is capable of distinguishing moderate to severe sleep apnea patients from normal controls, due to its greater sensitivity, compared to sleep logs, in detecting brief arousals from sleep. For patients with restless legs and periodic leg movements, the diagnostic value of actigraphy is limited by its tendency to underestimate the frequency of leg movements during sleep. However, it does show some promise in the assessment of treatment-related improvement.

Later-generation scoring algorithms have demonstrated greater accuracy than earlier versions in the detection of sleep and wake, improving the actigraph's ability to detect sleep latency, nocturnal awakenings, and total sleep time, variables important in evaluating an insomnia complaint. The actigraph appears to have a particular advantage over alternative assessment methods such as sleep logs in the measurement of awakenings during the night, as many of these awakenings appear to go undetected by patients and subjects completing sleep diaries. The ability of actigraphy for detecting activity also holds some promise in the identification of other disorders characterized by frequent movements such as obstructive sleep apnea and periodic limb movement disorder. Perhaps of greatest importance is the actigraph's ability to measure night-to-night changes in sleep patterns within a given individual, a function that has great value for assessing treatment effects and other factors that affect the consistency of a patient's sleep. This, combined with its relative economy in assessing sleep-wake patterns over extended periods of time, suggests a potentially important role for the actigraph in longitudinal research and clinical studies in which long-term changes in sleep patterns are of particular interest.

The actigraph's limitations, however, continue to restrict its value as a stand-alone diagnostic device. Recent research has reasserted the findings from previous studies that the accuracy of the actigraph to detect sleep and wakefulness declines as sleep efficiency is decreased, a problem particularly relevant to insomnia and other sleep disorders. There are indications that for the simple estimation of total sleep time, insomnia patients' subjective estimates outperform the actigraph (evidence level 4 C-b).[50] Moreover, although the actigraph may be able to distinguish patients with a particular sleep disorder (e.g., obstructive sleep apnea, periodic limb movement disorder) from normal controls, there is virtually no evidence to date that the actigraph can distinguish between different sleep disorders. Until such evidence becomes available, the actigraph's function in the assessment and diagnosis of clinical sleep disorders is likely to be restricted to the role of an adjunct to clinical history, sleep diary data, and PSG findings or to examine treatment effects and follow-up.

6.0 CIRCADIAN RHYTHMS

Activity is a standard marker of circadian rhythms in studies of nonhuman mammals. This section examines the use of wrist activity in the measurement of circadian rhythms in humans. In the studies reviewed here, wrist actigraphy was used in a number of different ways relevant to human rhythms. Methodologies included characterizing spontaneous rhythms in adults, children, infants and the elderly, exploring the relationships between activity rhythms and the light-dark cycle, helping to identify sleep or rhythm disturbances induced by change of schedule, measuring improvement in disturbed rhythms after experimental intervention, helping to diagnose circadian rhythm sleep disorders, characterizing rhythm abnormalities that accompany dementia or psychiatric

disturbance, and investigating the role of motor activity in cardiovascular rhythms.

6.1 Actigraphy for the Study of Circadian Rhythms

Several studies have demonstrated that human wrist activity often shows a robust circadian pattern. Pollak et al. showed that the circadian period of the actigraph-defined sleep/wake rhythm accurately predicted the period of the PSG-defined sleep/wake rhythm, measured simultaneously (evidence level 3C).[21]

Actigraphs have measured circadian rhythms under circumstances where it would not be practical to record with polysomnography. For example, Binkley measured wrist activity in one woman continuously for an entire year.[78] She found well-defined, entrained circadian rest-activity cycles, changes in sleep length synchronized with the menstrual cycle, and annual phase changes she attributed to daylight saving time. Wirz-Justice and colleagues presented several case reports in which actigraphs were worn daily by demented or psychiatric patients for extended periods of up to 1.5 years.[79-84] The long-duration recordings allowed the authors to produce plots that graphically revealed striking changes in circadian rhythms over time. These included severe, apparently medication-induced disruption of the rest activity cycle, the gradual consolidation of the cycle upon change of medication, circadian effects of imposed therapeutic rest/activity schedules, and the gradual decline of circadian organization over time. Siegmund et al. measured seven-day wrist activity rhythms in inhabitants of Papua New Guinea, living in a traditional culture without electric lights (evidence level 4C).[85] They found that rest-activity rhythms were synchronized with the light-dark cycle, and that time of arising was more consistent than bedtime. Actigraphic recordings in infants showed that circadian activity rhythms arose from ultradian antecedents. Periods of inactivity presumably encompassing sleep were shorter (9-12 hours/day) than typically found in European society. In another actigraphic study of infants, "sleep" differences were not explained by differences in temperament (evidence level 5D-b).[86] Dijk et al. measuring wrist activity during 10 to 16 days of space flight, visually identified imposed advances in the sleep-wake schedule, and noted that time of arising was more regular than bedtime (evidence level 3C).[32]

In the studies cited above, and many others,[87-91] circadian rhythm results were computed from actigraphic sleep/wake predictions. Usually, the phase marker was sleep onset time or sleep offset time. Similarly, Binkley marked circadian phase with visually identified "activity onset" and "activity offset," defined by threshold criteria similar to those used in some sleep/wake prediction algorithms (evidence level 4C-b).[92] Another way actigraphic sleep/wake predictions (or similar "activity level" scores) have been used to yield circadian results is by showing that actigraph-identified sleep is disturbed when people attempt to sleep out of phase with their endogenous rhythm, as in shift work,[93-96] jet lag,[92,97] illness,[91] or experimental manipulations of the sleep/wake cycle,[87,98] or by showing[98] that sleep is improved by treatment that normalizes rhythms.[93,99-101] For example, both Dawson et al.[93] and Yoon et al.[102] found that actigraphic indicators of sleep improved during the day following simulated night shift work in volunteers treated with bright light or melatonin, but not in those treated with placebo (evidence levels 4C-b). Actigraphy was also used to infer when shiftworking nurses slept and, along with shifts of the melatonin rhythm, demonstrated that a subgroup of nurses was able to successfully adapt to rapid changes in workshift (evidence levels 4C-b).[94,95]

Although three shift work studies reported negative results,[103-105] enough well-designed, well-controlled studies showed significant disturbance of actigraph-defined sleep after shift work or other circadian disturbance to make a convincing case that actigraphy can be useful for detecting such disturbances (evidence levels 3C to 4C-b).[87,91-95,97,98,106]

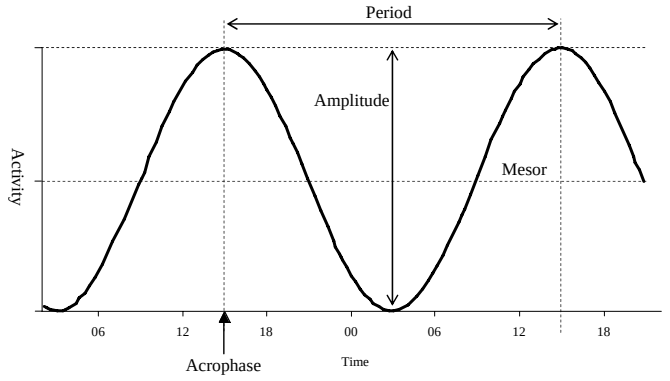


Figure 2—Circadian rhythm representation in which a cosine curve with a period at or near 24 hours is fit to the data by the least-squares method. The parameters that are of interest are acrophase (time of peak activity), amplitude (peak-to-nadir difference) and mesor (mean) of the fitted curve.

6.2 Actigraphy Algorithms for Computing Circadian Rhythms

As noted earlier, the study of rest-activity rhythms has a long history. Prolonged actigraphic recordings lasting for multiple circadian periods can therefore give valuable chronobiological information, even if no attempt is made to convert the rest-activity rhythm to the sleep-wake rhythm. To extract this information, the raw activity values are analyzed directly. The most popular method has been cosinor analysis,[43,89-92,107,108] in which a cosine curve with a period at or near 24 hours is fit to the data by the least-squares method. The parameters that are of interest are acrophase (time of peak activity), amplitude (peak-to-nadir difference) and mesor (mean) of the fitted curve (see Fig 2). A "five-parameter extended cosinor analysis" has also been used to provide a better fit to activity data, which typically deviate from the shape of a cosine curve.[109,110] The five model parameters are circadian minimum, amplitude, acrophase, alpha (width of the rhythm) and beta (steepness of fitted curve, which can approximate a square wave if beta is high). F-statistics for goodness-of-fit derived from this model have been used in studies of nursing home patients to detect a significant strengthening effect of light treatment on circadian activity rhythms (evidence level 4C-b),[110] and a significant weakness of the activity rhythm relative to rhythms of behavioral agitation and environmental light exposure (evidence level 4C-b).[109] Van Someren and colleagues found that two analyses that make no *a prioi* assumptions about the waveform of activity data, autocorrelation and interdaily stability, showed significant strengthening of activity rhythms in demented patients in response to light therapy, while simple cosinor analysis (and other analyses that assume a fixed waveform) showed no significant effect in the same data sets (evidence level 4C-b).[111] Autocorrelation is the correlation between activity values at specific time lags of interest. High autocorrelation at or near 24-hours indicates a robust circadian rhythm. Interdaily stability is a measure of the strength of coupling of a rhythm to environmental zeitgebers, based on the chi-square periodogram, which, in turn, is based on wave-form eduction (see below). Some investigators have computed the "circadian quotient" (amplitude/mesor) to characterize the strength of the circadian rhythm (more robust rhythms have a higher amplitude, but people who move more vigorously may also have higher amplitude; the circadian quotient expresses amplitude relative to mesor, providing a normalized value that allows comparison between individuals).[91,112] A similar normalized variable that does not rely on the assumption of a cosine fit is relative amplitude (based on the difference between the most active 10-hour interval and the least active 5-hour interval of the day).[111]

Additional circadian outcome measures that have been computed directly from raw activity data include the ratio of nighttime activity to daytime activity or total activity (evidence level 2B and 4C respectively),[91,99] standard deviation of sleep onset time,[113] intradaily variability (based on the changes in activity level from hour-to-hour),[100,111,114-116] various types of spectral analysis,[89-91,117] and waveform eduction. Waveform eduction is carried out by calculating an "average waveform" for some period. For example, if a period of 24.0 hours is chosen, succes-

sive activity levels at similar times of the 24.0-hour day are averaged. Sleep-wake consolidation is the extent to which continuous bouts of sleep and wakefulness are clustered into periods that are circadian (last for several hours). Waveform eduction can be quantified by a measurement related to the lengths of the "stair treads and risers" in cumulative plots of sleep vs. wakefulness.[21]

6.3 Actigraphy versus Other Methodologies for Determining Circadian Rhythms

Several studies compared circadian outcomes derived from wrist actigraphy to those derived from other measurement methods considered reference standards. Pollak's finding that actigraphic sleep/wake predictions have the same circadian period as PSG sleep/wake scores suggested that actigraphy could provide valid measurements of entrained sleep/wake rhythms (evidence level 3C).[21] Youngstedt et al. provided good evidence that the phases of actigraph-identified bedtime, wake-up time, mid-sleep time and acrophase were all significantly correlated with the acrophase of urinary 6-sulphatoxymelatonin secretion in entrained young and elderly adults living at home (evidence level 1A).[43] Cole et al. found similar home results in volunteers with delayed sleep phase syndrome (DSPS) (evidence level 2B).[44] Middleton et al. found that the phase and period of actigraph-derived sleep onset time, wake-up time and fitted cosine were generally consistent with those of both 6-sulphatoxymelatonin and "demasked" core body temperature in men undergoing experimental manipulations in constant dim light (both evidence levels 2B).[89,90] However, these studies also showed that activity rhythms were less stable than melatonin or temperature rhythms, and could be readily masked by voluntary behavior. Carskadon et al., studying adolescents, found correlations ranging from .39 to .82 between actigraph-identified sleep onset time at home and salivary dim light melatonin onset time (evidence level 2B to 3C).[118,119] However, in one study the correlation dropped to a non-significant level under an imposed light-dark cycle,[118] and in the other it was not significant on weekends.[119] Heikkilä et al. found that in children suffering a severe medical disorder, the circadian rhythm of wrist activity could be grossly disturbed despite normal rhythms of melatonin, temperature and cortisol (evidence level 5D).[120] Guilleminault et al. found that consolidated wakefulness, visually scored from wrist activity, only developed in infants after they established a circadian rectal temperature rhythm (evidence level 3C).[121] Blagrove et al. provided very strong evidence that actigraph-identified sleep was influenced directly by the central circadian pacemaker (presumably the suprachiasmatic nuclei, or SCN of the hypothalamus) (evidence level 3C).[87] They measured wrist activity during a forced desynchrony protocol in which volunteers lived on a 27-hour day (9 hours in bed, 18 hours up and active), so the pacemaker free-ran at a period closer to 24 hours, and sleep was attempted at various circadian phases. Despite the imposed rest-activity rhythm, actigraph-identified total sleep time was lower when sleep was attempted at an unfavorable phase of the circadian cycle. This strongly suggested that the influence of the circadian clock on actigraph-identified sleep could not be entirely masked by a socially-dictated rest/activity schedule. On the other hand, the masking effect of the imposed schedules was substantial, and this was likely to be true of actigraph studies in general. Because of their susceptibility to masking, wrist activity rhythms alone cannot be used as pure markers of SCN circadian output, even though they contain an SCN signal. Actigraphy has been used to "demask" the circadian temperature rhythm, by removing the effects of activity and inactivity (evidence level 5D-b).[98]

Another line of evidence that actigraphy can accurately characterize the circadian sleep/wake rhythm is that the rhythm of actigraph-inferred sleep/wake generally agrees with that of sleep/wake reported on sleep logs (evidence level 3C).[29] This raises the question of whether sleep logs are just as good as actigraphs for circadian measurements. Two studies suggest a possible advantage of actigraphy, that is, that it may identify naps that volunteers do not report on their sleep logs (both evidence level 4C-a).[88,103] However, actigraphy may also identify naps when none exist.

6.4 Actigraphy and Circadian Rhythm Sleep Disorders

There is good evidence that actigraphy can detect circadian phase delays in people with DSPS, corresponding to delays in melatonin rhythms (level 1A to 2B) e.g., (44,60,61). This evidence is summarized above in the section 5.2. Insomnia Secondary to Circadian Rhythm Disturbance. There are also case reports in which actigraphy identified systematic delays of the rest-activity cycle in non-24-hour sleep-wake syndrome.[75,76]

6.5 Actigraphy and Circadian Rhythms in Aging and Dementia

Actigraphy has been used to explore circadian rhythms in aging and dementia. Three studies found that the overall activity level declined with age (evidence level 4C-b to 5D-a),[108,122,123] as did the amplitude of the circadian rest-activity cycle (evidence levels 4C-b).[116,124] Fragmentation (hour-to-hour variability) of the rest-activity rhythm was found in healthy elderly[101,116] and could be reduced in elderly men by aerobic training (evidence levels 4C-b).[101]

Mishima found increased overall activity and nighttime activity in Alzheimer's disease (evidence level 4C-b).[125] Friedman et al. showed that actigraphic measures of circadian activity (including amplitude, acrophase and mesor) did not correlate significantly with behavioral disturbance in patients with Alzheimer's disease (AD) (evidence level 4C-b).[126] Martin et al. found little evidence of sundowning (increased agitation around sunset) (evidence level 4C-b).[109] Actigraphic rest-activity rhythms in demented patients were stabilized by increased illumination if vision was intact (evidence level 4C).[100]

6.6 Actigraphy and Cardiovascular Rhythms

Another group of studies used sleep and wake activity to help distinguish "dippers" (people whose blood pressure decreases normally at night) from "non-dippers" (blood pressure that remains the same or rises during sleep). Although sleep wake activity was not necessarily correlated with blood pressure or heart rate (evidence level 5D-b),[127] two studies found that dippers have lower nocturnal activity than nondippers (both at evidence level 4C).[128,129] Daytime activity levels were also correlated with the nocturnal dip in BP (evidence level 4C).[129] By using actigraphy to define sleep and wake periods, a calcium-channel blocker was found to have therapeutic effects in hypertensives that differed according to the time of day it was administered (evidence level 4C-b).[130] A third study found that defining "night" as the actigraph-identified sleep period yielded very different blood pressure results than did defining "night" by fixed clock time criteria (evidence level 5D-a).[131]

6.7 Actigraphy and Circadian Rhythms in Psychiatry

Actigraphy has also been used to examine circadian rhythms in psychiatry. Wirz-Justice and colleagues found severe disturbance of rest-activity rhythms in one bipolar individual[82] and several schizophrenic individuals recorded for extended periods (evidence level 5D-a).[79,81,83] Similarly, Martin et al. found that both rest-activity rhythms and actigraph-identified sleep were often seriously disturbed in 28 older schizophrenics (evidence level 4C-b).[132] The magnitude of disturbance was associated with the degree of neuropsychological impairment. Neuroleptic-induced akathisia was associated with increased motor activity in schizophrenic patients, at least at certain times of the day (evidence level 4C-a).[133] Two studies reported that specific depressive syndromes were characterized by distinctive circadian activity rhythms.[107,134] Glod et al. found blunted circadian amplitude but normal phase of wrist activity in children with Seasonal Affective Disorder, compared to healthy controls (evidence level 4C-b).[107] Lemke et al. found that depressed adult inpatients displayed significantly greater motor activity in the morning than the evening (evidence level 4C-b).[134]

These studies, taken together, provide preliminary evidence that actigraphy may prove useful for characterizing and monitoring the circadian

rhythm disturbances that often accompany psychiatric disorders.

6.8 Summary

In summary, actigraphy has been used successfully in a variety of human circadian studies. Wrist activity appears to be a valid marker of entrained PSG sleep phase, and a strong correlate of entrained endogenous circadian phase. Under non-entrained conditions, wrist activity rhythms may become dissociated from the endogenous rhythm of the SCN pacemaker; however, actigraphy still appears to be useful for identifying disturbed sleep caused by disruption of circadian rhythms, and improved sleep caused by treatments that improve rhythms. There is evidence that the circadian phase of wrist activity covaries with the phase of melatonin secretion in DSPS, supporting the use of actigraphy in helping to diagnose this condition. Actigraphy may also be useful in circadian characterization of non-sleep disorders, such as schizophrenia and hypertension. A variety of methods for analyzing circadian aspects of activity data show promise. It would be useful to formally compare these to arrive at standard methodology.

7.0 OTHER CLINICAL RESEARCH

Actigraphy has been used as a measure of sleep/wake activity or circadian rhythms in a broad range of clinical studies. These studies vary considerably with respect to the specific actigraphy variables of interest, the methodology used and the types of individuals studied. Unfortunately, many of these studies do not report adequate detailed information on the technical aspects of the actigraphy devices used, and few studies attempt validity testing on the use of actigraphy in the particular population or setting studied.

7.1 Actigraphy in Sleep Intervention Trials and Comparative Studies of Sleep/Activity

Much of the work using actigraphy as a measure of sleep disorders is reviewed earlier in this paper (see section 5.0). This section focuses on the use of actigraphy as an outcome measure in other sleep intervention trials and in comparative studies of sleep or activity.

In a placebo-controlled clinical trial of controlled-release melatonin treatment for insomnia in older people (mean age 76 years), Garfinkel et al. reported that melatonin administration resulted in greater sleep efficiency and shorter wake after sleep onset, both estimated by wrist actigraphy (evidence level 4C-b).[135] Friedman et al. used multiple modalities, including actigraphy, to measure sleep outcomes in a trial comparing the effects of sleep restriction and sleep hygiene treatments on the sleep of older adults (aged 55 years or older) with insomnia (evidence level 2B).[136] The main study outcomes found few between-group differences in treatment efficacy. However, in a sub-sample of 16 subjects who had simultaneous wrist actigraphy and polysomnography for 3 nights, wrist actigraphy estimation significantly correlated with polysomnographic estimation of total sleep time ($r = .96$), sleep efficiency ($r = .63$), sleep latency ($r = .72$) and wake after sleep onset ($r = .68$). In this study, wrist actigraph variables correlated more highly than sleep log data with polysomnography results.

Maus et al. performed actigraphy in a study of circulating catecholamines and aqueous flow in the eyes of normal subjects and in those with severe obstructive sleep apnea (evidence level 4C-b).[137] Sleep apnea subjects, who were untreated on the night of testing, had a significantly higher nighttime activity index as measured by actigraphy ($p<.001$) and lower sleep efficiency ($p<.001$) compared to healthy controls. In addition, there were significant differences in activity index and sleep efficiency in controls who were kept awake during the night versus those allowed to sleep.

Pollak et al. studied a small group of community-dwelling elderly people who frequently used bedtime medications (including benzodiazepines, minor analgesics, antihistamines and antidepressants) and compared them to elderly controls who did not have sleeping difficulty and did not use hypnotics (evidence level 4C-b).[138] Although there were no differences between groups when the 24-hour period was considered as a whole, post-hoc comparisons in the early morning hours indicated that subjects using bedtime medications became active, as measured by actigraphy, about 1.5 hours earlier in the morning than controls.

7.2 Actigraphy in Studies of Healthy Adults

Several studies involving normal individuals under differing testing situations have used actigraphy as a measure of sleep/wake or circadian rhythms. Duka et al. measured wrist movement in a placebo-controlled study of the effects of a beta-carboline benzodiazepine receptor antagonist on night sleep pattern in healthy male volunteers (evidence level 5D-a).[139] Compared to placebo, the benzodiazepine receptor antagonist induced activation as measured by actigraphy (i.e., frequency of movement and intensity of movement). French et al. used actigraphy to measure sleep patterns in military aircraft crew members undergoing simulated, long duration bomber missions (evidence level 4C-b).[140] They found shorter sleep duration and greater wrist activity during sleep periods during the first mission, with evidence of improvement in sleep in subsequent missions. In a study of the effects on sleep from caffeinated beverages in healthy volunteers, Hindmarch et al. found a dose-dependent negative effect (of caffeine) on total sleep time as estimated by wrist actigraphy (evidence level 4C-b).[141] In another study, Hindmarch et al. found that promethazine (a sedating antihistamine) caused a significant increase in percent sleep, as estimated by wrist actigraphy, during the daytime and across the study period compared with different doses of fexofenadine, loratadine and placebo (evidence level 4C-b).[142]

Jean-Louis et al. analyzed actigraphy data in a large sample (N=273) of community-dwelling residents of San Diego who had been identified by random telephone survey (evidence level 4C-b).[143] In this cross-sectional study, they found significant differences between men and women, and between Caucasian and minority subjects, in sleep variables estimated by wrist actigraphy. In a second smaller community-based sample (n=32), Jean-Louis et al. used wrist actigraphy in healthy volunteers and again found significant gender differences, with women having a better sleep profile than men (evidence level 4C-b).[122]

Mendlowicz et al. performed an observational study using wrist actigraphy in community dwelling volunteers. In regression analysis they found several significant predictors of depressed mood, including the following variables estimated by actigraphy: daytime activity level, sleep onset latency, wake after sleep onset, total sleep time and total time in bed (evidence level 5D-a).[144] Moorcroft et al. used nocturnal actigraphy to estimate sleep and wake periods and time of final awakening in people who reported the ability to self-awaken at a self-predetermined time without external means and found that they were in fact able to do so (with a 95% confidence interval of 4.1-10.7 minutes) (evidence level 5D-b).[145]

Pankhurst et al., studying the influence of bed partners on nighttime wrist activity in community dwelling adults living in the United Kingdom, found that subjects sleeping with bed partners had a greater number of movements than subjects who slept alone, and movements decreased during the temporary absence of the usual bed partner (evidence level 4C-b).[146] In a similar but larger sample in the UK, Reyner et al. found a significant decline with age in average movement as measured by wrist actigraphy, with men having more nighttime movement than women (evidence level 4C-b).[147] The authors compared sleep log reports of time of sleep onset with actigraphy estimation of sleep onset, and found that the time difference between the two methods was small; however, the actual time difference was not reported in the manuscript.

7.3 Actigraphy in Studies of Cancer-related Fatigue

Actigraphy has also been used in descriptive studies of cancer-related fatigue. In an observational study of breast cancer patients, Berger et al. found that greater reported cancer-related fatigue was significantly associated with a higher number of nighttime awakenings, lower amplitude

and lower peak activity as measured by wrist actigraphy (evidence level 4C-b).[148] In an observational study of cancer patients undergoing radiation therapy for bony metastases, Miaskowski et al. did not find a significant association between wrist actigraphy estimation of nighttime sleep and self-ratings of quality of sleep and feeling rested (evidence level 4C-b).[149] Using wrist actigraphy to measure circadian rhythms, Mormont et al. found that cancer patients with marked activity rhythms had better quality of life, reported less fatigue and had longer survival compared to those with rhythm alteration (evidence level 4C-b).[150] In multivariate analysis, rest-activity rhythm remained a significant predictor of one-year survival.

In a series of articles, Berger et al. reported findings from wrist actigraphy performed in women with breast cancer undergoing several cycles of chemotherapy (both evidence levels 4C-b).[148,151] They found that fatigue ratings were higher during chemotherapy, and negatively correlated with activity as estimated by wrist actigraphy. Subjects with lower circadian measures (specifically lower peak activity) had greater fatigue.

7.4 Actigraphy in Studies of Psychiatric Patients

Actigraphy has been used to investigate movement and sleep disturbance in psychiatric patients (circadian activity disturbance is discussed above in section 6.0. Circadian Rhythms). Dursun et al. conducted a descriptive study of wrist actigraphy estimation of sleep in outpatients with schizophrenia prescribed risperidone compared to those on "typical" antipsychotics, and to normal controls (evidence level 5D-a).[152] They found a greater degree of nighttime wrist movement (i.e., higher movement index) in patients on a typical antipsychotic compared to those on risperidone. Friedman et al. compared wrist actigraphy data with measures of behavioral problems in a sample of patients with Alzheimer's disease (AD) who were participating in a larger longitudinal study (evidence level 4C-b).[126] They found that greater behavioral disturbance was correlated with lower actigraphically estimated sleep efficiency ($r=-.35$, $p<.05$) and greater wake after sleep onset ($r=.43$, $p<.01$).

Lemke et al. used wrist actigraphy to estimate mean activity levels in psychiatric unit inpatients with major depressive disorder (evidence level 4C-b).[153] They found that subjects whose Pittsburgh Sleep Quality Index indicated poor sleep had higher mean nighttime motor activity levels that those who reported good sleep. In addition, subjects with fewer depressive symptoms had lower mean nighttime motor activity levels than those with greater depressive symptomatology.

7.5 Actigraphy in Studies of Adults with Other Specific Medical Conditions

Actigraphy has been used in a variety of clinical studies involving adults with other specific medical conditions. Baker et al. compared wrist actigraphy findings between menopausal women and controls, and found that menopausal women had more arousals and greater sleep disruption. In a study of sleep disturbance in cirrhosis, Cordoba et al. found that compared to normal controls, cirrhosis patients had decreased motor activity, more fragmentation of sleep and dampened rhythms, as measured by actigraphy (evidence level 4C-b).[154]

Redeker et al. reported a series of studies using actigraphy in adults undergoing coronary artery bypass graft surgery (CABG), and in adults hospitalized for cardiac conditions (all with evidence level 4C-b). In one study, 25 women (mean age 63.7 years) undergoing CABG had wrist actigraphy applied after admission to the open-heart recovery room/intensive care unit, and wore the actigraphs continuously throughout their hospital stays. Findings from the first postoperative week after CABG, indicated that, after controlling for preoperative functional status, there was a relationship between both recovery from surgery and length of stay with the rhythmic and linear patterns of activity. Positive linear trends in circadian activity periods were related to better functioning and shorter length of stay.[155] When wrist actigraphy was repeated up to four times over the 6 months following CABG, sleep consolidated and daytime sleep decreased and subjects' perceived sleep improvements were consistent with results of actigraphy.[156] In another sample of 22 men and women undergoing CABG, Redeker et al. found that activity levels and strength of circadian rhythms increased over days 2 to 5 post-operatively, with a longer time for recovery of activity in older adults.[155] Finally, in another sample of 33 men and women admitted to the hospital for acute myocardial infarction or unstable angina, Redeker et al. found that previous severity of heart disease was the strongest predictor of lower sleep efficiency and longer duration of awakenings during hospitalization.[157]

7.6 Actigraphy in Studies of Older Adults

Actigraphy is particularly useful in studies involving older adults, both in the community and in the nursing home. In addition to the community-based studies described above, which included healthy older people in their sample, studies specifically targeting the elderly have used actigraphy as outcome measures. Pollak et al. used wrist actigraphy in a descriptive study of 44 pairs of older people (aged 65 years or older) with disruptive nocturnal behaviors such as complaining and calling for help, and their principal caregiver (evidence level 4C-b).[158] Twenty-two of the elders met criteria for dementia. Both the older person and their caregiver wore wrist actigraphs. Activity level was less similar during the daytime between the older person and their caregiver, as compared to nighttime. In addition, actigraphy suggested that at night it was the elders that initiated the elder-caregiver interaction, thus disturbing the sleep of the caregiver.

Sleep and circadian rhythm variables deduced from actigraph recordings have been used as outcome measures in multiple studies of nursing home residents, a population that had been understudied and in which PSG is particularly difficult. Ancoli-Israel et al. found significant sleep disruption (with frequent nighttime awakening and frequent daytime sleeping, based on actigraphy) in a sample of 25 nursing home residents (evidence level 4C-b).[159] In another study, Ancoli-Israel et al. compared nursing home residents with severe dementia to those with moderate, mild or no dementia, and found that the severely demented group had lower activity mesor, lower amplitude and were more phase delayed than those with moderate, mild or no dementia (evidence level 4C-b).[112] Hourly profiles of sleep and wakefulness in this group suggested that the severely demented residents had more sleepiness during the day and night and residents with moderate or mild dementia had more wakefulness during the night (evidence level 4C-b).[160] Actigraphy with light exposure was also used to study the relationship between sleep and light exposure with results suggesting that higher light levels predicted fewer nighttime awakenings and later activity acrophase (evidence level 4C-b).[161] Additionally, when these same patients were treated with 10 days of bright light therapy, although there was no improvement in sleep at night, morning bright light delayed the peak of the activity rhythm (i.e., acrophase), increased the mean activity level (i.e., increased the mesor) and improved activity rhythmicity (evidence level 4C-b).[110]

Alessi et al. used wrist actigraphy estimation of sleep as an outcome variable in a controlled clinical trial of physical activity in nursing home residents (evidence level 4C-b).[162] They found no significant improvement in sleep associated with improved physical function. Likewise, in an observational study of incontinent nursing home residents, Alessi et al. found no significant differences in nighttime sleep variables between subjects on psychotropic medications and subjects not on these medications (evidence level 5D-b).[163] However, in a controlled trial of a combined physical activity and environmental intervention in nursing home residents, Alessi et al. found a higher percent sleep at night estimated by wrist actigraphy in the intervention group compared to controls (evidence level 4C-b).[164]

Cruise et al. performed an observational study in nursing home residents to study the nighttime environment and incontinence care practices in nursing home residents (evidence level 4C-b).[165] They found that 42% of nighttime waking episodes identified by wrist actigraphy were associated with noise, light or incontinence care. Ouslander et al. found that

nighttime urinary incontinence was not related to sleep disruption (evidence level 5D-b).[166]

7.7 Actigraphy in Studies of Children

Actigraphy has been increasingly used in children, particularly in studies involving children with behavioral, psychiatric or neurological illness. Corkum et al. compared wrist actigraphy estimates of sleep in children with attention deficit/hyperactivity disorder (ADHD) to normal controls and found no statistically significant differences in total sleep duration, sleep onset and number of nighttime awakenings by wrist actigraphy (evidence level 5D-b).[167] Glod et al. used waist placement of actigraphs in children who were victims of abuse, comparing their sleep to that of children with major depression or dysthymia, and with that of normal controls (evidence level 4C-b).[168] In this study, abused children had higher levels of nocturnal activity than both normal controls and depressed children, and the abused children had more difficulty falling and staying asleep. Hatonen et al. tested for differences in motor activity rhythms with melatonin treatment versus placebo in 5 children aged 12-19 with a neurodegenerative disease, neuronal ceroid lipofuscinosis (NCL) (evidence level 5D-b).[117] In these children, there were no differences between melatonin and placebo in actigraphic motor activity based on period analysis by maximum entropy spectral, autocorrelation or harmonic analyses. In a controlled trial of melatonin therapy in children with Rett syndrome (an X-linked genetic disorder with motor and cognitive impairment, and often severe sleep dysfunction), McArthur et al. found high variability in subject responsiveness to melatonin, but as a group, sleep onset latency was significantly reduced with melatonin during the first 3 weeks of the trial (evidence level 4C-b).[169]

Mennella et al. tested the immediate, short-term effects of ethanol in breast milk on actigraphy estimation of sleep in infants from 15 mother-infant pairs (evidence level 4C-b).[170] They found lower total sleep time, lower active sleep and shorter sleep bouts when infants received breast milk with ethanol compared to breast milk without ethanol.

Sadeh and colleagues, in two separate studies, used actigraphy to measure sleep in relation to cognitive functioning in preterm infants and school-age children.[171,172] In the first study, early mature patterns of sleep were related to later cognitive maturity (evidence level 4C-b).[171] In the second study, children with fragmented sleep had lower performance on measures of neurobehavioral functioning, particularly among the more complex tasks and behavior problems were more prevalent among poor sleepers (evidence level 4C-b).[172]

7.8 Summary

Actigraphy is increasingly being used in clinical research involving individuals of various ages, who are of normal health or with a variety of health conditions, and in a number of different settings. In the majority of these studies, actigraphy was used to measure sleep and activity rhythms that might not otherwise be available using traditional (e.g., PSG) techniques. In a growing number of sleep intervention trials, actigraphy performed for multiple days and nights of testing was reported to show evidence of beneficial treatment effects. Actigraphy has also been used in studies involving otherwise healthy adults to demonstrate sedating effects of various medications and to show differences in sleep during periods of sleep deprivation, for example, among military aircraft personnel on long flights. In addition, several large studies have used actigraphy in community-based samples to demonstrate differences between individuals based on age, gender, ethnicity, depressed mood, and other characteristics.

Another growing area of research is cancer-related fatigue, where studies involving multiple days and nights of actigraphy have demonstrated that cancer patients with more robust circadian rhythms of activity report less fatigue, better quality of life and have longer survival. Likewise, in a series of studies involving adults undergoing coronary artery bypass surgery, the strength of circadian activity rhythms as measured by actigraphy in the post-operative period was related to recovery from surgery and length of stay.

Actigraphy has been used extensively in studies involving older people, particularly in the nursing home setting. These studies have demonstrated significant sleep disruption among nursing home residents, and sleep and circadian rhythm disturbances have been shown to be more severe among residents with more severe dementia. In addition, actigraphy has been used to measure treatment effects in sleep intervention research in the nursing home setting, where other measures, such as PSG, would be extremely problematic to perform.

Finally, there is a growing literature using actigraphy in children. For example, actigraphy has been used to demonstrate differences in sleep between abused children and those with depression or normal controls. Actigraphy has also been used to test treatment effects of melatonin therapy in children with severe neurological disorders.

Taken as a whole, these clinical studies demonstrate the increasing experience in the use of actigraphy in a variety of populations, conditions and settings. Unfortunately, the majority of these studies do not report adequate detail on the technical aspects of the specific actigraphic devices used. However, it seems clear from these trials that the use of actigraphy enables studies involving multiple days and nights of testing, and allows populations that might otherwise not be studied, such as patients with dementia or young children, to participate in research studies and clinical trials of sleep/wake activity and circadian rhythms

8.0 DISCUSSION

The last published practice parameters for actigraphy only considered the use of actigraphy for the clinical assessment of sleep disorders.[1] Their conclusion in 1995 was that actigraphy should not be used for the clinical diagnosis of any sleep disorder, but that it might be a useful adjunct to a good history and examination, particularly if multiple days of information were needed, if objective data on the pattern of sleep was needed or in order to clarify the effects of compliance with treatment.[2]

Since that time advances have been made in actigraphs and in the algorithms that process their data both within the apparatus and on computers following downloading of the data. Additionally, over 210 articles and case studies have been published which have further examined the validity of actigraphy. As summarized in a recent review article by Sadeh and Acebo,[173] the number of yearly publications on sleep and actigraphy has risen steadily in the last ten years. In the research setting, actigraphs have been used for studying sleep disorders and circadian rhythms. Actigraphic variables have also been used as outcome measures in clinical trials, often as a replacement for the more traditional, but more expensive and cumbersome PSG.

One consistent finding of the current studies was that, when compared to PSG, actigraphy was found to be moderately valid and reliable for differentiating sleep from wake in normal, healthy adult populations but less reliable for identifying sleep as sleep became more disturbed. Taken together, these studies provide evidence that important applications of the actigraph may be in the assessment and in the measurement of the sleep variability found in patients with insomnia, in assisting in the diagnosis of circadian rhythm disorders, in characterizing and monitoring circadian rhythm disturbances that often accompany psychiatric disorders, in studying sleep/wake patterns in populations where PSG would be difficult if not impossible, and in the assessment of treatment effects and follow-up studies.

It is important to remember that actigraphy is not polysomnography. Although actigraphy may not be 100% accurate when compared to PSG, one still can get reliable information in situations where PSG is not practical. Actigraphy makes home recordings more accessible, permitting the evaluation of patients in their natural sleeping environment and minimizing laboratory effects that may alter a patient's typical sleep patterns. Actigraphy may provide an opportunity for subjects to adhere more closely to their scheduled bedtime and wakeup time than a PSG recording, thus providing a more accurate estimate of typical sleep duration than does PSG.

LIMITATIONS

In general, when actigraphy was compared to PSG, it was found to be both somewhat valid and apparently reliable in normal, healthy adult populations. Overall, actigraphy is best at estimating total sleep time. However, as sleep became more fragmented, the actigraph became less accurate in the detection of sleep and wake. Newer studies agree with older studies (e.g., Webster et al.,[11]) in suggesting that actigraphy may overestimate sleep and thus underestimate wake, particularly during the day when an individual is more likely to sit quietly while awake. In an effort to reduce this error, early investigators developed secondary algorithms that rescore sleep epochs as wake if adjacent to many wake epochs.[11]

While some data suggest that actigraphy consistently yields estimates of total sleep time and the number of awakenings that are higher than estimates on sleep logs, these results are more difficult to interpret, particularly since sleep logs themselves do not correlate highly with data from PSG. It is not unusual for clinicians to report that their patients are seen filling out a week's worth of sleep logs while in the waiting room, waiting to be evaluated. This brings up two questions. First, what is the meaning of a reliability study when the comparison is made with something other than a gold standard, such as when actigraphy is compared to sleep logs? For example, although the actigraphic estimates of total sleep time may have been higher than that reported in sleep logs, how do we know that the actigraph estimations were not actually more accurate than the sleep log estimation?

The second question is which is more important, the subjective report of the sleep log or the objective estimation of actigraphy? Many clinical trials are now using subjective reports as their final outcome measures, particularly in studies of insomnia, as they believe that if the patients feel they are sleeping better, it may not matter what the objective data show. If that is the case, then neither actigraphy nor PSG are necessary. If, however, a more objective estimate is desired, then actigraphy is a less expensive approach than PSG and has the added benefit of being able to record for multiple days and nights. When PSG is not feasible, the best approach may be to use a combination of actigraphy with sleep logs. When there is agreement between the two methods, confidence is increased in the results of both. When there is disagreement, it may reveal problems with one or the other.

Other problems with actigraphy relate to the determination of sleep onset latency and variables whose calculations depend on it, for example, sleep efficiency and wake after sleep onset. First, it is impossible to determine sleep onset latency accurately without either an accurate marker of bedtime, such as a very accurate sleep log or an event marker pushed at lights out. Activity monitors coupled with light sensors may be useful for objectively determining the time of lights out, although a bedpartner may continue to use lights after the person wearing the actigraph has gone to sleep. Second, studies to date have often reported poor agreement between sleep onset latency estimated by actigraphy and that determined by EEG. The problem may lie in the method of scoring, however, and not in the intrinsic properties of actigraphy. Cole et al.[28] found that the actigraph was more accurate (i.e., had a higher correlation) for identifying sleep onset latency than any other sleep variable, when an appropriate scoring algorithm was used (see section 4.3. Comparisons to PSG). If this finding could be replicated, it might be possible to substantially improve actigraphic estimates of sleep latency, sleep efficiency and wake time after sleep onset.

FUTURE RESEARCH

Standardization of acceptable norms needs to be established before actigraphy can be more generally used with full confidence in the realm of sleep/wake studies. More development and research of both the devices that record the data and the algorithms that process the data is needed. In addition, disclosure of types of algorithms used should be required in all manuscripts.

The question of the best placement of the actigraph must also be answered. The data suggest that the wrist in general is more accurate for sleep estimation than other placements. Although traditionally actigraphy has been recorded from the non-dominant wrist, newer data suggest that movement from the dominant wrist may reflect sleep and wake more accurately than movements recorded from the non-dominant wrist.

The problem of overestimating sleep must also be addressed. A potential approach to this problem might be the development of separate algorithms for scoring sleep from daytime vs. nighttime activity records. It would be desirable for future research to systematically evaluate these or other ways to overcome the actigraph's tendency to overestimate sleep. It may be that a different scoring algorithm is needed for periods when the individual is expected to be awake (out-of-bed periods) than the one currently used for periods during which the individual is expected to be asleep (in-bed periods). Studies of actigraphy compared to EEG outside of the traditional sleep period, in patients that are known to fall asleep during the day, need to be done to more reliably determine the effectiveness of actigraphy during waking hours.

SUMMARY

In summary, although actigraphy is not as accurate as PSG for determining some sleep measurements, studies are in general agreement that actigraphy, with its ability to record continuously for long time periods, is more reliable than sleep logs which rely on the patients' recall of how many times they woke up or how long they slept during the night and is more reliable than observations which only capture short time periods. Actigraphy can provide information obtainable in no other practical way. It can also have a role in the medical care of patients with sleep disorders. However, it should not be held to the same expectations as polysomnography. Actigraphy is one-dimensional, whereas polysomnography comprises at least 3 distinct types of data (EEG, EOG, EMG), which jointly determine whether a person is asleep or awake. It is therefore doubtful whether actigraphic data will ever be informationally equivalent to the PSG, although progress on hardware and data processing software is continuously being made.

Although the 1995 practice parameters paper determined that actigraphy was not appropriate for the diagnosis of sleep disorders, more recent studies suggest that for some disorders, actigraphy may be more practical than PSG. While actigraphy is still not appropriate for the diagnosis of sleep disordered breathing or of periodic limb movements in sleep, it is highly appropriate for examining the sleep variability (i.e., night-to-night variability) in patients with insomnia. Actigraphy is also appropriate for the assessment of and stability of treatment effects of anything from hypnotic drugs to light treatment to CPAP, particularly if assessments are done before and after the start of treatment. A recent independent review of the actigraphy literature by Sadeh and Acebo reached many of these same conclusions.[173]

Some of the research studies failed to find relationships between sleep measures and health-related symptoms. The interpretation of these data is also not clear-cut. Is it that the actigraph is not reliable enough to the access the relationship between sleep changes and quality of life measures, or, is it that, in fact, there is no relationship between sleep in that population and quality of life measures? Other studies of sleep disordered breathing, where actigraphy was not used and was not an outcome measure also failed to find any relationship with quality of life. Is it then the actigraph that is not reliable or that the associations just do not exist?

The one area where actigraphy can be used for clinical diagnosis is in the evaluation of circadian rhythm disorders. Actigraphy has been shown to be very good for identifying rhythms. Results of actigraphic recordings correlate well with measurements of melatonin and of core body temperature rhythms. Activity records also show sleep disturbance when sleep is attempted at an unfavorable phase of the circadian cycle. Actigraphy therefore would be particularly good for aiding in the diagnosis of delayed or advanced sleep phase syndrome, non-24-hour-sleep syndrome and in the evaluation of sleep disturbances in shift workers. It must be remembered, however, that overt rest-activity rhythms are susceptible to various masking effects, so they may not always show the

underlying rhythm of the endogenous circadian pacemaker.

In conclusion, the latest set of research articles suggest that in the clinical setting, actigraphy is reliable for evaluating sleep patterns in patients with insomnia, for studying the effect of treatments designed to improve sleep, in the diagnosis of circadian rhythm disorders (including shift work), and in evaluating sleep in individuals who are less likely to tolerate PSG, such as infants and demented elderly. While actigraphy has been used in research studies for many years, up to now, methodological issues had not been systematically addressed in clinical research and practice. Those issues have now been addressed and actigraphy may now be reaching the maturity needed for application in the clinical arena.

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APPENDIX A. ABBREVIATIONS

ACT - actigraphy
ADAS - Actigraph Data Analysis Software
ADHD - Attention deficit hyper-activity disorder
AIMS – Abnormal Involuntary Movement Scale
ANOVA - analysis of variance
ASA – Actigraphic Scoring Analysis
BL - baseline
BP - blood pressure
BRM - behavioral response monitoring
BT - bedtime
CES-D - Center for Epidemiologic Studies-Depression scale
CR - circadian rhythm
CSQP – Child Sleep Questionnaire Parent
D - day
DB - double-blinded
DSPS - delayed sleep phase syndrome
desats - desaturation events
DLMO - Dim Light Melatonin Onset
dom - dominant
dur - duration
Dx - diagnosis
ECG - electrocardiogram
EDS - excessive daytime sleepiness
EMG - electromyogram
epi - epinephrine
EPS – Simpson Angus Extrapyramidal Symptom Scale
F- female
f/u - follow-up
g-grams
GH - growth hormone
Grp - group
h/o- history of
HADS – Hospital Anxiety and Depression Scale
HAMD - Hamilton Depression Scale
HR - heart rate
h – hour(s)
IS: interdaily stability
IV: interdaily variability
log - sleep log or diary
LSEQ - Leeds Sleep Evaluation Questionnaire
Lt - left
M - male
meds - medications
mel – melatonin
MID – multi-infarct dementia
mins – minutes
MML – Mini-MotionLogger (AMI – Ambulatory Monitoring, Inc)
MMDG - mild-moderately demented group
MMNDG - Moderate, Mild or No Dementia Group
MMSE - Mini-Mental State Exam
mo - month
MSLT - multiple sleep latency test
ndom -non dominant
NINCDS-ADRDA – National Institute of Neurological and Communicative Disorders and Stroke and the Alzheimer's Disease and Related Disorders Association
NH - nursing home
norepi - norepinephrine
NS - not stated
Nt - night
num - number
OBJ - objective
OCP - oral contraceptive
OSAS - obstructive sleep apnea syndrome
PLM - periodic limb movements
PLMD/RLS - periodic limb movement disorder/restless legs syndrome
POMS-Profile of Mood States
PRMT - Probed recall memory test
PSG - polysomnography
PSQI - Pittsburgh Sleep Quality Index
PTSD – Post Traumatic Stress Disorder
pts - patients
PVT - psychomotor vigilance task

QOL - quality of life
QWB - Quality of Well Being
r - correlation coefficient
RA- relative amplitude
RCT - randomized controlled trial
RDI – respiratory disturbance index
Rt- right
Rx - drug
SAD – Seasonal Affective Disorder
SANS – Scale for the Assessment of Negative Symptoms
SAPS – Scale for the Assessment of Positive Symptoms
SB - single-blinded
SBJ - subjective
SDAT – Senile Dementia of Alzheimer's type
secs - seconds
SDG - Severe Dementia Group,
Sdur - Sleep duration
SE - sleep efficiency
SEI – Sleep Efficiency Index
SH - sleep hygiene
SHAPS-D - Snaith-Hamilton-Pleasure-Scale
SL - sleep latency
SOff - sleep offset
SOL - sleep onset latency
SOn -sleep onset
SP-sleep period
SQ - sleep quality
SSS - Stanford Sleepiness Scale
STAI- State Trait Anxiety Inventory
S/W - sleep/wake
SWT - sleep wake transitions
temp - temperature
TENS - transcutaneous electrical nerve stimulation
TIB - time in bed
TST - total sleep time
TWT - total wake time
Tx - treatment
VAS - visual analogue scale
W - wake
w/ - with
w/o - without
w/i - within
WASO - wake after sleep onset
wk - week
yr - year
6SMT - 6-sulphatoxymelatonin

Companies
AMI - Ambulatory Monitoring, Inc.
MM - Mini Mitter

Table 2—Evidence levels for technology papers

Citation - Author / Evidence Level	Study Criteria Design / Location / Protocol	Sample Size (Completed Study) / Mean Age (Range) / Medical Conditions	Comparison Measures / Actigraph apparatus / Placement / Epoch Length / Sensitivity / Scoring	Outcome Measures	Inclusion / Exclusion / Bias	Study Conclusion from paper	Comments from Reviewer
Acebo (36) 4C- a	Validation / Home / Nocturnal only for 30 mins prior to BT to 30 mins post BT; Study1: 4-7Nt ACT, Study2: 7D ACT, Study3: 7Nt ACT, 7Nt ACT	274 (224) / Grp1 NS (12-60 mos); Grp2 12.9 (11.2-14.4yr); Grp3 15.0 (14.0-16.2yr) / Normal	log used to estimate SOn & SOff; Observation by others (mother for Grp1) / MML / L ankle if under 36 mos, ndom wrist / 1 min / .05g / ASA ; Other: zero crossing	ACT: sleep start, SP, sleep mins, W mins during SP, SE	NS / Major genetic medical, psychological or sleep problems; meds that could affect sleeplessness; mental health or sleep problems in primary relatives / Few inferential statistical analyses presented	Loss of up to 28% of ACT data from children & adolescents should be expected; record for 7Nts to get 5 usable. Generally 5Nts ACT yielded reliable results for sleep start, W mins, SE, SP & sleep mins may require more than 7Nts of data to be reliable. Good reliability for sleep start time but poorest for SP.	ACT useful in children & adolescents
Ancoli-Israel (26) 3C	Validation / NH / Entire 24-h; 1D ACT; 1Nt (overlapping) PSG, Staff observations every 30 mins from 1000L to 1930L	10 (10) / 86.4±60 yrs / Severe dementia; All Pts wheelchair bound	PSG; Observation by staff / Actillume / wrist / 1 min / 003g. / Cole et al. '92	PSG: TST, total W time, sleep %; ACT: TST, total W time, sleep % for both max. ACT & sum ACT; Staff observations - S/W detection	Severe dementia (MMSE<20) / NS / Small sample size	Observation comparisons to ACT, Sensitivity 87%, Specificity 90%. PSG; ACT agreement rates (0.33 to 0.85 for max; 0.29 to 0.95 for sum) but not meaningful for this population. PSG comparison (r values): ACT MAX TST 0.81, % sleep 0.78, TWT 0.67; ACT SUM TST 0.91, % sleep 0.61, TWT 0.75.	Correlation of ACT (sum) w/ PSG for % sleep lowered by 2 outliers ACT showed more sleep than did PSG. EEGs different in this population making sleep scoring on PSG difficult; No inferential stats for ACT compared to observations
Blagrove (87) 3C	ACT Compared w/ other techniques; Forced desynchrony / Laboratory (dormitory used as lab) / Entire 24-h; BL 8Nt sleep midnight-0800; Sleep Dep.1: 26h; Forced desynchrony: 17 cycles (27hr D) sleep 9 h, W 18 h; Sleep Dep.2: 26hr; Recovery sleep: 9hr; continuous ACT	9 (9) / NS (19-20) / Normal	log; (temp reported elsewhere) / Gaewhiler / ndom wrist / 30 sec / NS / ACCORD software (UK) + Horne et al 1994 algorithm + custom algorithms	Log: BT, SOL, WASO, SOff, SBJ SQ; ACT: SOn, SOff, TST, movement index, freq. of movement onsets	Healthy, no sleep disorders/ NS / low num of subjects, all F, not blind to time of D	Movement freq. (weakly) predicts SBJ SE, SQ; Circadian time of going to sleep affected ACT TST & SBJ SE & quality (all reduced when starting sleep between 1000h and 1300h), but did not affect movement index or freq.	ACT appeared to detect expected reduction of TST induced by forced desynchrony protocol (poorer sleep when out of phase w/ temp rhythm), suggests ACT can detect a disturbance induced by circadian pacemaker, but no reference standard.
Blood (23) 3C	ACT compared w/ other techniques / Home / Nocturnal only for NS h; 1Ntt PSG+ACT+BRM, 1+ Nt timeout, 1Nt PSG+ACT+BRM (w/ 4 imposed awakenings during nights of recording)	8 (8) / F 27±1.4, M 33±8.3 / Normal	PSG; BRM / Actillume / dom arm / 1 min / NS / Action 3 (modified); Other: 0 crossing; SOL	PSG: SOL; ACT: SOL; BRM (light and tone conditions) SOL	NS / Meds, sleep disorders / Low sample size, forced wakes during night	ACT tends to represent quiet W as sleep; ACT consistently underestimated SOL; No usable inferential stats for Sensitivity, Specificity, or Accuracy	ACT good for measuring sleep but not good in detecting quiet W, SOL, WASO; focus of report was validating BRM. Much of the data graphed thus not possible to give mean and S.D.
Eissa (174) 3C	Retrospective / Home / 20-24 h; 1 D ambulatory BP monitoring + ACT + log	62 (62) / (6-71) / essential or secondary hypertension or normotensive	Log / Mini logger / ndom wrist / NS / NS / Ambulatory Monitoring	Ambulatory BP monitoring	Pt in data base who had successful ambulatory BP monitoring / NS / NS	In patients undergoing ambulatory BP monitoring compliance with ACT (91%) superior to log completion (71%) (more so in children and young adults). No diff in classification of hypertension status with ACT compared to log in 38 subjects completing both but dipper status (= greater than 10% drop in mean BP at Nt) was 55% misclassified using log compared to ACT sleep data (32% false negative and 23% false positive)	There is an advantage to using ACT when doing ambulatory BP monitoring to determine dipping status

Citation - Author / Evidence Level	Study Criteria Design / Location / Protocol	Sample Size (Completed Study) / Mean Age (Range) / Medical Conditions	Comparison Measures / Actigraph apparatus / Placement / Epoch Length / Sensitivity / Scoring	Outcome Measures	Inclusion / Exclusion / Bias	Study Conclusion from paper	Comments from Reviewer
Hauri (175) 3C	ACT compared w/ other techniques / Laboratory / Nocturnal only; 1Nt PSG+sleep switch+ACT	25 (25) /Grp 1: 44.5 (22-65) / 25.5 (19-40) /Grp 1: Insomnia, Grp 2, normal sleepers	PSG, other / NS / NS / NS / NS / Sadah et al. 1989	ACT: SOn, TST; FINGER SLEEP SWITCH; SOn TST	Grp 1: Insomnia; Grp 2;/ Normal sleepers /NS / NS	ACT not very good at measuring SOL; underestimates it "quite markedly"; ACT better than the sleep switch device & logs at TST compared to PSG but overestimates it	ACT was not focus of study but used as a comparison for the sleep switch device
Jean-Louis (22) 2B	Validation / Laboratory / Nocturnal; 1Nt ACT+PSG	20 (20) / 29.95±8.98 (21-53) / Normal	PSG; BT & morning questionnaire / Gaehwiler / dom wrist / 60 / 0.1g / ADAS; Other: bandpass 0.25-3.0kg	PSG: TST, SOL; ACT: TST, SOL, WASO	NS / No sleep path / Awakenings after SOn counted only if > 3 mins	The ADAS ACT scoring software correlates w/ PSG r=0.97 for TST w/ average discrepancy 12 mins.	
Jean-Louis (16) 3C	Validation; ACT compared w/ other techniques / Laboratory; Home /; Grp I. Nocturnal; Entire 24 h 1Nt ACT+log in home, 1Nt ACT & PSG in lab; Grp 2. Nocturnal Entire 24 h 1 D ACT+log+SSS in home, 3Nt ACT+PSG in lab	46 (46) / Grp1 30±9.0, Grp2 46.5±10.8 / Grp2 Insomnia	PSG / Grp1 Gaehwiler, Grp2 (AMI) / Grp1 dom arm, Grp2 NS / NS / NS / ADAS	PSG: TST; ACT: TST	Grp1 Normal / NS / NS	ACT is valid for assessing S/W; ACT is useful to assess S/W in insomniacs; ADAS is a valid software for ACT in different types of apparatus	
Jean-Louis (176) 4C-a	Validation / Home / Nocturnal; Entire 24-h; Grp1 24h ACT+log; Grp2 24h ACT+log; Grp3 1 Nt ACT+log; Grp4 1 Nt ACT+log; Grp5 3 or more Nt ACT+log	148 (148) / Grp1 30.1±13.1, Grp2 28±10, Grp3 34±10, Grp4 29± 14, Grp5 25.7±5.0 / Normal	NS /GAEWILER / Grp1 dom arm, Grp2 1 old, 1 new on dom arm, Grp3-1 on each arm, Grp4-dom wrist, Grp5-dom wrist / NS / NS / ADAS	log; ACT: TST, SE Index, SOL, WASO, Activity level, Activity counts>sleep threshold, num arousal periods>3 mins	NS / NS / NS	No difference in actigraph placement and (dom vs. ndom wrist or wrist vs. ankle) and reliability (between new instruments and new compared to old) Observed no first night effect	For first night effect study, would have been better to include third night of data also
Jean-Louis (177) 1A	ACT scoring software / Laboratory; Home / Nocturnal Entire 24-h; 1 wk ACT at home + SSS; 3 Nt PSG+ACT (only 1 night PSG+ACT analyzed)	26 (26) / 46.4±10.8 / NS	SSS / (AMI) / NS / 30sec/1 min / NS / ADAS; Other: zero-crossing	PSG: TST, SE; ACT: sleep threshold, WASO, TST, SE	Insomniac / NS / NS	ACT:PSG in insomniacs; ACT "is an excellent tool for unobtrusive documentation of S/W activity in individuals w/…insomnia"	Arousals after SOn defined as longer than 3 mins scored as W; several different r values reported for same data
Jean-Louis (46) 4C-a	Unblinded, nonrandomized, observational study, cross-sectional study / Home / Entire 24-h; 3D ACT	273 (273 (40-64) / normal, NS	diary/ Actillume (AMI) / 1 min / NS / NS / Automatic scoring rhythm; ACTION3	ACT: TST, SOL, SE index, mesor, amplitude (of the cosine) and phase (timing of the peak of the fitted cosine) Level of illumination	community dwelling residents of San Diego identified by random telephone survey / NS / NS	CR of illumination were significantly associated w/ activity and sleep rhythm measures. Higher amplitude of log illumination correlated with sleep phase (r = .16), lower SE index (r=-.15), and less reported daytime napping (r=-.16). Higher amplitude of activity correlated with sleep amplitude (r=.30), Sdur(r=.21) and less daytime napping (r = -.16).	Higher amplitude of activity (by ACT) was associated w/ less reported daytime napping. (r=-.16, p<.05).

Citation - Author / Evidence Level	Study Criteria Design / Location / Protocol	Sample Size (Completed Study) / Mean Age (Range) / Medical Conditions	Comparison Measures / Actigraph apparatus / Placement / Epoch Length / Sensitivity / Scoring	Outcome Measures	Inclusion / Exclusion / Bias	Study Conclusion from paper	Comments from Reviewer
Jean-Louis (12) 3C	Calibration & Validation / Grp 1: home; Grp 2, laboratory/ Grp 1: 24h ACT + PSG; Grp 2; 5Nt & 4D nocturnal PSG+24h ACT	Grp 1; 39 F (37) Grp 2: 4 M & 7 F (NS) / Grp 1: 63.7 (51 – 77) Grp 2: 25.4 (19-34) / Grp 1; post menopausal	PSG / Actillume / wrist / 1 min / 0.003g / zero-crossing threshold with Action 3	NS	Healthy /NS/NS	Grp 1: In bed: minute-by-minute agreement rate ACT with PSG = 85%, r = 0.98; mean difference between PSG & ACT = 21 mins, sensitivity = 94.8%, Specificity 40.6%. ACT missed much midsleep W; suggests may need second-by-second monitoring of activity to catch these. 24h: minute-by-minute agreement rate ACT with PSG = 89%, r = 0.90; mean difference between PSG & ACT = 1 min. Grp 2: 24h using Webster et al., (1982) scoring rules: minute-by-minute agreement rate ACT with PSG = 91%, r = 0.92; mean difference between PSG & ACT = 5 mins.	Authors conclude that Actillume useful for determining S & W at home & in lab with elderly and young, however different scaling factors in the scoring algorithm need for optimal results depending if ACT used in bed only or over 24h and with individual differences such as age and likelihood of WASOs. Shows need for more research to optimize use of ACT in various situations with various individuals.
Jean-Louis (24) 2B	Validation; ACT Compared w/ other techniques; Comparison of 2 ACTs & 5 quantification modalities / Laboratory / Diurnal; 5Nt & 4D nocturnal PSG+2 ACTs	5 (5) / Grp1 25± 6 / No medical conditions, emotional illness or sleep disturbance	PSG / Actillume & MML / wrist / 1 min / 0.003g / Action3; Other: Actillume-sum of activity and maximal activity; M M-zero crossing, time above threshold, & proportional integrating modalities	PSG: TST, SEI, W, S; ACT: min by min agreement w/ PSG, % PSG W misscored as sleep, % PSG sleep misscored as W, sensitivity, specificity	No medical conditions, emotional illness, or sleep disturbances / NS / 5 subjects of unreported sex; data from 10 of the 25 nights were not useable; no ANOVA to compare devices or modalities	Actillume performed comparably to MML and the different modalities of each were all comparable for S/W analysis. Although all 5 modalities performed well, proportional integrating modality seems better overall for this age Grp and zero crossing mode least desirable	
Kazenwadel (38) 1A	Validation / Laboratory / Nocturnal; 2wk BL, 4wks levodopa & lenserazide, 4wks placebo in randomized crossover design; 2Nt ACT+PSG w/ EMG at end of BL (1st was adaptation night) then 1Nt ACT+PSG w/ EMG at end of each Tx period	30 (29) / 51.0 (29-74) / PLMD/RLS	PSG / MOVOPORT / top of Rt foot between 1st & 2nd toes on pts reported most affected leg / 0.5 sec / NS / computer dichotomizing relative to a threshold followed by manual modifications	PSG: PLM, TIB, SEI; ACT: PLM, TIB	RLS + PLM / NS / NS	Measurement of PLMD by ACT is possible w/ 1/2-second epochs. Med made no difference in EMG & ACT correlations	Method requires considerable manual adjustment of computer analyzed ACT data to avoid underestimation. Movements of only one leg recorded by ACT
Krahn (30) 4C- a	ACT compared w/ other techniques / out-of-lab hospital bed / Entire 24-h; 3D ACT & log in A.M.	60 (30) / Median 58 (20-87) / NS	NS / (AMI) / wrist / NS / NS / Cole et al.	Log: TST, WASO, TIB, SOL; ACT: S, W, TST, WASO, TIB, SOL; Observations by nurses for S, W	Consecutive admits to med-psych or adult acute care inpatient units / Patient seeking 1:1 nursing care or other conditions / Patient selection limited to those able to comply w/ study design	Nurses observations of sleep in psychiatric patient agrees satisfactorily w/ ACT but pts self-reports using log in a.m. is not satisfactory	ACT as comparison standard for SL & nurse observation of patient

Citation - Author / Evidence Level	Study Criteria Design / Location / Protocol	Sample Size (Completed Study) / Mean Age (Range) / Medical Conditions	Comparison Measures / Actigraph apparatus / Placement / Epoch Length / Sensitivity / Scoring	Outcome Measures	Inclusion / Exclusion / Bias	Study Conclusion from paper	Comments from Reviewer
Lockley (29) 3C	ACT compared w/ other techniques / Home / Entire 24-h; mean nights/subject=23±7 (range 6-35) of ACT + log	49 (49) / 46.6±12.2 / Blind	log; mel; Urine samples / Motion loggers or MML / wrist / 1m / NS / Action 3; Other: Zero crossing mode	log: SOL, SOn, SOff, Num awakenings, dur awakenings, num naps, dur naps; ACT: SOL, SOn, SOff, Num awakenings, dur awakenings, num naps, total nap dur	Meds influencing sleep or mel / NS / NS	ACT and logs yielded similar results for some aspects of sleep but not others. Proportion of pts showing differences between ACT and log greater than those showing no differences.	Unique use: to see if sleep (daytime nap num & dur & night sleep dur) greatly altered by CR type (normal entrained, abnormal entrained, or free run)
Middelkoop (40) 4C-a	Validation / Home / Entire 24-h; 45 h ACT	10 (10) / 24.1±3.1 (19-33) / NS	Log / Gahwiler / both wrists & both ankles & trunk at navel / 5 sec (min) / 0.1g / ACTSTAR 1.0; Other: 0.25-3kg	log: Time to bed, light out time, SOL, num awakenings, rise time, num naps, nap dur; ACT: Activity level, epochs>, dur of epochs>0	Rt banded, healthy, no meds / NS / NS	Activity recorded at wrists > ankles > trunk. Motor activity lower at Nt comparably at all sites but significantly more activity of dom wrist during diurnal period, & wrist correlated more w/ trunk at Nt than ankles; opposite diurnally. Ndom wrist activity correlates more w/ trunk activity than does dom wrist activity; During sleep ACT reveals more whole body, generalized movement but during W there are more isolated limb movements	
Middelkoop (41) 4C-b	Validation / Home / 45 consecutive h starting at 12:00; 45 h ACT+log	20 (20) / 24.1±3.7 / Normal	NS / GAHWILER electronic CH-8634 Hombrechtikon / Lt wrist, Rt wrist, Lt ankle, Rt ankle, trunk (navel) / 5 seconds / NS / NS	ACT: Activity level	NS / NS / Healthy young adults only	Wrist placements detected more activity counts than ankle or trunk placements. dom wrist placement yielded greater diurnal activity counts than ndom. All sites clearly showed circadian sleep-W differences. Suggests more study w/ placements concomitant w/ PSG	Wrist placement superior to ankle or trunk. Dom wrist appears better for discriminating level of waking activity.
Minors (45) 4C-b	Technique Development / Home / Entire 24-h; 3-26 24-hperiods of ACT	8 (8) / Grp1 49, Grp2 (18-20), Grp3 26, Grp3 (43-74) / Normal Grps 1&2, CR disorder, DSPS Grp 3; Colorectal cancer Grp 4	log / Gaehwiler / ndom wrist / 6 mins / NS / NS	NS	NS / NS / Low sample size	Method developed for comparing level of activity in bed vs. out of bed (=”dichotomy indices”); Healthy subjects showed greater dichotomy than either pts w/ DSPS or colorectal cancer; Might be useful technique for study of circadian phase shift (shift-workers, jet lag) & illness	
Minors (96) 4C-a	Repeat measures, 2 conditions compared / Home / Entire 24-h; 2 Ds rest ACT & 3 Nt shifts ACT	8 (8) / (18-35) / Normal	log / Gaehwiler / ndom wrist / 30 sec/1 min / NS / NS	ACT: relative activity levels	Night shift nurse / NS / NS	When data is corrected for length of sleep D sleep has greater activity levels than night sleep; Difference between W activity and sleep activity levels tends to be less during night work shifts	ACT can be useful in studying adjustment to shift work This paper is a further analysis of data in an earlier study.

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Monk (31) 3C	ACT compared w/ other techniques / Space Shuttle Columbia / Entire 24-h; Diurnal; 72 h ACT+PSG+log; 7D nothing; 72 h ACT+PSG+log	4 (4) / 42.5 (38-47) / Healthy	PSG; log / Actillume / ndom arm / 1 min / NS / 5 consecutive mins of 0 (sleep) or non-zero (W onset) counts	PSG: SOn, SOff, Sdur, SE, SOL, WASO, Sleep stages; ACT: SOn, SOff, Sdur SE, SOL, WASO	No sleep disorders; 2 astronauts, 2 payload specialists / NS / Only 4 subjects	ACT during space flight clearly identified SOn & SOff better than log as well as sleep dur & SE as compared to PSG. Even good correlation of ACT counts & different sleep stages, but ACT failed to detect a .98 min SOL. Overall ACT is a simple efficient means of evaluating sleep in space when PSG is not feasible	During space flight
Otsuka (178) 5D-a	Validation / Laboratory; Out-of-lab hospital bed / Entire 24-h; 72+h ACT 7 ECG, (also BP for 48h & HR for 24h)	44 (44) / Grp1 (28-46), Grp2 (28-78) / Normal; Healthy	ECG; BP; HR / Activetracer / waist / 1 sec / 0.01 to 0.50g / NS	ACT: Activity level; BP		Simultaneous ACT & BP can be used to show relationship of S/W w/ BP. Suggests S/W rhythms of about 7 Ds (circaseptan) in addition to circadian & a 3.5 D (circasemiseptan) rhythm in irregular S/W cycles but able to identify individual differences in all these	Hard to pull data out of this article; uses a lot of individual examples.
Pollak (18) 4C-b	Validation; 2 ACT devices compared reliability, validity, artifact rejection / NS / 7-92h ACT (mean=41.5)	5 (5) / 33.20 (22-47) / Normal	None / 1. MML (AMI Model 20.000), 2. Activity monitor (Gaehwiler Electronics model 280 32k v1) / ndom wrist / 30 sec / for Mini-Motionlogger-manufacture's software for Gaehwiler-NS	ACT: Activity counts	NS / NS / Low sample size; wide range of durs of ACT measurement; no comparison measures	Both devices were reliable. Related is the need for the instrument to detect small sleep movements and interruptions; again G was poor. Because of above, G would over estimate sleep and sleep continuity. AM is better than G for S/W detection	Good study; almost pilot study; showing need for standardization of criteria for acceptability in ACT instruments
Pollak (21) 3C	Validation & Reliability / Laboratory / 7 D + N ACT + PSG in time isolated, free-run condition	15 (14) / NS (20 – 35 & 70 – 72) / healthy, no sleep problems	PSG / ActiTrac & CSA Activity Monitor / non-dom wrist / 30 secs / 0.024 & 0.033 g / 1) single threshold & 2) "logistic regression" with moving 20 minute window	NS	Healthy with no sleep problems	ACT is adequate for determination of S/W circadian rhythm, rest/activity cycles, and S-consolidation but not otherwise as a substitute for PSG because it overestimates S dur and SE but misses WASOs. No differences between the two ACT apparatus. Sensitivity = 86.6% for N only, 62.2% N + D because failed to show D S. Specificity = 89.6% for N using logistic regression; approached 100% for D. Agreement rate (a poor measure in general) = 76.9% for D + N, 82.0% for N only. ACT & PSG have poor agreement on W to S and S to W transitions. Some indication that the stages of sleep are reflected in level of ACT ranging from high for W to stage 1 then REMS then stage 2 then SWS at low end.	Unique scoring and data processing. Makes a strong case for superiority of PSG over ACT for most applications.

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Reid (25) 3C	Validation; ACT compared w/ other techniques / Laboratory / Diurnal; Entire 24-h; ACT+PSG (when sleep) for 1Nt adaptation, 2D of 12 h D shift (night sleep), 2D 12hr night shift (D sleep), 1 1/2D "off"	32 (32) / Grp1 21.2±2.7, Grp2 43.9±6.8 / NS	PSG / Gaehwiler / ndom hand / 30 sec / 0.1g 125 ms sampling time (8 kg) Baudpass filter 0.25-3.0 kg / NS	PSG: Sleep, Wake, SOn, SOff; ACT: S, W, SOn, SOff	NS / Smokers, taking meds, sleep disorders / Lab shift work studies may not completely reflect real world, their older subjects were really middle-aged.	ACT valid for S/W activity & sleep dur (although ACT different from PSG for SOff) but not as good for more specific measures such as SE; ACT: agrees more with PSG for young adult than for middle-aged because more quiet W scored as sleep in latter , as the likelihood of sleep decreases so does ACT accuracy.	
Roehrs (37) 2B	Validation: ACT compared w/ other techniques / Laboratory / Diurnal only for 11 h; 1D placebo-8hr TIB, 2-7D recovery, 1D placebo-4hr TIB, 2-7D recovery; 1D placebo-0hr TIB, 2-7D recovery, 1D diphenhydramine 50mg-8hr TIB; in Latin Square design	34 (17) / 27.9±4.3 (19-35) / Normal	MSLT / MML / ndom wrist / 30 / NS / Action-W	PSG: MSLT, SOL; ACT: SOL, % inactivity, counts per active epoch	Healthy, normal S/W patterns, no sleep complaints, <250 mg/D caffeine consumption, no Rx of drug/alcohol abuse, non-smokers / NS / ACT scoring software not specifically developed to assess daytime sleepiness	ACT can be used to show changes in daytime epochs of inactivity due to changes in sleepiness. MSLT show difference between 8h, 4h, 0h while diphenhydramine intermediate to & differed from both placebo-4hr TIB & placebo-0hr TIB. Counts during active epochs didn't yield any significant difference. MSLT was more sensitive than ACT to sleep loss but ACT may represent more real-world index of effects of sleepiness	ACT used to measure daytime sleepiness (lapses)
Sadeh (35) 4C	Comparative Tx; ACT compared w/ other techniques / Home / 1 wk ACT+log BL; 1 wk or more ACT+log during 1 of 2 interventions	50 (50) / 14.11±4.21 (9-24) / Nt waking problems	log / (AMI) / NS / NS / NS / ASA	log: SOn, Sdur, Sleep%, night awakenings; ACT: SOn, Sdur, Sleep%, night awakenings, quiet sleep, active sleep	Nt waking problems & whose parents complied w/ an intervention / NS / ACT scoring software not specifically developed to assess daytime sleepiness, No untreated control Grp	ACT+log showed improvement during time a Tx was applied but no difference between Txs; Parental log not as good as ACT re: whether children's sleep improved during Tx (60% agreement rate)	ACT+log showed improvement during time a Tx was applied but no difference between Txs
Sadeh (33) 4C-a	ACT compared w/ other techniques / Home / Nocturnal only for NS h. mean=6D (range: 3-12) ACT+log	66 (66) / 14.7±4.6M (7-26M) / Healthy	log / AM-16 / leg / NS / NS / ASA	log: SOn, Sdur, Sleep percent, num awakenings; ACT: SOn, Sdur, S%, num awakenings	Nt waking problems / NS / pts all referred to sleep clinic for night waking problems	Both ACT+log should be used in assessing sleep problems of infants	Paper rightly concludes that both ACT+log should be used in assessing sleep problems of infants because either alone distort or miss some data
Sadeh (17) 1A	Validation; ACT compared w/ other techniques; reliability / Laboratory & Home NS / Nocturnal; 1. PSG & ACT; 2. 42-48h w/ 2 ACT on same wrist	44 (44) / Grp1 22.6±1.7 (20-25), Grp2 13.8±1.9 (10-16), Grp3 (12-46) / NS	PSG / AMA-32 / 1. 1 dom & 1 ndom wrist, 2. 2 on same wrist / 1 min / NS / zero crossing (& based on 1st 10 adult pts)	PSG & ACT: S, W - Minute by minute comparison	Normal / NS / NS	S/W derived from ACT is robust & little affected by device placement although activity levels differed between dom & ndom wrist during SP & wakefulness but resulting ability to discriminate sleep was relatively unaffected by this.	Paper contains suggestions for proper use of ACT
Sforza (39) 2B	validation / laboratory / nocturnal only for 7.5 h, 2N (s/b Nt? PSG/ACT(n= 10; CPAP titration on night 2) in PSG/ACT (n=25)	35 (35) / 54.8±1.6 (37-72) / 13 OSAS, 22 EDS or snoring or RLS/PLMD	PSG; Anterior tibialis EMG / Gaehwiler / upper Rt foot / 5 sec / 0.1g / NS	PSG: PLM (via EMG); ACT: PLM	NS/Technical problems during recording/ Most pts Dx w/O SA	ACT: EMG Movements – leg ACT not valid. R=0.78 but ACT underestimates movements, especially those <3 sec and < 50 mv but was reliable across 2 nights in 8/10 subjects thus not valid for DX PLMD but valid for Tx evaluation.	Conclusions differ from those of Kazenwadel, et al., 1995 due to more sophisticated analysis

Citation - Author / Evidence Level	Study Criteria Design / Location / Protocol	Sample Size (Completed Study) / Mean Age (Range) / Medical Conditions	Comparison Measures / Actigraph apparatus / Placement / Epoch Length / Sensitivity / Scoring	Outcome Measures	Inclusion / Exclusion / Bias	Study Conclusion from paper	Comments from Reviewer
Shinkoda (27) 3C	ACT compared w/ other techniques / Laboratory / Nocturnal; 3Nt ACT+PSG	4 (4) / (20-33) / NS	PSG / AMA-32CL / ndom wrist / 30s (but 1 min compared to PSG) / NS / Cole et al 1992; Other: Zero crossing mode	PSG: S,W, TST, SOL, SEI, WASO, num awakenings; ACT: S, W, TST, SOL, SEI, WASO, num awakenings	NS / NS / very low sample size	ACT correlates w/ PSG for TST, SOL, SEI, WASO, num awakenings	
Tikotzky (34) 4C-a	Observational /NS /put on 1 h before sleep, removed 1 h after wake, 4-5 N	NS (59) M, 29, F, 30 (3.8-6.1) /normal	Sleep log-diary / AMA-32; AMI / non-dom wrist / NS / NS / Sadeh ASA	ACT: SO, TST, % sleep, # wakes	NS/NS	Parents log correlated well with ACT but less accurate in sleep quality measures. 41% of kids had fragmented sleep	
Van Someren (179) 4C-b	Technical considerations / Laboratory; while performing 6 tasks / NS	25 (25) / Grp1 28±4, Grp2 80±9 / NS	NS / Entran / dom wrist / NS / ±2g / NS	NS	NS / NS / NS	Use of bandpass of 0.25 to 11kg for ACT is better to measure all movement. May under record movements especially in young. It also tends to reduce “gravitational artifact”.	
Van Someren (14) 5D-a	Technical / NS / NS	25 (25) / Grp1 Young Adults, Grp2 Elderly / NS	None / NS	NS	NS / NS / ACT scoring software not specifically developed to assess daytime sleepiness	The bandpass filter of typical ACT appears to be too narrow & may miss some movements .5-11Hz may be better. This is especially important for studies of aging since younger tend to have more rapid movements that can be missed w/ the prevailing cut-offs	Highly theoretical w/ little information on where the data shown came from
Verbeek (180) 3C	Validation / laboratory / NS	20 (20) / 47.7 (33 – 64) / insomnia	PSG; log / NS / NS / NS / NS / Cole et al., 1992	NS	healthy / NS / NS	ACT overestimates TST in insomniacs by mistaking lying still but awake for sleep. PSG better than ACT; both better than logs.	Too many procedural details not specified.
Violani (42) 4C-a	Parallel design / Laboratory (nocturnal study); Home (diurnal study) / Entire 24-h; 1wk log; 1Nt PSG+ACT on each wrist & each ankle, 1Nt PSG+ACT on either wrist or each ankle, 1Nt PSG+ACT in opposite positions from previous night	16 (16) / (19-28) / NS	PSG; log / 4 motion logger / each wrist & each ankle / 1 min / NS / zero crossing Action 2	ACT: Activity levels	Normal sleep dur and schedule, healthy / NS / NS	During W Rt hand shows more intense activity than Lt that disappears during early sleep but reappears during later sleep that cannot be accounted for by a difference in arousal. No such differences noted in ankle activity.	

Table 3—Evidence levels for studies of sleep disorders

Citation - Author / Evidence Level	Study Criteria Design / Location / Protocol	Sample Size (Completed Study) / Mean Age (Range) / Medical Conditions	Comparison Measures / Actigraph apparatus / Placement / Epoch Length / Sensitivity / Scoring	Outcome Measures	Inclusion / Exclusion / Bias	Study Conclusion from paper	Comments from Reviewer
Aronen (67) 4C-b	Observational study / home / entire 24 h, 3D ACT	49 (NS) M, 26, F, 23 /9.73 (1.39) / normal	None / AMI mini-motion logger / belt / 1 min / NS / AMI	Behavioral: child behavior checklist, teacher report form	No meds/no meds / small sample size, low power, high Type I error due to multiple tests	ACT sleep times related to teacher-reported symptoms; decreased sleep related to more externalizing symptoms	
Cole (44) 2B	RCT, parallel / Home / Entire 24 h 2D BL; 5D Tx; 2D post Tx	78 (45) / 25±6 / DSPS	None / Actillume / wrist / NS / NS / NS	Log; ACT; behavioral; Mood; 6-SMT	NS / non DSPS, serious health problems, regular med use, Rx/alcohol abuse, serious psychiatric problems, recent travel/shift work / NS	Acrophase of 6-SMT advanced by bright light, no difference at f/u. Advance sustained only in late-phase pts. Late-phase pts SOn and SOff advanced by bright light.	
Collado-Seidel (73) 4C-b	Controlled clinical trial, cross-over design / Home / Nocturnal; 5Nt BL ACT; 5Nt Rx ACT; 5Nt placebo ACT	37 (30) / 58±10 / PLMD/RLS	Questionnaire; Observation by others (physician) / Movoport (Rimkus) / foot / NS / NS / NS	ACT: PLM per h of TIB, time w/o movement; Others: QOL ratings; physician-rated clinical global impressions, SBJ QOL	Improvement in Symptoms w/ L-dopa 1st 4 h, ≥ 2 wakes longer than 20 mins or 1 longer than 1 h, Increase in PLMs 2nd half of night / NS / None	Tx improved: num PLM / h, (p,.001) % of TIB w/o leg movements, (p<.001) SBJ QOL, (p<.001) num of PLM episodes, (p<001) num of PLMs per episode, (p<.001) dur of PLM episodes (p=.005)	
Dagan (57) 5D-a	Case series / Home / Entire 24-h; 4-7D ACT BL to help diagnose DSPS; f/u questionnaire ≥ 1 yr after 6-wk mel Tx	61 (NS) / 30.17±11.26 (16-54) / DSPS	None / MML (AMI) / wrist / NS / NS / NS Sadeh; Other: zero-crossing mode	Survey	No meds, DSPS Dx, mel Tx, finished ≥ 1 yr prior to study / No control Grp	96.7 % report mel helped DSPS, 91.5% relapse after mel cessation	No validation of ACT other than pt. report ACT used only to aid initial Dx of DSPS. Outcome assessed only by questionnaire, not ACT.
Dagan (54) 5D-b	Cohort study / Home / Nocturnal 8 h	27 (27) / Grp1 31.9±6.31, Grp2 30.5±5.5 / normal; PTSD	log / (AMI) / wrist / NS / NS / Sadeh et al '89	log; PSG; Health questionnaire	Free of sleep-affecting Rxs for 10-Ds / NS / NS	No sig. diffs, in ACT sleep variable b/t PTSD pts & normal controls; no correlation b/t ACT sleep variables & AM reports; no correlation b/t ACT sleep variables & sleep parameters on health questionnaire	
Drinnan (70) 5D-b	ACT compared w/ other techniques / Home / Nocturnal only for 6 h; 1Nt PSG/ACT	40 (36) / 48±12 (20-73) / Snoring, EDS	PSG; Epworth / IC Sensors / L wrist, L ankle / NS / NS / Custom	PSG; ACT; Epworth	NS / NS / Sample limited to pts presenting for Tx; only 1 Nt assessed	No significant correlation between ACT & apnea, EEG arousal, or respiratory phase; L ankle ACT/L tibia EMG r=.73 (p<.001); L ankle ACT/L wrist ACT r=.55 (p<.001); detection of limb movement predictive of arousal, but EMG more than ACT	
Elbaz (71) 3C	ACT compared with other techniques /lab / nocturnal only for 8 h 1 Nt PSG, ACT	20 (20) M, 15, F, 5 / 52 (15) / OSAS	PSG, Resp variables / Cambridge Actiwatch / non-dom wrist / 1 min / NS / NS	PSG sleep variables, ACT	NS/NS	For ACT TST & PSG TST, r=.74, p<.0001; for ACT RDI & PSG RDI, r=.976, p<.0001; for RDI based on TIB, r = .94 Sensitivity & negative predictive value lower for TIB RDI than ACT RDI in severe OSA patients.	ACT & respiratory variables provided good assessment of RDI and was somewhat better than resp variables alone

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Franck (62) 4C-b	Cohort study / Home / Entire 24-h; 3D ACT	33 (33) / Grp1 10.61±3.5, Grp2 10.87±3.27 / Normal, HIV+	log; Self report; Parental report / MML (AAM-32) / NS / 2 mins / NS / Action 3	log; ACT	NS / For controls: Chronic medical conditions, regular med use / All infected pt's undergoing Rx therapy	Parental reports indicated HIV-infected children to have less sleep, more awakenings, & more nightmares than controls; child logs showed no diff. in sleep characteristics or daytime fatigue; ACT showed greater num of awakenings, lower SE, W time during the Nt, less SE for HIV+ pts	
Guilleminault (51) 4C-b	NS/ Home / Nocturnal; 1Nt PSG screening, 4wk Tx; 4Nt ACT; 7Nt log	32 (30) / Grp1 44±8, Grp2 44±8, Grp3 44±8 / Insomnia	Questionnaire; log / MML / dom arm / 2 mins / NS / NS	log; ACT; Self-reported sleep: TST, SL, num W	SL > 30min or TST < 360min, No Rx sedative-hypnotic use / NS / NS	No diff for SH or SH + Exercise, for SH + light, TST higher, SL lower, W lower	TST from logs < ACT TST, SL logs > SL ACT, W logs < W ACT
Guilleminault (181) 5D-b	Case series / Laboratory and home / Nocturnal only for 8 h; 1 Nt PSG; 7 Nt log and ACT	184 (184) / M 34±8 (18-52), F 39±12.5 (18-54) / Head/Neck trauma and hypersomnia	PSG, MSLT, Epworth, SSS, log / NS / NS / NS / NS / NS	Log; PSG: MSLT, AHI, SOREMPs; Behavioral variables; Mood variables	NS / NS / self-selected sample	EDS associated w/impaired daytime function. 24-h coma, head fracture, or immediate neurosurgical intervention associated w/ ESS> 16 and MSLT <5. Sleep apnea associated w/ whiplash.	ACT had little role in results or conclusions.
Hayes (182) 4C-b	Cross-sectional study / Home / Nocturnal only for 9 h; 1Nt ACT	30 (27) / Grp1 80.9mo±7.2 SEM / Normal	Time-lapse video / Electrostatic bed pad / head/shoulder & buttocks / 1 sec / NS / FFT, Periodgram	ACT: AFFT	Normal sleeper; mid-infancy to pre-puberty / NS / None	Movement intensity & movement bout structure integrity during sleep decreased w/ age; decline in bout dur w/ age; increase in bout freq. w/ age	
Hering (63) 5D-b	NS / Home / Entire 24-h; 3D ACT	NS (NS) / Grp1 8.0±3.0, Grp2 8.0±2.3 / Normal, Insomnia, Autism	log /(AMI) / wrist / NS / NS / Sadeh '89	log; ACT	NS / NS / NS	log of parents showed differences in AM W time, early Nt arousals, & multiple Nt arousals	
Jean-Louis (53) 5D-b	Observational study / Home / Entire 24-h; 3D ACT	273 (NS) / 51 (40-64) / Normal	None / Actillume / wrist / 1 min / NS / Action 3	Mood: QWB scale, CES-D	NS / NS / Mean age somewhat high (N50) to be representative of the adult population; used pts received from random telephone dialing-those who consented may be more likely to have problems	ACT-measured sleep variables not significantly correlated w/ QWB or CES-D scores	
Jean-Louis (16) 3C	Validation; ACT compared w/ other techniques / Laboratory; Home /; Grp 1 Nocturnal; Entire 24 h 1Nt ACT+log in home, 1Nt ACT & PSG in lab; Grp II. Nocturnal; Entire 24 h 1 D ACT+log+SSS in home, 3Nt ACT+PSG in lab	46 (46) / Grp1 30±9.0, Grp2 46.5±10.8 / Grp2 Insomnia	PSG / Grp1 Gaehwiler, Grp2 (AMI) / Grp1 dom arm, Grp2 NS / NS / NS / ADAS	PSG: TST; ACT: TST	Grp1 Normal / NS / NS	ACT is valid for assessing S/W; ACT is useful to assess S/W in insomniacs; ADAS is a valid software for ACT in different types of apparatus	
Jean-Louis (177) 1A	ACT scoring software / Laboratory; Home / Nocturnal Entire 24-h; 1 wk ACT at home + SSS; 3 Nt PSG+ACT (only 1 night PSG+ACT analyzed)	26 (26) / 46.4±10.8 / NS	SSS / (AMI) / NS / 30sec/1 min / NS / ADAS; Other: zero-crossing	PSG: TST, SE; ACT: sleep threshold, WASO, TST, SE	Insomniac / NS / NS	ACT:PSG in insomniacs; ACT "is an excellent tool for unobtrusive documentation of S/W activity in individuals w/…insomnia"	Arousals after SOn defined as longer than 3 mins scored as W; several different r values reported for same data

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Kazenwadel (38) 1A	Validation / Laboratory / Nocturnal; 2wk BL, 4wks levodopa & lenserazide, 4wks placebo in randomized crossover design; 2Nt ACT+PSG w/ EMG at end of BL (1st was adaptation night) then 1Nt ACT+PSG w/ EMG at end of each Tx period	30 (29) / 51.0 (29-74) / PLMD/RLS	PSG / MOVOPORT / top of Rt foot between 1st & 2nd toes on pts reported most affected leg / 0.5 sec / NS / computer dichotomizing relative to a threshold followed by manual modifications	PSG: PLM, TIB, SEI; ACT: PLM, TIB	RLS + PLM / NS / NS	Measurement of PLMD by ACT is possible w/ 1/2-second epochs. Med made no difference in EMG & ACT correlations	Method requires considerable manual adjustment of computer analyzed ACT data to avoid underestimation. Movements of only one leg recorded by ACT
Kerkhof (56) 4C-b	Correlational / Home / 14D oral temp, VAS SBJ alertness; 14Nt log, VAS SQ.; 11D ACT	80 (80) / 34.8±10.1 / Insomnia	log; Temp / Gaehwiler / ndom hand / 30 sec / 0.1g / custom	log; Temp; ACT: mean activity count (MR), immobility (IMM), fragmentation (FR)	6 mos. Serious sleep complaints / NS / NS	Significant difference in MR b/t early & late temp phase pts no difference for FR or IMM q(p) values greater for early phase Grp	
Kramer (68) 4C-b	Cross-sectional study/ home / 14 D sleep logs, 11 D ACT, 14 D oral temp	40 (40) Grp 1 M 21. Grp 2 M, 19 / Grp 1 65.1 (59-74 (4.4) Grp 2 20.8 18-26 (2.2) / normal	Sleep log, diary/ Gaewhiler / non-dom wrist / 30 sec / 0.1g / NS	Sleep diary, log; ACT	Exclusion: psychiatric, neurological disease, cardiovascular disease, drug abuse / NS	Young subjects had more TIB variability than elderly subjects; p<.001. Elderly subjects had advanced sleep phase relative to younger subjects. Elderly subjects had more midnight awakenings than young subjects. Sleep logs showed less TST and SE for elderly subjects.	
Kunz (183) 4C-b	Unblinded, nonrandomized / Laboratory, Home / Nocturnal only 8 h; 2 Nt PSG BL; 14 Nt ACT BL; 2 Nt PSG post Tx; 14 Nt Tx	9 (9) / 57 (40-71) / PLMD, Depression, RSBD, Parkinson's dysautonomia	PSG, log / 2AK / wrist / NS / NS / NS	Log; PSG; ACT	NS / RLS / small sample	Tx improved well being in 7 of 9 pts, PSG movement parameters improved w/ Tx, ACT measured movement reduced by Tx	No measurement of sleep variables w/ ACT
Kushida (19) 2B	Validation / Laboratory / Nocturnal 8 h 1Nt PSG, ACT, log	100 (100) / 49±14.7 / OSAS, narcolepsy, insomnia, PLMD/RLS, UARS	PSG; log / AW4 MM / ndom wrist / 30s / .01 g / Oakley '97	log; PSG; ACT	NS / NS / self-referred pts, mixture of Dx	ACT over estimated TST by 1.0-1.8 h; log overestimated TST by 0.3 h; num of awakening more accurate for ACT than log; ACT high threshold algorithm: sensitivity = .98; specifying = .76 accuracy = .28	
Middelkoop (69) 4C-b	Validation / Home / 1Nt ACT, log	167 (116) / 53.6±10.7 / OSAS	log; Oronasal thermistry / Gaehwiler / ndom arm / 15 sec / NS / % epochs count>0; Other: Counts/epoch, dur of uninterrupted activity, dur of immobility (DIP), fragmentation index	Log; ACT; Respiration (apnea index)	Habitual snoring w/ excessive daytime sleepiness and/or nocturnal respiratory arrests / NS / Apnea of pts was mild, may have led to lower discrimination	AI ≥ 5 Grp. Greater than AI <1 & AI < 5 groups for movement index & frequency Index. DIP sig diff in 3 Grps, ETOH related to DIP, DIP correlated w/ AI	
Nagtegaal (61) 1A	Controlled clinical trial, DB, cross-over design / Laboratory, Home / Nocturnal, Entire 24-h; 1D rect temp (pre Tx), 1Nt PSG (Placebo mel), 3D ACT (placebo), 14D ACT (mel), 1D rect temp (post Tx)	30 (25) / 37.3±15.3 / CR disorder	PSG; log; Temp / NS / NS / NS / NS / NS	Log; temp; PSG; ACT	NS / Under age 12, prior use of mel, liver disease, renal failure, severe neurological or psychiatric disorder, pregnancy / NS	Temp markers showed advance after Tx; pts more refreshed (logs) w/ Tx compared to placebo	

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Okawa (58) 4C-b	Comparative Tx / Home / Entire 24-h / 14D ACT, body temp BL, Tx (time not indicated)	11 (11) / Grp1 32.3 (16-46), Grp2 28.4 (17-34) / CR disorder	Log; temp / (AMI) / ndom wrist / NS / NS / NS	Log; temp; ACT	NS / NS / Small sample size	6/11 pts responded to mel Tx; temp phase shifted first, followed by shift in S/W cycle	No statistical analysis reported, no controls
Sadeh (66) 4C-b	Cross-sectional study / home / 4-5 D ACT on school nights; sleep logs, sleep habits questionnaire	140 (140) M 72, F 68 Grp 1 N=50; Grp 2 N= 37; Grp 3 N = 53 / grp 1 7.0 (7.2-8.6 (o.34); Grp 2 9.7 (9.3-10.4 (o.30); Grp 3 11.8 (9.9-12.7 (0.45) / normal	Questionnaire, sleep log/ diary / AMI AMA-32 / non-dom wrist / 1 min / NS / ASA	Sleep diary/log, ACT	Exclusion: no acute physical illness or behavioral problems	Night –to-night reliability for ACT > .70 for most measures. Older subjects had delayed sleep onset times, shorter sleep periods, and shorter sleep times than younger subjects. Girls had longer sleep times and more motionless sleep than boys; increased family stress correlated with poorer sleep quality, increased daytime sleepiness assoc. with greater age and shorter sleep period per ACT	
Sadeh (64) 4C-b	Observational study / out –of-lab hospital bed / entire 24 H, 1 D ACT anthropometric measures	262 (220) M-115, F-105. Grp 1, 102, Grp 2, 118 / 20.4 and 20.4 / normal and other gestational diabetes	None / AMI AMA -32 / Rt ankle / 1 min / NS / ASA	ACT and Others, anthropometric measures	NS / NS	Newborns slept twice as much during nighttime hours than daytime. Infants of gestational diabetic mothers (IGDM) had significant correlations between skinfold measurements and quiet sleep. Later gestational age assoc. with increased quiet sleep percent	
Sforza (39) 2B	Validation / laboratory / nocturnal only for 7.5 h, PSG/ACT(n= 10; CPAP titration on night 2) 1 nt PSG/ACT (n=25)	35 (35) / 54.8±1.6 (37-72) / 13 OSAS, 22 EDS or snoring or RLS/PLMD	PSG; Anterior tibialis EMG / Gaehwiler / upper Rt foot / 5 sec / 0.1g / NS	PSG: PLM (via EMG); ACT: PLM	NS/Technical problems during recording/ Most pts Dx w/OSA	ACT: EMG Movements – leg ACT not valid. R=0.78 but ACT underestimates movements, especially those <3 sec and < 50 mv but was reliable across 2 nights in 8/10 subjects thus not valid for DX PLMD but valid for Tx evaluation.	Conclusions differ from those of Kazenwadel, et al., 1995 due to more sophisticated analysis
Trenkwalder (72) 1A	Controlled clinical trial, DB, cross-over design / Laboratory, Home / Nocturnal; 1Nt PSG/ACT + 2Nt PSG BL, 1Nt PSG/ACT + 2Nt PSG Tx (L-Dopa), 1Nt PSG/ACT + 2Nt PSG PL (Placebo)	32 (28) / Grp1 53±9 (37-73), Grp2 49±11 (29-66) / RLS, Uremia	PSG, log, Self report, Observation by physician in charge / Moroport, Rimkus / leg / NS / NS / NS	log, PSG, ACT, SBJ ratings	NS / Other sleep disorders, psychotropic meds, Rx abuse Hx / Small Grp size decreased power of between-Grp comparisons	No diff. b/t idiopathic & uremic RLS, L-Dopa only effective during 1st 4 h of sleep	ACT systematically underestimated PLMs relative to PSG, ACT confirmed PSG finding of diminished effectiveness after 4 h.

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Wicklow (55) 4 C-a	Observational study / home / 3D ACT audio recording of intrusive thoughts at bedtime, sleep diary	Ns (NS) M, 7, F, 14/ 36 (19-60; 10.8) / insomnia	Sleep log, diary / Cambridge Actiwatch / wrist / 1 min / NS / NS	Sleep diary, log / ACT, others; self-report of obtrusive thoughts, pre-sleep arousal scale	Exclusion; receiving tx for sleep disorder, medical problems affecting sleep, psychopathology, no sleep onset problems/ subjects recruited from general population, not presenting patients	Mean ACT sleep latency < mean diary sleep lat, $p < .001$. Mean ACT SE > mean diary SE, $p < .008$. Mean ACT TST > mean diary TST, $p<.004$. ACT/ diary sleep latency, $r=0.419$, $p<.001$. ACT/diary SE $r = 0.194$ (ns). ACT /diary TST $r = 0.526$, $p <.001$. ACT sleep latency correlated with rehearsal/planning thoughts and thoughts about autonomic functions. No correlation between diary sleep lat and any thought category.	
Wilson (52) 5D-b	Validation, ACT compared w/ other techniques / Home / Nocturnal; 2D ACT/log	40 (40) / 44.9±7.9 / Insomnia, Chronic pain	Self-report, Questionnaire, log / MML / ndom wrist / 15 sec / NS / AMI ‘94	log, ACT	NS / Fibromyalgia, other medical problems / None	ACT & log both showed low SE, long WASO, low TST; No diff on ACT variables b/t high severity & low severity pain Grps	

Table 4—Evidence levels for studies involving circadian rhythms

Citation - Author / Evidence Level	Study Criteria Design / Location / Protocol	Sample Size (Completed Study) / Mean Age (Range) / Medical Conditions	Comparison Measures / Actigraph apparatus / Placement / Epoch Length / Sensitivity / Scoring	Outcome Measures	Inclusion / Exclusion / Bias	Study Conclusion from paper	Comments from Reviewer
Ancoli-Israel (112) 4C-b	Unblinded, nonrandomized, observational study / NH / Entire 24-hs; 3D ACT	NS (77) / Grp1 85±7.9 (60-100) Grp2 87±5.6 (74-96) / NH residents	None / Actillume / wrist / 1 min / ≥ .003g / Cole, Kripke et al 1992	ACT: total mins sleep, % sleep, total mins awake, % awake, num awakenings, length of each awakening, mesor, acrophase, amplitude, circadian quotient; Mood: Geriatric Depression Scale; Others: MMSE	NS / NS / Subject selection criteria NS	SDG slept more during Nt and D than MMNDG; SDG had lower activity mesor, more blunted amplitude, and were more phase-delayed than MMNDG	
Ancoli-Israel (110) 4C-b	RCT, unblinded, parallel / NH / Entire 24 hs; 18 D ACT, 10 D Tx w/either morning bright light, evening bright light, evening dim red light, daytime sleep restriction	118 (77) / 85.7±7.3 (60-100) / Demented NH pts	None / Actillume / wrist / 1 min / NS / Action3 sleep 5 parameter extended cosine	ACT: D sleep, Nt sleep, ACT acrophase, mesor, circadian goodness of fit	NS / NS / NS	No improvements in Nt sleep or D alertness with Tx. Morning bright light delayed ACT peak, increased mesor and strengthened rhythmicity	
Binkley (92) 4C-b	Observational study / transmeridian travel / Entire 24-hr, 17-32 D ACT including Ds before, during and after travel	6 (6) / 41.8 (27-56) / Normal, 17 records in 6 people, east-west vs. north-south vs. no travel	none / Motionlogger / wrist / 5 mins / 5-mins, acrophase / daily activity onset, offset, motions/	ACT: Phase shift of daily activity onset, offset and acrophase. Magnitude of motions/5-mins and activity dur (“alpha”)	NS/ NS / convenience sample, low sample size, no control Grp	Activity phase shifted in same direction, but often not same amount, as time zone change. Lower activity mean and dur at destination.	Very high r (R squared = 0.939) between time zone shift and activity acrophase shift; however, not compared to any circadian reference standard.
Blagrove (87) 3C	ACT Compared w/ other techniques; Forced desynchrony / Laboratory (dormitory used as lab) / Entire 24-hs; BL 8Nt sleep midnight-0800; Sleep Dep.1: 26hs; Forced desynchrony: 17 cycles (27hr D) sleep 9 hr, W 18 hr; Sleep Dep.2: 26hr; Recovery sleep: 9hr; continuous ACT	9 (9) / NS (19-20) / Normal	log; (temp reported elsewhere) / Gaewhiler / ndom wrist / 30 sec / NS / ACCORD software (UK) + Horne et al 1994 algorithm + custom algorithms	Log: BT, SOL, WASO, SOff, SBJ SQ; ACT: SOn, SOff, TST, movement index, freq. of movement onsets	Healthy, no sleep disorders/ NS / low num of subjects, all F, not blind to time of D	Movement freq. (weakly) predicts SBJ SE, SQ; Circadian time of going to sleep affected ACT TST & SBJ SE & quality (all reduced when starting sleep between 1000h and 1300h), but did not affect movement index or freq.	ACT appeared to detect expected reduction of TST induced by forced desynchrony protocol (poorer sleep when out of phase w/ temp rhythm), suggests ACT can detect a disturbance induced by circadian pacemaker, but no reference standard.
Carskadon (118) 2B	Nonrandomized, Controlled clinical Trial, unblinded, cross-over design / Laboratory and Home / Entire 24 hs; continuous ACT throughout study, 7D home, self selected schedule (salivary DLMO last night), 8D home, fixed light-dark schedule (salivary DLMO last night), 3D long (14 h) Nt w/PSG, ~36 hs modified constant routine w/ MSLT and PSG	19 (14) / M 12.7±1.0 (11.2-14.1) F 13.1±0.7 (12.2-14.4) / normal	PSG, mel / Mini ACT AMA-32 (AMI) / ndom wrist / NS / NS / Sadeh et al ‘94	Log; mel; endocrine measures cortisol; PSG: SOn, SOff; ACT: SOn, SOff; MSLT	NS / irregular sleep, sleep disorders, illness, psychiatric disorder / NS	Phase of SOn, SOff, DLMO less dispersed after fixed light-dark than self-selected light-dark. ACT SOn to SOff r=0.72, ACT SOn to DLMO r=0.82, ACT SOff to DLMO r=0.76 during self-selected but not fixed light-dark. Mel offset significantly correlated with age (r=0.62) and tanner stage (r=0.62).	ACT to PSG r SOn>0.80 in 11 of 14 cases and r SOff>0.80 in 10 of 14. Although main study design not blind, comparisons of ACT to DLMO and PSG were blind. 71 % of ACT sleep offsets w/in 18 min of PSG sleep offsets.
Carskadon (119) 3C	Observational study / laboratory and home / Entire 24 hs; 14 D ACT and log and phone message machine at SOff, 1 salivary DLMO, PSG, MSLT, repeat in 9th and 10th grade w/ 1 h earlier school start time in 10th.	40 (26) / 15±0.5 / normal	Log / Mini-ACT (AMI) / NS / NS / NS / Sadeh et al ‘94	ACT: SOn, SOff, TST	NS / sleep disorders, illness, psychopathology / NS	SOff but not SOn, DLMO later in 10th, more sleepiness on sleep onset REM in 10th	ACT data scorable on 9 of 10 Nts. ACT SOn and SOff correlated 0.39 to 0.51 w/DLMO on school Nt, but r’s NS on weekend.

Citation - Author / Evidence Level	Study Criteria Design / Location / Protocol	Sample Size (Completed Study) / Mean Age (Range) / Medical Conditions	Comparison Measures / Actigraph apparatus / Placement / Epoch Length / Sensitivity / Scoring	Outcome Measures	Inclusion / Exclusion / Bias	Study Conclusion from paper	Comments from Reviewer
Cole (44) 4C-b	RCT, single blinded / home / Entire 24 hs; 7D ACT BL, 5D ACT Tx (last 5D of 26 D Tx period), 2D ACT f/u	78 (59 assigned to Tx) / 25 (14-34) / DSPS-SOn before or after 0200hs.	Log, mel,/ Actillume / wrist / NS / NS / lab developed	mel 6-SMT; ACT	18-40 yrs, ICSD criteria for DSPS / non DSPS sleep disorder, serious health problem, meds, alcohol abuse, Rx, serious psychiatric problems, recent shift work or jet lag / NS	Bright light and behavioral Tx advanced the 6-SMT acrophase vs. dim light placebo Tx, but post-Tx phases were listed earlier. However, pts with late 6-SMT acrophases did have phase advances (vs. placebo) of 6-SMT and SOn as well as decreased AM sleepiness.	ACT used to determine BL sleep phase and post-Tx sleep phase. Tx: bright/dim light (26 D) and behavioral Tx (systematic advance of bedtime and time of arising, avoid daytime naps, minimize afternoon/evening light). Light mask: 2700 lux / 57 lux when eyelid closed.
Dagan (57) 5D-a	Case series / Home / Entire 24-hs; 4-7D ACT BL to help diagnose DSPS; f/u questionnaire ≥ 1 yr after 6-wk mel Tx	61 (NS) / 30.17±11.26 (16-54) / DSPS	None / MML / wrist / NS / NS / NS Sadeh; Other: zero-crossing mode	Survey	No meds , DSPS Dx, mel Tx, finished ≥ 1 yr prior to study / No control Grp	96.7 % report mel helped DSPS, 91.5% relapse after mel cessation	No validation of ACT other than pt. report ACT used only to aid initial Dx of DSPS. Outcome assessed only by questionnaire, not ACT.
Daurat (97) 4C-b	Controlled clinical trial; DB / Hotel rooms set up as lab / Entire 24-hs; 6D ACT BL, 1D temp BL, flight, 6D ACT post flight, 1+1D temp post flight, Zopiclone or Placebo before bed Nts 1-4 post flight	36 (24) / 51.2±2.2 / Normal	Temp (n=19) / Actiwatch / ndom wrist / 1 min / NS / Actisom (P.Denise, France)-sleep visually scored, cosinor for phase	Temp; ACT: sleep dur, activity index, ACT acrophase & amplitude; Mood: VAS "mood"; Jet lag Sx VAS "tired", "ill-being", "digestive", "energy"	Healthy, no meds x3 mos, no time zone travel / Core temp not unmasked	Zopiclone improves ACT identified sleep after transmeridian travel $F(1,22)=6.3$, $p<.05$; The greater the dysynchronization of CRs post-flight the shorter the sleep dur. Zopiclone did not improve SBJ jet lag	ACT detected both circadian shift and sleep disturbance
Dawson (93) 4C-b	RCT, parallel design (blinding not mentioned) / Lab / Entire 24-hs apparently, 2Nt DLMO BL (Nt sleep) & core temp, 3D ACT (Nt work, D sleep) & core temp, 24hs DLMO & core temp (sleep not described) Random assign. to bright light, dim light, mel or placebo during shift work Ds	36 (36) / 23.6±3.9 (18-30) / Normal	None / Gaehwiler / ndom wrist / 30 sec / NS / Root mean square (RMS) activity times dur	Temp; mel; DLMO, ACT: movement index, total energy, energy during arousal, energy during non-arousal; Behavioral: cognitive performance	NS / NS / NS	Bright light shifted DLMO, reduced core temp during D sleep, improved ACT SQ better than mel Tx or placebo. Mel didn't shift DLMO, but improved sleep & reduced core temp somewhat.	ACT variables showed significant differences between light and placebo and often between light and mel Tx during D sleep in simulated shift work.
Dijk (32) 3C	Controlled clinical trial, DB, nonrandomized / Space shuttle, pre, post flight / Entire 24 hs; ACT: 1-2 D 2 mos pre flight; 1-2 D 1 mo pre flight; 0-7 D 1 wk pre flight; 10-16 D in flight; 4 D PSG in flight; 5 D ACT post flight; 3 D PSG post flight; 0-3 D other measures post flight	5 (5) / (37-46) / normal	PSG, log, mel urine, temp core and ingestible sensor, urinary cortisol / MML and Actillumes / ndom wrist / NS / NS / Cole/Kripke	Log; ACT: SP time, TST; neurobehavioral Assessment Battery	All astronauts / NS / Cannot distinguish effects of space flight from those of work schedule; small sample	Space flight associated w/ reduced ACT SP time, SBJ SQ, performance and delayed cortisol rhythm relative to scheduled sleep. ACT Sdur longer on PSG recording Nt; might reflect greater adherence to sleep schedule on PSG Nt. No benefit of mel on sleep observed.	ACT detected apparent bias in PSG sleep measurement
Eissa (131) 5D-a	Observational study, Case series / Home / Entire 24-hs; 1D ACT 1D ambulatory BP monitoring	46 (46) / 42.9±21.8 / Hypertension	BP / MML / ndom wrist / NS / NS / Cole	ACT: W vs. sleep dichotomy	Consecutive hypertension pts. / Possible daytime removal artifact could have overestimated D sleep (naps)	Estimates of circadian or sleep-induced BP reduction ("dipping") differ when "actual sleep" is defined by ACT than when it is defined by fixed time-of-D criteria	Actigraph-identified sleep assumed to be "true" sleep by authors

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Evans (88) 4C-a	Observational study / Home / Entire 24-hs; 2D ACT & log	14 (14) / 81.2±5.9 (71-91) / Normal	log / Motion logger / ndom wrist / NS / NS / (AMI) software	log; ACT: SOn, SOff, TST, num naps, nap mins, num arousals	Healthy elderly / sleep meds, tranquilizers, sleep disorders, neuro or psychiatric problems / Artifact rejection not mentioned so possible overestimation of D sleep; subjects selected for no sleep complaints, so finding of satisfaction w/ sleep to be expected	Elderly have frequent arousals, reduced SEI, short sleep, naps more frequent than expected; naps underreported; satisfied w/ sleep	Results could mean that ACT is valuable for detecting naps not reported in log, but possible that wakeful inactivity was misscored as sleep by ACT; findings of fragmented nocturnal sleep and greatest nap frequency in afternoon consistent w/ other studies' findings w/ PSG in elderly
Glod (107) 4C-b	Case-control study / Home / Entire 24-hs; 3D ACT, compare ACT rhythms in SAD vs. normal children	26 (26) / Grp1 11.0±3.3, Grp2 11.6±3.7 / Grp1 SAD, Grp2 Normal	NS / Motion logger / Belt / 1 or 5 mins / NS / NS	ACT: cosinor 24h & 12h harmonic and periodogram	SAD Dx, med-free, healthy / NS / NS	Children w/ SAD have less robust circadian activity rhythms & lower circadian amplitude than normal controls, but no phase delay of activity	ACT rhythm distinguished children w/ a psychiatric disturbance from controls; Dependent variable was activity level (belt-worn monitor) not sleep
Gruber (113) 4C-b	Case-control study / Home / 5N ACT	102 (NS) / Grp1 9.6±2.7 (6-14), Grp2 9.9±1.7 (7.5-11.5) / ADHD vs. control	Log / NS / NS / NS / NS / Sadeh	Log; ACT: SOn, SP, SE, TST, longest sleep, quiet sleep (no motion), Nt awakenings	DSM-IV ADHD / NS / NS	More instability of ACT SOn, SP duration, and TST in ADHD than control. No difference in mean values. Only ACT, not log, detected higher standard deviations.	
Guilleminault (121) 3C	NS / Home / 24-72 hs oral temp at birth every 3 hs, At 3,6,8,16, and 20 weeks: 60 hs to 7D ACT and rectal temperature	12 (NS) / newborns / normal	PSG / Vitalog / wrist / 2 mins / NS / visually scored	ACT: longest inactivity	NS / NS / some lost data. Rectal temp endogenous rhythm masked by rest-activity rhythm.	Rectal temp rhythm established by 6 week age in 2 of 12 infants and by 10 week in 12 of 12. Longest ACT inactivity 'closely related' to longest PSG SP. Lowest temp occurred at time of longest ACT inactivity. Consolidated W only occurred after rectal temp rhythm established.	
Heikkila (120) 5D-a	Case-control study / Laboratory / 5D ACT and log, 24 hs serum mel and cortisol and axillary temp	24 / Grp1 24 (16-32), Grp2 7 (3-10), Grp3 12 Grp4 NS / Neuronal Ceroid-Lipo-fuscinosis (NCL), juvenile NCL, infantile NCL, Jansky-Bielschawski disease, Normal control	Mel, temp, cortisol / (AMI) / wrist / 1 min / NS / Cole Kripke	Mel; Endocrine-cortisol; ACT: SOn, % sleep	NS / NS / Possible masking of mel by light and temp by activity	Sleep-wake rhythm grossly disturbed, but mel, cortisol and temp rhythms usually normal in NCL patients.	No statistics on sleep
Honma (184) 5D-a	Observational study / Mental Hospital / Entire 24-hs; ≥ 10D ACT	13 (8) / 84.9±7.8 (74-96) / Dementia & Delirium	NS / model not specified (AMI) / ndom wrist / 1 min / NS / visual & chi square periodogram	ACT: diurnal pattern, dom period	NS / NS / Small sample, high dropout rate, SBJ analysis (except periodogram)	Identified 4 circadian "types" of pts, activity patterns varied w/ clinical manifestations of delirium; dom period near 24h in all cases, (some had secondary 12h peak)	Actigraph identified 24h rhythm in 8 of 8 cases, despite severe behavioral disturbance
Huang (116) 4C-b	Observational study / Home / Entire 24-h; 5-7 D ACT	65 (65) / young 24±4, middle-aged 42±3, old 68±6, oldest 83±4 / none	None / Actiwatch-L-plus (Cambridge Neurotechnology, Cambridge, UK/ wrist / 1 min / NS / Rhythmwatch and Sleep Analysis 98 Software (Cambridge Neurotechnology)	Sleep diary, mean illuminance, ACT TST, SE, SOL, wake num, num naps in D, fragmentation index, interdaily stability (IS), intradaily variability (IV), least-active 5 h (L5), nonparametric circadian amplitude	Healthy / physical, psychiatric or neurological illness, cognitive disorders, insomnia, alcohol or drug abuse, extreme morning or evening type	Compared to young and middle-aged volunteers, old and oldest volunteers had lower TST, SE, and circadian amplitude, longer SOL, and more awakenings, sleep fragmentation, IV and naps. IS did not differ between the four groups, suggesting similar synchronization to Zeitgebers.	

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Jean-Louis (143) 4C-b	Unblinded, nonrandomized, observational study, cross-sectional study / Home / Entire 24-hurs; 3D ACT	NS (273) / M 51±7, F 52±7 (All 40-64) / Community dwelling residents of San Diego identified by random telephone survey.	None / Actillume (AMI) / wrist / 1 min / NS / Action3 (Cole et al 1992 w/ Webster's re-scoring rules)	ACT:TIB, TST, SOL, SE, sleep (amplitude, mesor, and phase), activity (amplitude, mesor, and phase), illumination (amplitude, mesor, and phase); SBJ mood	NS / NS / Comorbidity NS	Significant gender differences, men had shorter TST, lower SE, shorter TIB, lower Sleep amplitude, higher illumination amplitude and higher illumination mesor; significant white vs. minority differences, white sample had longer TST, longer SE, shorter SOL, greater sleep amplitude, and higher sleep mesor. Total sample average TST was 6.22 hs.	Authors refer to their unpublished work comparing wrist ACT to PSG in women aged 51-77 w/ 89% min-by-min agreement, r =.90.
Jean-Louis (124) 5D-b	Cross-sectional at various ages / home / 3d ACT Grps 1a + 1b (3 x 24 hs); 7d ACT Grp 2 (7x 24 hs)	NS / NS / Grp1a 80F (19-62), Grp1b 144F (40-64), Grp2 149F (50-81) / normal	Log / Actillume / wrist / NS / NS / NS	ACT	Grp2 were post menopause / NS / NS	No age-related decline in actigraphic sleep dur.; no age-related change in CR parameters except for gradual decline in level and amplitude.	ACT used as index of sleep gave no reference standard.
Jean-Louis (122) 4C-b	Unblinded, nonrandomized, observational study / Home / Entire 24-hs; 5D ACT	NS (32) / 44.76±20.64 / Healthy normal volunteers	SSS, log / Gaehwiler Electronics (Hombrechtikon, Switzerland) / dom wrist / 60 sec / ≥.1g / ADAS	ACT: TST, SE index, WASO, SOL, frequency of transitions between sleep and wakefulness, daytime activity level, auto- r (amplitude of activity)	NS / NS / Small sample size	Women had a better sleep profile than men by ACT	Relatively small sample
Jockovich (105) 5D-b	Controlled clinical trial, DB, cross-over design /home /diurnal only for sleep period. 1 mg mel or placebo 30-60 min before day sleep after night work. Two series of = 3 night shifts separated by = 1 week. ACT during day sleep	19 (19) / NS / normal	None / NS / NS / NS / NS / NS	ACT; SE, TST, SOL: Behavioral variables; SSS (Stanford Sleepiness Scale) : Mood ; POMS (profile of Mood States)	emergency medical residents working night shifts / heavy alcohol or caffeine, opioids, benzodiazepines / mel tx timing not optimized for circadian effect	No effects of Mel Tx on D sleep or Nt sleepiness or mood	
Kario (185) 5D-b	NS / Home / Entire 24 hs	NS / 48±8.6 (33-66) / mild, untreated hypertension	None / (AMI) / waist while awake, wrist while asleep / NS / NS / NS	ACT: weighted average activity 6 mins before each BP measurement (every 15 mins during W, every 60 mins during sleep); Ambulatory BP	NS / cardiovascular events or used anti-hypertensive meds / NS	Physical activity (i.e. ACT motor activity is one of the determinants of ambulatory BP and its diurnal variations. No dippers exhibited greater sleep activity than extreme dippers.	
Kubota (98) 5D-b	NS / Home; Laboratory / Dim light (150 lux) vs. bright light (3000 lux) from 19 – 21.30 each evening for 5 days.	6 (NS) / 26 (21-35) / Normal	NS / (AMI) / NS / NS / NS / NS	Temp	NS / NS / NS	Evening bright light exposure for 2 ½ hs delays temp nadir from 04:08 to 05:29 and disturbed subjective sleep.	
Leary (129) 4C-b	Case series / Clinic / 24 h ACT + ambulatory BP monitoring	434 (434) / 47.9 / hypertension	None / Gaehwiler / dom wrist / 10s / 0.1 g / NS	ACT; Nocturnal fall ('dip') in systolic and diastolic BP	Consecutive pts referred for evaluations of hypertension / NS / NS	Daytime motor activity (ACT) was positively correlated w/ nocturnal dip in BP. Higher Nt motor activity was negatively correlated w/ the nocturnal dip.	ACT used to quantify D & Nt activity levels. ACT was not an object of study.
Lemke (134) 4C-b	Observational study / out-of-lab / 72 hr	16 (16) / 54 (24-65) / major depression episode w/ melancholic features	NS / Acotmeter, Zak, Germany / ndom wrist / 2 mins / 0.1 g / NS	ACT: mean activity level 7- 9 AM vs. 7-8 PM; Mood: multiple affective adjective checklist	NS/ Parkinson's & other movement disorders / NS	Depressed in-pts displayed significantly greater motor activity in the morning compared to evening, but subjects felt more active in PM, and more tired & depressed in the AM.	

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Lockley (29) 3C	ACT compared w/ other techniques / Home / Entire 24-hs; mean nights/subject=23±7 (range 6-35) of ACT + log	49 (49) / 46.6±12.2 / Blind	log; mel; Urine samples / Motion loggers or MML / wrist / 1m / NS / Action 3; Other: Zero crossing mode	log: SOL, SOn, SOff, Num awakenings, dur awakenings, num naps, dur naps; ACT: SOL, SOn, SOff, Num awakenings, dur awakenings, num naps, total nap dur	Meds influencing sleep or mel / NS / NS	ACT and logs yielded similar results for some aspects of sleep but not others. Proportion of pts showing differences between ACT and log greater than those showing no differences.	Unique use: to see if sleep (daytime nap num & dur & night sleep dur) greatly altered by CR type (normal entrained, abnormal entrained, or free run)
Lowden (186) 4C-b	Controlled clinical trial, unblinded, randomized, crossover design / NS / entire 24 h. Two trips each with 1 tx in counterbalanced order. Tx 1: maintain home sleep time. Tx 2: adopt local sleep time. 10 D ACT (3 D BL), 1 D air travel 9 h east, 2 D layover, 4 D f/u	23 (19) / 42 (31-59) M, 15; F, 4 / NS	NS / AMI / non-dom wrist / 1 / NS / Action 1.24	Sleep diary/log, Act: BT, wake-up time, time awake, naps, TST; Behavioral; Karolinska Sleepiness Scale; Others: jet lag rating	NS /NS	Staying on home time greatly reduced jet lag symptoms and sleepiness during layover but not after returning home	ACT detected numerous effects of flight pattern and timing of predicted sleep-wake and detected treatment effect on time spent awake before main sleep
Luboshitzky (187) 4C-b	Case-control / Home / Entire 24 hs; 48 h urine 6SMT, 5 D ACT, 5 D light measurement	46 (NS) / Grp1 72.7±6.1, Grp2 61.0±5.7, Grp3 33.3±8.4 / Alzheimer's disease, healthy elderly, healthy young	Mel / Mini-ACT AMA-32 (AMI) / wrist / NS / NS / ACT Scoring Analysis, other: light meter on shirt	ACT: SOn, SOff, SP time, TST, SE, longest continuous sleep, WASO, min inactivity; Behavioral: MMSE; light exposure	NS / NS / 6SMT pooled into all D and all Nt samples so low resolution	6SMT lower in AD and normal elderly than young. Compared to elderly and young normals, AD pts have poorer sleep. No relation between 6SMT and sleep. SOn and SOff earlier in AD and elderly normal than young normal.	Study not designed to measure 6SMT phase. ACT not adequately compared to reference standard.
Luna (103) 4C-a	Observational study / Workplace / Entire 24-hs; 21D ACT, oral temp every 4h, sleep loss, mood and performance rated daily at mid-shift	14 (9) / NS / Normal shift workers	log / 'model #32', (AMI) / wrist / NS / NS / General activity analysis program (Elsmore)	Log: TST temp: visual inspection of plot, ACT: total activity, Behavioral: collected insufficient data, Mood: POMS	Rapid rotation shift work (air traffic control), Present for dur of study / NS / 27% of ACT data lost due to technical difficulties; temp masked; problems w/ data reduction for home sleep analysis	Masked temp retained diurnal orientation on Nt shift. Subjects felt more fatigue & confusion and less vigor on Nt shift, activity mean lower on Nt shift, More ACT identified sleep at work on Nt than on D or swing shift	ACT may have identified unreported on-duty naps in Nt shift air traffic controllers. ACT & self-report agreed there was more sleep during Nt work than on other shifts. D sleep after Nt shift was not worse than sleep after other shifts, possibly due to scoring methodology.
Lushington (188) 4C-b	Longitudinal study / NS / 2 wks log & ACT	NS (NS) / 23.5 (18-31) / normal	NS / NS / wrist / NS / NS / Gaehiler Electronics	Mel urinary; log	NS / NS / NS	Urinary mel onset from a single Nt can be used to predict subsequent onset times w/ in ± 97 mins. A close temporal relationship was also formed between mel onset and SOn	Log used to determine SOn times & these were then "confirmed" from ACT times
Mansoor (128) 4C-b	NS / NS / NS	NS (NS) / 57 (10) / untreated hypertension	None/ MML (AMI) / dom wrist / 1 min / NS / NS	ACT: mean & peak ACT before each BP/HR reading (every 5 mins); Ambulatory BP, HR	NS / NS / NS	Correlation of motor activity, BP and HR is highly variable from pt to pt. Nondippers have higher sleep activity than dippers.	
Martin (109) 5D-b	NS / NH / Agitated Behavior Rating Scale (ABRS) x 60.5 h; ACT x 3D (72 h)	NS (74) / 82.5±7.6 (61-99) / Alzheimer's disease	NS /Actillumes (AMI) / NS / 1 min / NS / Action 3 (AMI)	ACT: max + mean activity; Agitated Behavior Rating Scale; and Illumination Level	NS / stroke, psychiatric disorder, pre-dating dementia / NS	The mean acrophase for agitation was 14:38. Only 2 pts (2.4%) were "sundowners"	

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Martin (132) 4C-b	Observational study / NS / ACT x 3D; entire 24-hs	NS (NS) / 58.3±9.8 (45-76) / Schizophrenia	Log / Actillume (AMI) / non-dom wrist / NS / NS / Action 3 (AMI)	ACT: Sleep, wake; MMSE, QWB, Brief Psychiatric Rating Scale, SAPS, SANS, AIMS, EPS, neuropsychological examinations, light exposure	NS/ NS / NS	There were important disturbances of CRs and S/W, which were related, cognitive functioning and low levels of illumination exposure	
Middelkoop (41) 4C-b	Validation / Home / 45 consecutive hs starting at 12:00; 45 hs ACT+log	20 (20) / 24.1±3.7 / Normal	NS / GAHWILER electronic CH-8634 Hombrechtikon / Lt wrist, Rt wrist, Lt ankle, Rt ankle, trunk (navel) / 5s / NS / NS	ACT: Activity level	NS / NS / Healthy young adults only	Wrist placements detected more activity counts than ankle or trunk placements. dom wrist placement yielded greater diurnal activity counts than ndom. All sites clearly showed circadian sleep-W differences. Suggests more study w/ placements concomitant w/ PSG	Wrist placement superior to ankle or trunk. Dom wrist appears better for discriminating level of waking activity.
Middleton (89) 2B	RCT, DB, crossover design / Lab / 2x30D free-run in 4 lux; mel Tx first 15 Ds at 20:00, crossover to placebo Tx for 2nd 15 Ds. Separate 30 D w/ placebo 1st 15 days. Continuous ACT, rectal temp, urinary mel sulphatoxy, logs	10 (8) / 23.9±0.75 / Normal	Mel sulphatoxy, core temp (demasked) / MML (AMI) / wrist / 20 sec / NS / Cosinor & spectral analysis; Action3 sleep analysis Cole	log; core temp-(demasked); mel sulphatoxy acrophase and period; ACT: acrophase, SOn, SOff	Normal mel level & timing / NS / Small sample, but problem offset by good experimental design	Mel Tx phase-shifts sleep & core temp rhythms. Mel Tx usually synchronized the S/W rhythms but only inconsistently synchronized the core temp rhythm	Circadian phase of wrist activity and demasked core temp generally agreed, providing OBJ evidence that ACT can provides useful circadian phase measurements
Middleton (90) 2B	Observational study / Lab / Entire 24-hs; 21D free-run in L/L 4 lux & knowledge of clock time continuous ACT, rectal temp, urine every 4h, performance every 3h while awake	6 (6) / 26±2.7 / Normal	log; mel sulphatoxy; core temp / MML (AMI) / wrist / 20-30 sec / NS / Cole, regression on cosinor acrophases, spectral analysis	log; temp; mel sulphatoxy; ACT: SOn, SOff, TIB, TST, WASO, SEI, activity acrophase; Behavioral: performance	NS / NS / Temp not demasked, small sample	Mel, temp & activity rhythms free-ran in 5 of 6 individuals. In the 6th, only mel free-ran. Temp may have remained at 24h period due to masking by the rest-activity cycle.	Activity rhythm usually agreed w/ the mel & temp rhythms. Agreement w/ the mel rhythm provides OBJ evidence that ACT can be a useful phase marker. Agreement w/ temp provides weaker evidence because it may be due to masking.
Mishima (99) 4C-b	RCT, unblinded, cross-over design / NH / Entire 24-hs; continuous ACT for 1 wk pre-Tx, 2 wks Tx, 1 wk post-Tx, ≥ 4 wks washout cross-over; Tx=5-8000 lux 9-11am; Control=300 lux 9-11am	22 (NS) / Grp1 81, Grp2 78 / Grp1 Vascular dementia, Grp2 Alzheimer's dementia	None / (AMI) / ndom wrist / 1 min / NS / activity counts used, sleep not scored	ACT: Total, daytime & nighttime activity, % night/total activity	DSM IV Dx of vascular dementia or Alzheimer's / mixed dementia excluded / Unable to blind Tx, small N	Vascular Dementia: daily bright light reduces nighttime activity; Alzheimer's Dementia: bright light does not affect activity rhythm	Shows ACT detected Tx effect in well-designed, controlled trial. Suggest ACT useful to detect outcome in CR Tx study
Mishima (125) 4C-b	NS / NS / Entire 24 hs; 7 + 24 hr Ds. SDAT & MID grps compared	41 (NS) / Grp1 6.4±7.6, Grp2 79.1±5.6 / SDAT (N=20), MID (N=21)	Temp ambulatory Rectal / MML (AMI) / nondom Wrist / 1 min / NS / NS	Temp; ACT: mean total daily activity, mean D activity, mean Nt activity, % Nt to D activity	NS / mixed (SDAT and MID) dementia, severe motor disturbances, sleep disorders /NS	The SDAT grp showed positive correlation between activity (total daily activity and %Nt activity) and dementia severity.	

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Mormont (150) 4C-b	Unblinded, nonrandomized, observational study, cohort study, longitudinal study / Home / Entire 24-hs; 3D ACT	200 (192) / 58 (20-75) / Ambulatory metastatic colorectal cancer pts referred for chronomodulated chemotherapy	None / ACT (AMI) / NS / 1 min / NS / NS	Endocrine measures: circadian changes in cortisol & WBC; ACT: auto-r at 24h & a dichotomy index comparing amounts of activity when in bed & out of bed, mean activity; Mood: HADS (scale of anxiety and depression); QLQ-C30 - Quality of Life Scale for European Organization for Research & Treatment of Cancer	NS / Poor general health (World health Organization performance status 72) / NS	Pts w/ marked rest/activity rhythms had a 5-fold higher survival rate at 2 yrs, had a 5-fold higher survival rate at 2 yrs, had better QOL & reported less fatigue. Rest/activity rhythm remained a significant predictor of survival in multivariate analysis.	
Nagtegaal (60) 3C	Case report / home / entire 24 h; 24 h ACT before Tx w/ mel, after Tx w/ melatonin at 03 30 & after Tx at midnight	1 (1) / 15 (NS) / head injury	Self report, mel, temp; apparatus: Gaewiler Electronic; nondom wrist; NS	Temp, mel, ACT	NS / NS /NS	Etiology of DSPS was presumed to be head injury. DSPS responded favorably to mel	ACT was used to "quantify her S/W behavior," but no quantitative analysis was done. By visual inspection ACT period of low activity corresponded to period of mel secretion and low rectal temp
Otsuka (178) 5D-a	Validation / Laboratory; Out-of-lab hospital bed / Entire 24-hs; 72+hr ACT 7 ECG, (also BP for 48hs & HR for 24hs)	44 (44) / Grp1 (28-46), Grp2 (28-78) / Normal; Healthy	ECG; BP; HR / Activetracer / waist / 1 sec / 0.01 to 0.50g / NS	ACT: Activity level; BP		Simultaneous ACT & BP can be used to show relationship of S/W w/ BP. Suggests S/W rhythms of about 7 Ds (circaseptan) in addition to circadian & a 3.5 D (circasemiseptan) rhythm in irregular S/W cycles but able to identify individual differences in all these	Hard to pull data out of this article; uses a lot of individual examples.
Park (106) 4C-b	Observational study/ home/entire 24 h	12 (NS) M /32.4 ± 6.8 (23-44) / rotating 3 shift workers, age < 25, 26-35, >36	None/AMA32 cl by AMI / non-dominant & wrist /1 min / NS /Cole/Kripke and other was zero crossing mode	ACT : TST, BT, wake-up, num nap, nap dur, amplitude, activity on duty	NS / Small sample	TST on nt shift < D shift < evening shift. TST decreases with age	Authors state that ACT results correspond to their previous PSG results in nt workers
Pollak (123) 4C-b	Case-control study / NS / Entire 24 hs; 9D ACT	NS (86) / Grp1 80.7±7.9, Grp2 73.7±7.2, Grp3 7.3±10.2, Grp4 58.1±16.0 / NS	NS / MML (AMI) / ndom wrist / NS / NS / NS	NS	Age ≥ 65, occurrence of disruptive nocturnal behaviors / NS / NS	Demented older people were significantly less active in the daytime than their caregivers, and circadian rest–activity amplitudes were smaller	
Poyurovsky: (133) 4C-b	Case-control study / NS / Entire 24 hs; ACT x 24 hs	NS (NS) / Grp1 36.4 (19-50), Grp2 29.6 (18-49) / Schizophrenia w/ or w/o neuroleptic induced akathisia	None / ACT AMA 32 (AMI) / NS / 1 min / NS / 0.1 g / NS	ACT: overall motor activity, SL, sleep dur, sleep continuity, SE; Barnes akathisia scale	NS / Psychotic agitation / NS	Schizophrenic in-pts w/ neuroleptic induced akathisia were motorically more active from 11:30 to 14:15 and from 18:00 to 21:00 than those w/o neuroleptic akathisia.	
Quera-Slava (94) 4C-b	Nonrandomized / workplace / 5-7 D	NS (40) / Grp1 36±7, Grp2 35±7 / normal	NS / Gaehwiler / wrist / NS / NS / NS	log; mel (urinary 6-sulfatoxy mel); ACT	NS / NS / NS	Night-shift workers slept more on Ds off. (ACT inactivity). Some night-shift workers are able to switch acrophase of urinary mel (to 1208 hr, mean)	
Quera-Salva (95) 4C-b	NS / laboratory (2Nt) / NS	40 (40) / Grp1 36±7, Grp2 35±7 / normal; 20 on fixed night shift, 20 on fixed D shift	log / actigraph/photometer (Gaehwiler Electronic, Physiocom, Paris, France) / ndom Wrist / 1 min / NS / Actison (Axon. Physio, com. Paris, France)	log; mel (urinary sulfatoxy –mel); ACT: TST; Performance (Stemberg recovery test for seven letters; 4-choice reaction time test. Urine samples (Q2h x 24 hr)	25-55 yrs of age good health; No Rxs affecting mel, not anxious, depressed / NS / NS	6/20 (30%) of night shift nurses were physiologically able to adapt to a fast-shifting S/W schedule. This shift was associated w/ a change in the acrophase of 6-sulfatoxy mel	

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Reid (25) 3C	Validation; ACT compared w/ other techniques / Laboratory / Diurnal; Entire 24-hs; ACT+PSG (when sleep) for 1Nt adaptation, 2D of 12 hr D shift (night sleep), 2D 12hr night shift (D sleep), 1 1/2D "off"	32 (32) / Grp1 21.2±2.7, Grp2 43.9±6.8 / NS	PSG / Gaehwiler / ndom hand / 30 sec / 0.1g 125 ms sampling time (8 kg) Baudpass filter 0.25-3.0 kg / NS	PSG: Sleep, wake SOn, SOff; ACT: Sleep, wake, SOn, SOff	NS / Smokers, taking meds, sleep disorders / Lab shift work studies may not completely reflect real world, their older subjects were really middle-aged.	ACT valid for S/W activity & sleep dur (although ACT different from PSG for SOff) but not as good for more specific measures such as SE; ACT: agrees more with PSG for young adult than for middle-aged because more quiet W scored as sleep in latter, as the likelihood of sleep decreases so does ACT accuracy.	
Sakurai (108) 5D-a	Observational study, ACT vs. Light / Home / Entire 24-hs; 3-4D ACT & light & logs, nurse interview at home	35 (35) / (65-95) / Normal	log, illumination / Actillume / ndom wrist / NS / NS / Cole et al. & Cosinor (Action3)	ACT: activity mesor, amplitude, continuity of activity; illumination (lux)	Healthy elderly / NS / No mention of exclusion of off-wrist artifact, all Ms	activity mesor and amplitude correlate negatively w/ age in 65-95 range, decreased "sleep amplitude" in 80-95 range, about 1/2 of subjects who show "discontinuous movement" have low light exposure	Mesor results clear, but other results not explained in sufficient detail to interpret. Phase & goodness of circadian fit NS
Samel (189) 4C-b	NS / laboratory / Entire 24 hs; 29D ACT conditions: normal CO2 concentration and elevated CO2	4 (4) / (23-29) / normal	None / piezoelectric accelerometer / ndom wrist / NS / 1.0 g / NS	Temp: level, circadian, amp. Acrophase; ACT: sdur., activity level; mood: fatigue questionnaire; salivary samples urinary cortisol, catecholamines, (6OH mel sulphate)	NS / NS / NS	CO2 levels up to 1.2 % (as occur during manned space missions) do not impair circadian temp or S/W playtimes but do ↓ D mean activity level & D man temp and circadian amplitude	
Satlin (91) 3C	ACT compared w/ other techniques / Hospital bed / Entire 24-hr; 72 hr ACT and rectal temp	Grp1 28 (28) Grp2 10 (10) / Grp1 71.4±5.4 (61-82), Grp2 72.8±5.9 (67-80) / Grp1 Alzheimer's, Grp2 normal	Rectal temp / (AMI) actigraph, model NS / Grp1 ankle, Grp2 waist / 5 mins / NS / mean D and Nt activity, cosinor, variance spectra, interdaily stability, circadian correlation	ACT: mean and % D and Nt activity, circadian variability, acrophase, mesor, amplitude, deviation from 24-hr rhythm	Probable Alzheimer's / psychiatric, neurological, acute medical disorders / different actigraph placement in pts vs. controls, temp rhythm masked by activity	Alzheimer's temp rhythm delayed but normal amplitude and 24-hr entrainment. Alzheimer's activity rhythm delayed, more variable, lower amplitude, more nocturnal activity. In pts w/ large phase angle between activity and temp, more sleep fragmentation and lower temp amplitude	PLMs could account for some findings because only pts had actigraph on ankle. Both activity and core temp acrophases were delayed in pts, but not clear if source is circadian pacemaker or masking.
Scher (86) 5D-b	NS / NS / Nocturnal 2Nt ACT	NS (NS) / 1 yr±14D / normal	None / MML (AMI) / L ankle / NS / NS / NS	ACT: SOT, Sdur, num of awakenings, activity level, SE; Temp rating	Normal, full-term infants / NS / NS	Results did not support a general link between S/W regulation in infancy and temperament characteristics	
Shapiro (127) 5D-b	Observational study; longitudinal study / home / 2 D ACT (48hs)	NS (104) / 67.0 (55-79) / NS	None / MML (AMI) / dom wrist / 1 min / NS / NS	Ambulatory BP, HR, diary (time, posture, activity) zero-crossing mode	Healthy + active / neurological cardiovascular, renal, endocrine + psychiatric Disorders, & med affecting cardiovascular system / NS	Activity was not correlated w/ BP or HR between subjects, waking or sleeping. Within subjects, activity was weakly correlated w/ HR & BP	
Shochat (161) 4C-b	Observational study, ACT vs. Light exposure / NH / Entire 24-hs; 3D ACT and illumination monitoring	77 (66) / 85.76±7.3 / Institutionalized elderly, dementia (all except 3 of the completers)	Illumination, Dementia rating scale / Actillume / wrist / 1 min w/ 10 sec sub-epochs for max activity (i.e. max 10 sec/min) / NS / NS, but Ancoli-Israel et al. 1997 NH algorithm implied	ACT: % sleep & W, num naps, mins W between maps, num night awakenings, dur of each awakening; median & mean illumination, min > 1k lux & > 2k lux	NS / NS / NS	Low illumination in NH pts, higher light in D associated w/ fewer Nt awakenings, but not higher D activity, nor D wakefulness, severe dementia predicted more D sleep, light acrophase correlates w/ activity acrophase, more mins/D bright light predicts later activity acrophase	

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Siegmund (85) 4C-b	Observational study / home / Entire 24 hs, 7 D ACT	39 (39) / (4wks-62yrs) / normal	Observation, tape recordings, photographs, video / actometer, ZAK, (Gmblt, Simbach, Germany) / ndom Wrist / 2 mins / NS / AKTOGRAPH ZAK Gmblt, Simbach, Germany	ACT: no formal variables described	NS/ NS / NS	In infants circadian rest-activity patterns develop out of ultradian components. Adult rhythms well related to natural light-dark cycle. Variability of sleep/rest termination smaller than its onset. Mean sl dur. Of infants aged < 11 mos 9-12 h/D; adults 7-10 h/D. Women often slept longer than men	
Van Someren (100) 4C-b	NS / out-of-lab hospital bed / Entire 24 hs; 5 D ACT bright ambient light (mean 1136 lux) vs. BL (436 lux)	29 (22) / 79±2 (64-97) / Dementia (16 AD, 3 MID, 2 Alcoholism, 1 normal pressure hydrocephalus severe visual deficiencies in 5 pts	None / self-made / NS / NS / 1.0 g / NS	ACT: “Interdaily stability”. (IS) “Interdaily variability”, (IV) amplitude of rest-activity rhythm (AMP)	SDG pts / NS / NS	Brightened whole-D light (436→1136 lux) ↑ IS (↑ coupling of rest-activity rhythms to environmental zeitgebers), ↓ IV (↓ fragmentation) more stable rest-activity rhythm but no change in AMP. These responses prevented by severe visual deficits.	No reference to standard
Van Someren (101) 4C-b	Longitudinal study / Home / Before aerobic training 5 ½ D ACT; Aerobic Training for 3 mos (10 Subjects/ no training 8 controls); After training 5 ½ D ACT; 1 yr after training 5 ½ D ACT	NS (10) / 73±1.5 / normal	None / self-made / wrist / NS / NS / NS	ACT: Daily +hourly variability of activity & amp. Of circadian rest/activity rhythm	Had to be healthy / NS / NS	Aerobic training reduces “fragmentation” (h-to-h variability) of the rest- activity rhythm in healthy elderly men.	ACT data are inadequately analyzed. Paper was poorly referred.
Van Someren (190) 4C-b	RCT, parallel, SB / NH / Entire 24-hr, 4D ACT BL, 4D ACT after 6 wk Tx, 4D ACT at 6 wk follow-up; Tx = TENS or placebo	Grp1 19 (14), Grp2 8 (8) / Grp1 84±1.5, Grp2 77±3.5 / Grp1 Alzheimer’s, Grp2 Normal	none / Apparatus: self-made; wrist; NS; Scoring: interdaily stability (IS), intradaily variability (IV), relative amplitude (RA)	ACT: IS, IV, RA	Include early stage probable Alzheimer’s / Exclude neuroleptic meds, visual deficiencies /low sample size	Higher IV, lower RA, and trend for lower IS in Alzheimer’s vs. normal elderly. TENS increased IS in Alzheimer’s, but did not improve IV or RA.	No reference standard.
Van Someren (111) 4C-b	Open trial/ NH/ compared data analysis methods for 2 studies: Study 1: 28D ACT during 5D BL, 10D bright light tx, 13 D F/U/ entire 24 h	4 and 17 (NS) / NS/demented	None/ 1) Actillume; 2) home made/ 1) non-dom wrist; 2) non-dom wrist /NS / NS / Sleep NS	ACT: Compared cosinor, complex demodulation periodogram, autocorrelation, interdaily stability, intradaily variability, relative amplitude	NS / NS	Non-parametric variables, especially interdaily stability and 24-h autocorrelation are more sensitive to circadian disturbance at rest-activity rhythm than parametric analyses such as cosinor	
White (130) 4C-b	DB; randomized; cross-over design / home / Entire 24 hs	85 (75) / 57.8±9.1 / Stage I or II hypertension	None / MML (AMI) / wrist / NS / NS / Cole et. al.	ACT: sleep vs. W; Ambulatory BP, HR	II hypertension, systolic BP > 200, diastolic BP > 110, Bradycardia, Tachycardia, Recent stroke or MI, renal or hepatic dis; uncontrolled diabetic / NS / NS	Morn. & even. Times of administration of nisoldipine (a long-acting dihydropyridine Ca++ channel blocker) have similar effects on 24 hr BP and HR. However, comparison of sleep & W periods revealed differential BP and HR effects for morn. Vs. even. dosing	ACT was used to determine sleep & W times by the built-in algorithm of the AMI recorder or by use of an event marker built on activated by a pt when retiring or awakening
Wirz-Justice (81) 5D-a	Observational study, Case series / Hospital or Home / Entire 24-hs; 3-7 wk ACT	7 (NS) / 50.0±6.5 (38-57) / Schizophrenia	None / Gahwiler / non-dom wrist / 1 min / NS / periodogram	Visual inspection of activity plot, “best tau,” (circadian period), “best omega” (circadian amplitude)	single-drug therapy for schizophrenia for at least 1 yr, compliant with actigraphy / NS / small sample size, Tx not randomly assigned, no placebo	Four patients taking classical neuroleptics had disturbed circadian rhythms, three taking clozapine had highly regular rhythms	

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Youngstedt (43) 1A	RCT, unblinded parallel design/ Home / Entire 24-h, Home: 5-7 D ACT, light monitoring, and log, 2 x 24-h mel urine 6-SMT; lab: 30 H urine 6-smt, 5 D PSG under randomly assigned lighting conditions	Grp1 72 (72), Grp2 30 (30) / Grp1 68.0±4.3 (60-79), Grp2 NS (20-40) / Grp1 elderly w/ insomnia or depression, Grp2 young normal	Log, mel (6-SMT) / Actillume (AMI) / wrist / NS / NS / Jean Louis 2001	Log; PSG: SOL, TST, WASO, AHI, myoclonus index; ACT: SOL, TST, WASO, BT, W times, mid-sleep time; Behavioral: Insomnia self-rating, SBJ sleep; Mood: Depression CES-D; Other: illumination acrophase and illumination mean 4 h before BT, 4 h after arising	Young: healthy good sleepers, elderly: insomnia or depression / apnea, acute health problems, high use of meds that affected mel / Results for elderly w/ insomnia or depression may not be same as for general elderly population	Elderly w/ insomnia or depression had poorer synchronization between mel and sleep (both home ACT and lab PSG), earlier self-selected sleep times (only measured at home w/ ACT, correlated w/ earlier mel acrophase), lower TST and higher WASO (both home ACT and lab PSG) Circadian malsynchronization correlated w/ poorer sleep in lab.	Directly compared ACT to mel reference standard for CR (evidence level 1A); indirectly compared ACT to PSG (level 3C). Home ACT phase validated by agreement w/ mel phase. Home ACT sleep results generally agreed w/ lab PSG results, except on SOL.
Yoon (102) 4C-b	RCT, unblinded, cross-over design / workplace / Diurnal; 4Nt night work, Tx during Nt 1,2,3; $ D ACT during day sleep performance tests N 1,3, and 4; 4 Nt alertness ratings; repeated for each of 3 treatments, 1 mo apart: 1. Room light, 2. Bright light, 3. Bright light and a.m. sunglasses	12 (NS) / (21-24) / normal shift workers	None / MML / left wrist / NS / NS / Action3	ACT: SP time, SL, TST, SE; Behavioral: Backward Masking Test, Digit symbol substitution test; Alertness VAS	Shift work nurses / NS / volunteers not blind to differences between 3 Tx	Day sleep and alertness during Nt work improved most by bright light plus a.m. sunglasses, followed by bright light alone. No effect on performance.	ACT identified sleep showed significant effect of circadian rhythm Tx; ACT results in D sleep agreed w/ SBJ alertness result in Nt work.

Table 5—Evidence levels for other clinical studies

Citation - Author / Evidence Level	Study Criteria Design / Location / Protocol	Sample Size (Completed Study) / Mean Age (Range) / Medical Conditions	Comparison Measures / Actigraph apparatus / Placement / Epoch Length / Sensitivity / Scoring	Outcome Measures	Inclusion / Exclusion / Bias	Study Conclusion from paper	Comments from Reviewer
Alessi (162) 4C-b	RCT, unblinded, parallel design / NH / Nocturnal only for 13 hs; 2Nt ACT BL, 2Nt ACT final wk intervention	65 (65) / Grp1 84.4±7.2, Grp2 85.1±7.6 / Incontinence	None / 1C Sensors / dom wrist / 2 mins / NS / NS	ACT: TST, % sleep, dur of sleep episodes, longest sleep episodes	In physical restraints, incontinent / Coma, inability to respond, combativeness, terminal illness / Only pts w/ incontinence or in physical restraints	No improvement in sleep associated w/ improved physical function	Can't generalize to other NH populations
Alessi (163) 5D-b	Observational study / NH / Nocturnal only for 13 hs; 2Nt ACT	186 (176) / Grp1 86.2±7.1, Grp2 86.1±9.1 / Incontinence	None / NS / dom wrist / 2 mins / NS / NS	ACT: TST, % sleep, mean dur sleep episodes, peak dur episodes	Incontinence / Comatose, unable to respond, combative / Only incontinent pts	Pts on meds had higher means for sleep but not significant	ACT used just at night; observations of sleep used during the D
Alessi (164) 4C-b	RCT; unblinded; parallel design / NH / Nocturnal only for 12 hs; 5Nt ACT BL, 5D Observations BL, 5Nt ACT f/u, 5D Observation f/u; Intervention: physical activity during D and extra quite and dark at night w/ decreased interruptions to change diapers	29 (NS) / Grp1 88.6±10.4, Grp2 88.3±5.7 / Incontinence	Observation / NS / Dom wrist / 2 mins / NS / NS	ACT: % sleep, max dur of sleep episode, mean dur sleep episode	Incontinence / Coma, severe aggression stay < 3 mos / All subjects incontinent; leads to question of generalizability	In subsample of 10 subjects, validated ACT w/ observations: 92% agreement. At f/u, intervention Grp had ↑ % of sleep	In subsample of 10 subjects, validated ACT w/ observations: 92% agreement
Ancoli-Israel (112) 4C-b	Unblinded, nonrandomized, observational study / NH / Entire 24-hs; 3D ACT	NS (77) / Grp1 85±7.9 (60-100) Grp2 87±5.6 (74-96) / NH residents	None / Actillume / wrist / 1 min / ≥ .003g / Cole, Kripke et al 1992	ACT: total mins sleep, % sleep, total mins awake, % awake, num awakenings, length of each awakening, mesor, acrophase, amplitude, circadian quotient; Mood: Geriatric Depression Scale; Others: MMSE	NS / NS / Subject selection criteria NS	SDG slept more during Nt and D than MMNDG; SDG had lower activity mesor, more blunted amplitude, and were more phase-delayed than MMNDG	
Ancoli Israel (159) 5D-b	Unblinded, nonrandomized, observational study / NH / Entire 24-hs; 1D ACT	25 (25) / M 89.0±4.2, F 86.5±6.2 / NH residents	None / Actillume / wrist / NS / ≥.003g / Ambulatory Monitoring (Actillume) software	ACT: mins awake, mins asleep, % time awake, % time asleep, mean length of awakenings, mean lux exposure	Nursing home residents / NS / low sample size, subject selection criteria NS	Minutes awake: 555D, 396Nt; Minutes asleep: 130D, 325Nt; %Time awake: 81%D, 56%Nt; % time asleep: 19%D, 44%Nt; num of transitions from wake to sleep: 22D, 37Nt; Mean length of awakening (mins): 33D, 10Nt; Mean lux: 63D, 2Nt	
Baker (191) 4C-b	Unblinded; nonrandomized; observational study; case-control study / Home / Entire 24-hs; ACT 1 wk	NS (28) / 46.8 (40-55) / Menopause	Questionnaire; log / Gaehwiler / ndom wrist / 30 sec / NS / ref to older paper, but no details	log; ACT: arousal/non-arousal; Mood: POMS, STAI	NS / OSA, PLMS / Possible selection bias, unclear cause not well described	Menopause pts had more arousals & greater sleep disruption	Rather than rest or sleep, called variable "arousal"
Berger (151) 4C-b	Unblinded; nonrandomized; observational study; prospective, descriptive repeated measure / Home / Entire 24-hs; ACT 96hs chemo 1, ACT 72hs midpt chemo cycle, repeated for 3 cycles of chemo	72 (60) / 49.5 (30-69) / Breast Cancer	None / NS / ndom / NS / NS / NS	ACT: mesor, amplitude, num wakes; Other: Piper Fatigue Scale	NS / NS / NS	Fatigue higher during chemo; fatigue negatively correlated w/ activity	No normal controls for comparison
Berger (148) 4C-b	Unblinded, nonrandomized, observational study, cohort study, longitudinal study, repeated measures / Home / Entire 24-hs; ACT performed 6 times, 4D ACT at beginning of chemo for 3 cycles, 3D ACT at midpt between chemo for 3 cycles	72 (60) (30-47) / 49.5±8.64 (33-69) / Normal, Breast cancer pts	Questionnaire - Fatigue / MML / ndom hand / 5 sec every min / NS / Action3 (AMI)	ACT: mesor, amplitude, peak activity, nighttime awakenings; Revised Piper Fatigue Scale (to measure cancer-related fatigue)	Stage I or II breast cancer, scheduled to begin chemotherapy after breast surgery, English-speaking, Karnofsky score ≥ 60 / NS / NS Drop-outs had most severe symptoms	The num of nighttime awakenings had the strongest assoc. w/ cancer-related fatigue. Subjects w/ higher fatigue had lower amplitude & lower peak activity	Did not look at standard measures of sleep

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Cordoba (154) 4C-b	Unblinded, nonrandomized, observational study, case-control study / Home / Entire 24-hs; ACT 5D, M-F (no weekends)	NS (40) / Grp1 51 (37-69), Grp2 50 (NS), Grp3 52±2, Grp4 52±2 / Cirrhosis	Questionnaire / Actillume / Wrist / 1 min sampled 20 sec / NS / Action 3	ACT: TIB, SE, num wakes, WASO	NS / Shift work, alcohol / Low sample in the sub-group of ACT pts	Compared to normals: motor activity ↓ in pts, fragmented sleep ↑ in pts, rhythm dampened in pts	
Corkum (167) 5D-b	Unblinded, nonrandomized, observational study / Home / Entire 24-hs; 7D ACT	50 (50) / Grp1 9.1±1. 4 (7-11), Grp2 9.7±1.3 (7-11) / Grp 1 ADHD, Grp2 Normal controls	Child Sleep Questionnaire-Parent version (CSQ-P); log completed by parent / MML / ndom wrist / NS / >.01g / ActionW2	log; ACT: total sleep dur, SOn, num Nt awakenings, restlessness; CSQ-P: SOn difficulties, Nt waking, difficulties arising, restlessness, BT resistance	NS / verbal IQ & performance IQ<80, brain injury, pervasive developmental disorder, autism, psychosis, PTSD, primary disorder of anxiety or affect / NS	CSQP: ADHD Grp had longer sleep durs, more difficulty w/ SOn; more ADHD subjects were "restless sleepers" had more BT resistance; ACT: no statistically significant differences between the two Grps; log: ADHD Grp had longer sleep dur & more BT resistance	ACT results were not compared to CSQ-P or log findings
Cruise (165) 4C-b	Observational, prospective study / NS / Nocturnal only for 10 hs; 2Nt (non-consecutive)	276 (225) / 84.9±9.8 / Incontinence	NS / NS / wrist / 2 mins / NS / NS	ACT: TST, % sleep, peak sleep, mean dur; body movement	>65 yrs, incontinence, no in dwelling catheter / NS / None	42% of waking episodes were associated w/ noise, light or incontinence care	
Dagan (192) 4C-b	Unblended, nonrandomized, observational study /home / nocturnal only for NS h. 3 Nt ACT	24 (24) / Grp 1 M, 12; Grp 2 M, 12 / Grp1, 1 9.6 (6-12, SD = 1.6) Grp 2, 7.9 (6-9.6, SD = 1.2) / Grp 1 = ADHD	Questionnaire (parent) / Actigraph – AMI / hand / NS / NS / automatic scoring analysis program (CAMI)	ACT; SE, Activity level, 'quiet' sleep percentage, SON, Sdur; Others: S/W questionnaire variables NS	Inclusion: Grp 1 =ADHD. Grp 2, healthy children / small sample size. Controls significantly younger than cases	ADHS children had lower SC, higher activity level, and lower 'quiet' sleep percentage than controls. No differences between groups on subjective parental reports of sleep.	Subjective parental reports of sleep not compared to ACT
Daurat (97) 4C-b	Controlled clinical trial; DB / Hotel rooms set up as lab / Entire 24-hs; 6D ACT BL, 1D temp BL, flight, 6D ACT post flight, 1+1D temp post flight, Zopiclone or Placebo before bed Nts 1-4 post flight	36 (24) / 51.2±2.2 / Normal	Temp (n=19) / Actiwatch / ndom wrist / 1 min / NS / Actisom (P.Denise, France) –sleep visually scored, cosinor for phase	Temp; ACT: sleep dur, activity index, ACT acrophase & amplitude; Mood: VAS "mood"; Jet lag Sx VAS "tired", "ill-being", "digestive", "energy"	Healthy, no meds x3 mos, no time zone travel / Core temp not unmasked	Zopiclone improves ACT identified sleep after transmeridian travel $F(1,22)=6.3$, $p<.05$; The greater the dysynchronization of CRs post-flight the shorter the sleep dur. Zopiclone did not improve SBJ jet lag	ACT detected both circadian shift and sleep disturbance
Dinges (193) 5D-b	Controlled clinical trial, unblinded, nonrandomized, subjects served as their own controls / Laboratory (in the Univ. Gen. Clin. Res. Ctr) / Entire 24-hs; 10-12D ACT consecutive (2D BL, 7-8D sleep restriction, 1-2D recovery sleep)	20 (16) / 22.9 (NS) / Normal	MSLT on D 2 of BL & D 5 of sleep restriction; SSS; log w/ VAS of SQ and several other measures; Observation by others (none were compared to ACT) / NS / wrist / NS / NS / NS	log; ACT; Mood: POMS; PVT, PRMT	NS / PSG screening to ensure they had no sleep disorders, MSLT to ensure their daytime sleep propensities were between 8 & 20 mins / low sample size	ACT data not specifically reported. Agreement between ACT & other sleep measures was NS.	No specific ACT data reported.
Duka (139) 5D-a	Controlled clinical trial, DB, nonrandomized, cross-over design, placebo-controlled / Laboratory / Nocturnal only for NS h; 2Nt ACT (1Nt ACT placebo, 14D washout, 1Nt ACT Tx or 1Nt ACT Tx, 14D washout, 1Nt ACT placebo)	8 (8) / 27.1±0.5 (21-34) / Healthy	PSG (Nihon-Kohden 17-channel, EEG, EOG, EMG); Temp (rectal); VAS / Actometer ZAK-GMBH / dom wrist / 2 mins / >.1G	Endocrine measures-plasma prolactin, GH cortisol, ACT: frequency of movement, intensity of movement; VAS	NS / Extreme morning & evening types, no acute or chronic illnesses, no meds for 4wks, no h/o sleep disturbances, no benzodiazepines / Low sample size	B-carboline ZK 93426 (benzodiazepine antagonist w/ weak inverse agonist activity) induces activation measured by ACT & disturbs sleep measured by PSG	ACT was not compared to the other sleep measures

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Dursun (152) 5D-a	Unblinded, nonrandomized, observational study / Home / Nocturnal only for NS h; 5Nt ACT	24 (24) / Grp1 36.1±9.2, Grp2 35.1±11.5, Grp3 33.8±11.6 / Grp1: schizophrenia on risperidone; Grp2: schizophrenia on a "typical" antipsychotic (not risperidone); Grp3: normal control; Grps1&2: DSM IV Dx of schizophrenia for at least 2 yrs.	VAS /Actigraph / Rt wrist / NS / NS / Actplan and Actstat software (Switzerland)	ACT: movement index (MI)= total num of points w/ movement ÷ total num of points recorded; VAS rating of SQ and morning sleepiness	NS / Rxs that affect 5-HT concentrations; chronic alcoholism; CNS infections; cancer; medical disorder that causes sleep abnormality / low sample size; not randomized	Nighttime MI in Grp2 > Grp1 but no significant differences between Grps1 & 2 in VAS scores	VAS results not directly compared to ACT
French (140) 4C-b	Unblinded, nonrandomized, observational study / High fidelity weapons systems trainers (flight simulators) / Entire 24 hs; 12D ACT	NS (32) / NS / Normal	None / NS / wrist / NS / NS / Walter Reed Algorithm (General Activity Program)	Melatonin: Salivary; Endocrine: Salivary cortisol; Mood: POMS; body pain survey; cognitive performance test battery, activity log, 2-mins electrophysiologic measure, 30-S voice record, oral temp, fatigue score	Operationally qualified crew members participating in simulated, long dur bomber missions / NS / NS	Crews had less sleep during mission 1, compared to missions 2 & 3. Recovered normal sleep dur w/in 48 hs after mission 3. Least restful sleep after mission 1.	
Friedman (136) 2B	RCT, SB, parallel design, ACT compared w/ other techniques in a subsample / NS / Entire 24-hs; 4D ACT BL, 4D ACT Tx, 4D ACT f/u	39 (35) / Grp1 61.9±7.1, Grp2 65.1±8.6, Grp3 65.1±5.8 / Insomnia, Age ≥55	PSG; MSLT; SSS; log; urine samples to ensure no sleep med use / (AMI) / ndom wrist / 30 sec / NS / ACTION 1.32	Log: TST, TIB, SE, SL, WASO; PSG: TIB, TST, SE, SL, WASO; ACT: TST, SE, SL, WASO	NS / Acute unstable medical or psychiatric illness, chronic illness associated w/ insomnia, specific sleep disorder such as sleep apnea, sedating or stimulating meds, no sleep meds for ≥3 wks / NS	Few between-Grp differences in Tx efficacy.	ACT correlated more highly than log w/ PSG
Friedman (126) 4C-b	Unblinded, nonrandomized, observational study, cohort study / Home / Entire 24-hs; 6D ACT	101 (48) / 70±6.9 (56-88) / Alzheimer's disease (AD) by NINCDS-ARDRDA criteria	None / Actigraph, Ambulatory Monitoring Inc / wrist / 30 sec / NS /ACTION 1.3	ACT: TST, SE, SOn, WASO, circadian activity, (amplitude, acrophase, mesor); Behavioral: MMSE, Time Based Behavioral Disturbance Questionnaire, Alzheimer's Disease Assessment Scale	Participants in longitudinal study of AD / NS / Non-response bias - ACT data in only 48 "records" from sample of 101 subjects	Significant correlations between higher Time Based Behavioral Disturbance Questionnaire overall score, SE & WASO. No significant correlation between circadian activity measures and Time Based Behavioral Disturbance Questionnaire	Measures of poor sleep by ACT correlated w/ more overall disruptive behavior in AD; but not w/ nocturnal disruptive behavior
Garfinkel (135) 4C-b	RCT, DB, cross-over design, placebo-controlled / Home / Nocturnal only for NS h; 3Nt ACT BL, 3Nt ACT Tx, 1 wk washout, 3Nt ACT Tx	NS (12) / 76±8 (68-93) / Insomnia; Independently living older people w/ medical conditions and w/ other meds.	Mel / Somnitor (Neurim Pharmaceuticals, Tel Aviv, Israel) / wrist / NS / NS / "automatic scoring algorithm" by Cole, Kripke et al	ACT: SL, SE, TST, WASO	NS / NS / Low sample size	SE was significantly greater after w/ mel than placebo and WASO was shorter w/ mel than placebo	Urine 6- sulphatoxy-mel measured at BL only
Gertner (171) 4C-b	Randomized, prospective / out of lab, hospital bed / 72 h, 2 successive sessions	36 (34) / M, 20, F, 14, (newborns) / normal & premature infants	None / AMI minature actigraphs / ankle / NS /NS / Sadeh	ACT; % quiet sleep, activity level, TST	NS/NS	Early biological maturity related to child's developmental status. Decreased TST, increased activity at night all predictive of higher developmental scores	Used in preterm newborns
Glod (168) 4C-b	Unblinded, nonrandomized, observational study, case-control study / Home / Entire 24-hs; 3D ACT	NS (44) / Grp1 8.3±1.9, Grp2 9.4±2.3, Grp3 10.0±1.6 / Grp1 normal, Grp2 physical & or sexual abuse, Grp3 major depression or dysthymia	None / Motion logger (AMI) / waist w/ wrist in a subsample / 5 mins / Accelerations >.01g / Mactivity, Activity Analyze	ACT: TST, SE, SOn, TIB, WASO, num nighttime awakenings; Behavioral: Child behavior checklist; Mood: K-SADS-E (Schedule for Affective Disorders and Schizophrenia for School-age Children-Epidemiologic version)	NS / Grp1 no significant psychopathology / NS	Controls vs. depressed children had no significant differences in sleep parameters by ACT. Physical abuse appeared to be the factor associated w/ sleep disturbance rather than Post Traumatic Stress Disorder.	Waist placement of the actigraphs

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Glod (194) 4C-b	Unblended, randomized, non-randomized, observational study, case-control study / home or hospital inpatients / entire 24 h, 3D ACT (weekdays)	NS / (22) Grp 1 M – 13, F – 6; Grp 2, M – 9, F-6 / grp 1, 9.4 (SD = 2.3); Grp 2 8.3 (SD = 1.9) /none, Grp 1 = physically and or sexually abused; Grp 2, healthy controls	None / NS / belt-worn / NS / NS / NS	ACT: diurnal activity, diurnal skew, % low-level activity, mesor, amplitude, % relative amplitude, acrophase; Mood, schedule for Affective Disorders and Schizophrenia for School-Age Children-Epidemiologic Version; Child Behavior checklist	Inclusion: medication-free and medically healthy (two in Grp 1 had illness) / NS / Patient selection (Grp 1 mostly in patients, Grp 2 outpatients)	Abused children were 10% more active than normals ($p<.05$), and had few periods of low-level daytime activity ($p<.01$). Later age of abuse was associated with circadian dysregulation.	
Haimov (195) 4C-b	Controlled clinical trial, DB, randomized, cross-over design / home (33 subjects), NH (18 subjects) / entire 24 h, 7 D ACT; 7 D ACT Tx 1, Tx 2, and Tx 3: 7 D ACT during last week of Tx 4 (2 mo); 7 D ACT f/u (Grp 2 only) Tx = melatonin (2 mg fast or sustained release or 1 mg sustained release) or placebo/	NS (51) / Grp 1; M, 4, F, 4; Grp 2, M, 6, F, 12; Grp 3, M, 19, F, 6 / Grp 1; 73.1 (SD=3.9); Grp 2; 81.1 (SD = 8.9) Grp 3; 71.4 (SD = 5.2) / other: Grp 1 independently living insomniacs; Grp 2, institutionalized insomniacs; Grp 3, independently living elderly w/o sleep disorders, good clinical condition, not depressed, not demented	Questionnaire, sleep log, diary, melatonin / NS / wrist / NS /NS /Sadeh, et al.	Sleep diary, log , melatonin, ACT; TST, SE, SL, mean activity level during sleep	Inclusion: Participants in prior study of mel and sleep, Grp 1 and Grp 2 had lower peak mel secretion / NS / NS	Improved SE and activity level during sleep with a 2 mg sustained release mel, and improved SL with 2 mg fast-release mel. Further improvement after 2 mo 1 mg sustained release mel.	
Hatonen (117) 5D-b	SB, nonrandomized, comparative Tx, placebo-controlled / Home / Entire 24-hs; 7D ACT BL, 7D ACT Tx w/ placebo, 7D ACT Tx w/ 2.5mg mel, 7D ACT Tx w/ 5mg mel	NS (5) / 14.6 (12-19) / Insomnia, neuronal ceroid lipofuscinosis (NCL)	log / (AMI) / wrist / 1 min / NS / Action 3.15	log; ACT: normal vs. fragmented motor activity rhythm (period analysis by max entropy spectral, auto-correlation and harmonic analyses)	All had NCL: / NS / low sample size	2 subjects had abnormally fragmented activity rhythms during BL & placebo or mel didn't affect rest/activity rhythms. In 3 subjects families reported slightly improved SQ w/ mel.	Very little actual data reported.
Hindmarch (141) 4C-b	RCT, unblinded, cross-over design, each subject acted as their own control / Laboratory - Medical Research Center / Entire 24-hs; 5 separate test Ds of ACT w/ at least 6D washout period between test Ds	NS (30) / 27.3±0.7 (19-36) / Healthy habitual tea & coffee drinkers	LSEQ / AMI AMA-32 Motionloggers (AMI) / ndom wrist / 30 sec / NS / Stanley 1997	ACT: TST; Critical Flicker Fusion Test; Choice Reaction time; Line Analogue Rating Scale	Healthy nonsmokers / NS / Subjects were not blinded to the drinks	Caffeine had dose dependent negative effect on getting to sleep and quality of sleep by LSEQ and dose-dependent negative effect on TST by ACT	
Hindmarch (142) 4C-b	RCT, DB, crossover design / Laboratory - Medical Research Ctr. / Entire 24-hs; 6D ACT Tx, Washout of 4D or more between test Ds	NS (24) / 32.6 (19-58) / Healthy normal volunteers	None / Ambulatory Monitoring, Inc / ndom wrist / NS / NS / ACTION 3	ACT: % sleep, % W; Critical Flicker Fusion Threshold; Choice Reaction Time; Line Analogue Rating Scales for Sedation	NS / No meds other than OCP's, no alcohol, nicotine or caffeine / NS	Promethazine (an antihistamine w/ sedating side effects) increase % sleep during the daytime and across the study period compared w/ fexofenadine, loratoadine and placebo.	
Humphreys (196) 5D-a	Observational study / women's shelter / interview and 2D ACT & log	54 (50) NS (NS) / battered women	Sleep log-diary/mini-motion logger / wrist / 30 sec / NS / Action 3	Sleep diary-log – behavioral; Pittsburgh Sleep Quality Index fatigue, VAS; ACT	NS/NS/NS	Battered women experience sleep disturbance and daytime fatigue	ACT sleep assumed to be true sleep
Ito (197) 4C-b	Controlled clinical trial, unblended, nonrandomized, parallel design / NS / entire 24 h, 7 D ACT BL, 7 D ACT Tx 1 (bright light) 7 D ACT Tx 2 (bright light or bright light and vitamin B12	NS (30) M, 12, F, 16 / 78.3 (NS) / normal, Alzheimer's dementia	None / AMI / NS / NS / NS / NS/	ACT: D and NT percent sleep, D and Nt awakenings, Others, MMSE, Clinical Dementia Rating	NS/NS/NS	No change with bright light alone. Bright light plus vitamin B12 decreased daytime percent sleep and num of naps. No Nt differences	

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Jean-Louis (143) 4C-b	Unblinded, nonrandomized, observational study, cross-sectional study / Home / Entire 24-hurs; 3D ACT	NS (273) / M 51±7, F 52±7 (All 40-64) / Community dwelling residents of San Diego identified by random telephone survey.	None / Actillume (AMI) / wrist / 1 min / NS / Action3 (Cole et al 1992 w/ Webster's re-scoring rules)	ACT: TIB, TST, SOL, SE, sleep (amplitude, mesor, and phase), activity (amplitude, mesor, and phase), illumination (amplitude, mesor, and phase); SBJ mood	NS / NS / Comorbidity NS	Significant gender differences, men had shorter TST, lower SE, shorter TIB, lower Sleep amplitude, higher illumination amplitude and higher illumination mesor; significant white vs. minority differences, white sample had longer TST, longer SE, shorter SOL, greater sleep amplitude, and higher sleep mesor. Total sample average TST was 6.22 hs.	Authors refer to their unpublished work comparing wrist ACT to PSG in women aged 51-77 w/ 89% min-by-min agreement, r =.90.
Jean-Louis (122) 4C-b	Unblinded, nonrandomized, observational study / Home / Entire 24-hs; 5D ACT	NS (32) / 44.76±20.64 / Healthy normal volunteers	SSS, log / Gaehwiler Electronics (Hombrechtikon, Switzerland) / dom wrist / 60 sec / ≥.1g / ADAS	ACT: TST, SE index, WASO, SOL, frequency of transitions between sleep and wakefulness, daytime activity level, auto- r (amplitude of activity)	NS / NS / Small sample size	Women had a better sleep profile than men by ACT	Relatively small sample
Jean-Louis (46) 4C-a	Unblinded, nonrandomized, observational study, cross-sectional study / Home / Entire 24-hs; 3D ACT	273 (273) / (40-64) /	Log / Actillume (AMI) / 1 min / NS / NS / Automatic scoring rhythm; ACTION3	ACT: TST, SOL, SE index, mesor, amplitude (of the cosine) and phase (timing of the peak of the fitted cosine) Level of illumination	Community dwelling residents of San Diego identified by random telephone survey / NS / NS	CR of illumination was significantly associated w/ activity and sleep rhythm measures. Higher amplitude of log illumination correlated with sleep phase (r = .16), lower SE index (r=-.15), and less reported daytime napping (r=-.16). Higher amplitude of activity correlated with sleep amplitude (r=.30), Sdur (r=.21) and less daytime napping (r = -.16).	Higher amplitude of activity (by ACT) was associated w/ less reported daytime napping. (r=-.16, p<.05).
Jean-Louis (198) 2B	Unblinded, nonrandomized, observational study / laboratory / nocturnal only for NS h, 2 Nt PSG, 1 Nt ACT (on second NT of PSG)	NS (24) M 17, F, 7 / 45 (SD = 9) / 18 with insomnia, 6 with hypersomnia, current major depressive episode	PSG / Gaehwiler / writ / 60 sec / >0.1g / ADAS	PSG: SOL, WASO, SE, TST; ACT: TST, SE, Mood: Beck Depression Inventory, HAMD	Inclusion; recruited from ongoing PSG studies / NS /NS	ACT scoring criteria based on healthy young adults did not perform as well in this depressed sample as criteria optimized for this sample.	½ of sample used to calibrate new ACT scoring algorithm and other ½ of sample used to validate the new algorithm
Jean-Louis (199) 4C-b	DB, randomized, cross-over design / home / entire 24 h, 5D ACT Tx 1 (6 mg mel or placebo); 5D ACT Tx 2 (placebo or 6 mg mel)	NS (10) / M, 4, F, 6 / 68.8 (SD = 15.8) / self-reported s/w disturbance, Alzheimer's disease	SSS, sleep log, diary, VAS / NS / wrist / NS / NS / ADAS	Sleep diary, log, ACT; TST, SE index, WASO, TWT, SWT and rest-activity amplitude; Others: Alzheimer's Disease Assessment Scale, Digit span, Digit symbol substitution, finger tapping, MMSE	Inclusion: Aging and Alzheimer's Registry, self-reported s / w disturbance,/ Exclusion, sleep apnea, PLM, medical, neurological or psychiatric illness other than Alzheimer's disease / low sample size	Mel enhanced rest-activity rhythm, reduced SOL, reduced SWT, and improved recall of previously learned materials	
Kario (200) 5D-b	Unblended, nonrandomized, observational / NS / 1 D simultaneous ACT and ambulatory BP monitoring	NS / (231) M, 126, F, 105 / 46 (30-66, SD= 8.9) / normal	None / AMI / waist while awake, wrist during sleep / NS / NS / NS	ACT: physical activity during S and W, Mood; Brief Symptom Inventory) depression and anxiety) Symptom rating checklist-90-Revised; Others: 24 h ambulatory BP monitoring	Inclusion: enrolled in larger work site blood pressure study/ Exclusion no hypertension, depression or anxiety meds; not shift worker / NS	Depression was associated with disrupted diurnal BP variation independent of physical activity by ACT in men, but not women	Nt physical activity (by ACT) was used to estimate SQ, but no ACT sleep findings reported
Lee (201) 4C-b	Cross-sectional study / Home / Entire 24 h; 2 D ACT	104 (100) / 38.3±7.8 / HIV	Questionnaire / MML / wrist / NS / NS / Action3	Log; ACT; Mood	NS / Dementia neuropathy use of illicit substances, hospitalization / NS	Pts averaged 6.5 h/Nt; 45% napped. CD4 cell counts unrelated to sleep, high fatigue grp had more disturbed sleep and more depression symptoms. Rhythm strength inversely related to daytime dysfunction, directly related to napping, TST.	

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Lemke (153) 4C-b	Unblinded, nonrandomized, observational study / Entire 24-hs; 3D ACT	NS (52) / 43.0±12.5 / Psychiatric unit in-pts w/ DSM IV criteria for major depressive disorder	Questionnaire, log PSQI / Aktometer (ZAK, Germany); ndom hand; 2 mins; Sensitivity: >.1g; Scoring: ZAK software	Log: TST, SWT, SQ VAS; ACT: mean activity; Mood: HAMD (German versions)	NS / Psychotic features and or neuroleptics, meds changed during study period, motor system disorders (e.g. Parkinson's disease) / Low sample size of good sleepers for comparison to poor sleepers by PSQI, differential reporting bias (more severely depressed pts may exaggerate sleep problems on log)	PSQI "poor" sleepers had higher mean nighttime motor activity than "good" sleepers; Depressed pts w/ less depressive symptoms had lower mean nighttime motor activity & higher log-reported SQ	Manuscript Table 2 incorrectly labels poor & good sleepers (correct in the text); ACT data only analyzed as mean activity levels, not S/W
Maus (137) 4C-b	Controlled clinical trial, unblinded, nonrandomized / Laboratory / 22 hs; Grp1 (normals) 2D ACT (1D ACT normal control, 1D ACT no sleep allowed), Grp2 (Sleep Apnea) 1D ACT allowed to sleep but w/o respiratory assistance (nasal CPAP)	NS (NS) / Grp1 31 (22-45), Grp2 56 (38-74) / Normal in Grp1 (healthy controls-students & health care workers), severe OSAS in Grp2	None /Actigraph (AMI) / NS / 1 min / NS / Sadeh, Technician Sleep Laboratory, Israel	Endocrine: urine norepi and epi; ACT: Activity index, SEI Nighttime pulse oximetry-desats	NS / h/o eye surgery, chronic eye disease, asymmetric intraocular pressures, meds known to affect aqueous humor flow / Patient selection: Grp2 older than Grp1	Sleep apnea Grp had higher nighttime activity index by ACT and lower SEI compared to controls allowed to sleep	
McArthur (169) 4C-b	RCT, DB, Tx order, cross-over design, comparative Tx, placebo-controlled / Home / Entire 24-hs; 10 wks of ACT (7D ACT BL, 28D ACT Tx, 7D ACT washout, 28D ACT Tx)	NS (9) / 10.1±1.5 / Rett Syndrome (stage III or IV)	log by caregivers, SOL, num of awakenings & final morning awakening / (Ambulatory Monitoring, Inc) / NS / NS / NS / Action3	log; ACT: TST, SE, num of awakenings, SOL	NS / NS / Low sample size	SOL significantly reduced by mel during the 1st 3 wks of trial	High variability in subject responsiveness to mel
McCarten (202) 4C-b	Controlled clinical trial, unblinded, nonrandomized, cross-over design / lab / 10 D & N ACT	NS (7) / M 7, 73 (62-81) / disrupted sleep, Alzheimers Disease	observation by nurses / AMI / dom wrist / NS / NS / NS	ACT: SO, # awakenings, TST during day , mean activity	Alcohol or drug abuse, serious medical illness, severe depression / low sample size	Nurses observations agreed with actigraphy. Triazolam had no significant effect on TST at night SO, # arousals, or TST during day. No sig drug effects on memory	
Mendlowicz (144) 5D-a	Unblinded, nonrandomized, observational study / Home / Entire 24-hs; 5D ACT	NS (32) / 50.00±23.97 (18-79) / Normal community dwelling volunteers	SSS, log / Gaehwiler Electronics / wrist / NS / NS / ADAS	ACT: daytime activity level, TST, SOL, transition from sleep to wakefulness, WASO, TIB; Mood: depressed mood from Alzheimer's Disease Assessment Scale; Alzheimer's Disease Assessment Scale, SSS, MMSE, VAS	No psychiatric or medical problems / NS / small sample	Age was associated w/ TIB, TST & WASO; significant predictors of depressed mood were daytime activity level, SOL, WASO, TST, & TIB	
Mennella (170) 4C-b	RCT, SB, cross-over design / Private carpeted room w/crib / 3.5 hs; 2 test Ds in each infant, separated by 1 wk; infants bottle-fed 100 ml of breast milk w/ 40ml (32mg) ethanol	15 mother/infant pairs (13 mother/infant pairs) / Grp1 27.4yrs±1.1 (22-34), Grp2 2.7mos±0.3 (1.5-5.6mos) / NS	None / AMA-32 (AMI) / infant's Lt leg / 1 min / NS / Sadeh et al	ACT: sleep %, total mins quiet sleep, total mins active sleep, longest SP, SL, num of sleeping bouts, mean activity count during wakefulness	Nonsmoking, lactating women and their infants / NS / NS	Short-term exposure to small amounts of alcohol in breast milk alters sleep in infants	Authors refer to another study where adding vanilla flavor did not alter the infant's sleep
Miaskowski (149) 4C-b	Unblinded, nonrandomized, observational study / Home / Entire 24-hs; 2D ACT	NS (22) / 56.6±13.0 / Cancer pts w/ painful bony metastases	Log; Likert scales of SQ and feeling rested / MML / wrist / NS / NS / Action3	ACT: TST, SE & num of awakenings; Mood: CES-D; Others: Lee Fatigue Scale, pain numeric rating scale	Receiving radiation therapy for painful bony metastases, age ≥ 18, spoke English, Karnofsky score ≥ 50, pain intensity ≥ 2.5 on a 0-10 scale, x-ray bone mets & on opioids / NS / NS	No significant correlations between the OBJ measures of sleep and self-ratings of feeling rested quality of sleep. Time spent napping was positively related to increased amounts of sleep the night before.	No evidence of first night effect b/t 2 consecutive nights of wrist ACT

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Miller (203) 5D-a	Unblended, nonrandomized, case series / home / entire 24 h, ACT BL, ACT placebo, ACT Tx (with methylphenidate or pemoline), num days ACT NS	NS (15) Grp 1 methylphenidate, M-6; F-2; Grp 2 Pemoline, M-5, F-3 / Grp 1; 7.5 (SD = 2.1) Grp 2 9.1 (SD = 2.3)/ normal, ADHD, Grp 1 received methylphenidate, Grp 2 received pemoline	None / NS /NS /NS /NS/ NS	ACT: motor activity " while awake" and "while asleep", Others: Connors parents' rating scale (hyperactivity); Global rating scale (of improvement)	NS/NS/low sample size	Wake activity, sleep activity and hyperactivity decreased with methylphenidate. Awake activity increased and asleep activity and hyperactivity index decreased with pemoline (statistical testing NS)	Minimal specific information on the study's methodology and the lack of statistical testing reported makes the findings difficult to interpret.
Mishima (99) 4C-b	RCT, unblinded, crossover design / NH / Entire 24-hs; continuous ACT for 1 wk pre-Tx, 2 wks Tx, 1 wk post-Tx, ≥ 4 wks washout cross-over; Tx=5-8000 lux 9-11am; Control=300 lux 9-11am	22 (NS) / Grp1 81, Grp2 78 / Grp1 Vascular dementia, Grp2 Alzheimer's dementia	None / (AMI) / ndom wrist / 1 min / NS / activity counts used, sleep not scored	ACT: Total, daytime & nighttime activity, % night/total activity	DSM IV Dx of vascular dementia or Alzheimer's / mixed dementia excluded / Unable to blind Tx, small N	Vascular Dementia: daily bright light reduces nighttime activity; Alzheimer's Dementia: bright light does not affect activity rhythm	Shows ACT detected Tx effect in well-designed, controlled trial. Suggest ACT useful to detect outcome in CR Tx study
Moorcroft (145) 5D-b	Unblinded, nonrandomized, observational study / Home / Nocturnal only from 8:00pm until 10 mins after awakening; 3Nt ACT	NS (15) / (19-62) / People able to self-awaken at a self-predetermined time w/o external means	log to get intended W time for the next morning /Actigraph (AMI) / NS / NS / NS / NS	log; ACT: Sleep & W periods, time of final awakening	Able to self-awaken / NS / Low sample size	Data suggested that these people could awaken at a self-determined time.	
Mormont (150) 4C-b	Unblinded, nonrandomized, observational study, cohort study, longitudinal study / Home / Entire 24-hs; 3D ACT	200 (192) / 58 (20-75) / Ambulatory metastatic colorectal cancer pts referred for chronomodulated chemotherapy	None / ACT (AMI) / NS / 1 min / NS / NS	Endocrine measures: circadian changes in cortisol & WBC; ACT: auto-r at 24h & a dichotomy index comparing amounts of activity when in bed & out of bed, mean activity; Mood: HADS (scale of anxiety and depression); QLQ-C30 (QOL)	NS / Poor general health (WHO performance status 72) / NS	Pts w/ marked rest/activity rhythms had a 5-fold higher survival rate at 2 yrs, had a 5-fold higher survival rate at 2 yrs, had better QOL & reported less fatigue. Rest/activity rhythm remained a significant predictor of survival in multivariate analysis.	
Ouslander (166) 5D-b	Case series, descriptive / NH / Nocturnal only for 9 hs; ACT 1 Nt BL, 2 mos later, ACT 1 Nt 2nd BL	73 (73) / 86.9±7.2 / Incontinence	NS / NS / NS / 2 mins / NS / NS	ACT: Sleep intervals	NS / NS / No information on how (sleep) ACT recorded	Incontinence was not related to sleep disruption	Built own actigraph
Pankhurst (146) 4C-b	Unblinded, nonrandomized, observational study, cohort study, cross-sectional study / Home / Nocturnal for NS hs; 8Nt ACT	Study1 96 (92) / (23-67) / couples slept together, Study2 (95) / NS / subjects who slept alone. All subjects were community dwelling people living near 4 UK airports	Log / Gaehwiler Electronics Hombrechtikon, Switzerland / NS / 30 sec / >.1g / ACCORD (author's own program)	log; ACT:"actiblip" incidences	NS / Hypnotics, pain that seriously disrupted sleep / Comorbidity was not addressed	Men had more movements. For sleep partners, 1/3 of movements were common to both partners; subjects sleeping w/ partner had more movements; movements decreased when partner absent	ACT data not scored as S/W but as "actiblips" (movement)
Pat-Horenczyk (160) 4C-b	Unblinded, nonrandomized, observational study / NH / Entire 24-hs; 1D ACT	77 (67) / Grp1 85, Grp2 87, All 85±7.3 (60-100) / NH residents w/ dementia; SDG-MMSE<20, MMDG-MMSE ≥20	None / Actillume / NS / NS / ≥.003g / NS	ACT: mins asleep each hr, fully asleep each hr, fully awake each hr	NS / None (most pts had multiple medical diagnoses and were taking multiple meds) / NS	SDG slept more at each hr, and more than during meal times. Peak of sleep occurred 2 hs earlier in SDG Grp, MMDG had more wakefulness at night and SDG had more sleepiness during D	
Paul (204) 4C-b	Unblended, nonrandomized, observational study /home / entire 24 h, ACT 5 D prior to re-supply mission and until mission completed	NS (NS) NS (NS) / normal	None / Precision control Design / wrist / 1 minute / NS / Win Act 1.2	ACT: num and dur of sleep episodes; Others, psychomotor tasks; serial choice reaction time, logical reasoning task serial subtraction task and multitask	Inclusion: Canadian Air Command pilots and co-pilots / NS/ NS	Amount of daily sleep decreased during the 3 D prior to mission. During mission, worst sleep on night 2. During mission, decreased self-rated alertness and increased fatigue	

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Pollak (138) 4C-b	Case-control study / Home / Entire 24-hs; 12 Nt&D ACT	15 (15) / Grp1 75.9, Grp2 72.0 / NS	None / Vitalog PMS-8 / wrist / 1 min / NS / NS	log; ACT: activity	NS / NS / Small sample size	Rx uses (i.e. those taking meds at BT) become active 1.5 hs earlier in the morning	
Pollak (158) 4C-b	Case series / Home / Entire 24-hs; 9 D&Nt ACT	88 (44 pairs) / Grp1 77.9 (64-92) Grp2 61.9 (29-86) / NS	NS / MML / Ndom wrist / 0.5 min / NS / NS	log; ACT: activity level	65+; have care giver; disruptive nocturnal behavior (DNB) / NS / NS	Behavior of elders & caregivers were less similar in daytime than at Nt; at Nt it was elders that initiated interaction, thus disturbing sleep of caregiver	Presents a partial mathematical model of spontaneous motor behavior. Used video at Nt to watch interactions between elder & caregiver
Redeker (156) 4C-b	Observational study; longitudinal study / Home; out-of-lab hospital bed / Entire 24-hs; 7D postoperative in hospital, 7D Early recovery at home, 7D resume activities, 7D complete resumption of activities	22 (13) / Grp1 63.7±9.9 (43-83), Grp2 62±10.76 (43-78) / Coronary artery bypass graft surgery	NS / MML / ndom wrist / 1 min / NS / ACTION	ACT: TST, num wakes, mean W time, mean sleep interval, % sleep; Sickness Impact Profile	NS / NS / Low sample in follow-up	Significant daytime sleep & fragmented nighttime sleep during hospitalization; Over 6 mos period post-surgery, sleep consolidated & daytime sleep lower; Perceived sleep improvements consistent w/ ACT measures	Nice longitudinal follow-up (6 mos)
Redeker (205) 4C-b	Case series, time series / Out-of-lab hospital bed / Entire 24-hs; Continuous for entire hospital D	25 (17) / Grp1 63.67±9.86 (42.83) / Coronary bypass surgery	None / MML / ndom / 1-min / NS / Action	ACT: Activity counts; Sickness Impact Profile	NS / NS / Small sample	Relationship between rhythmic & linear patterns of activity w/ recovery; i.e. Positive relationship between length of stay & dysfunction w/ shorter activity periods associated w/ less dysfunction. Positive circadian activity periods were related to better functioning & shorter stay	Looked at rhythms as an outcome
Redeker (157) 4C-b	Observational study, descriptive, correlational / Out-of-lab hospital bed / Entire 24-hs; Continuous for course of hospital stay (range = 1-10D)	40 (33) / M 56.1±11.9, F 59.5±10.9 / Cardiac disease: acute myocardial infarction, unstable angina	None / MML / ndom / 1-min / NS / Action 3	ACT: Night interval, TST, SE, num wakes, dur of sleep interval, dur of wakes; Veran & Synder-Halpern Sleep Scale-pts. Perception of their sleep; Sleep loss subscale of pt. Sleep screener	Exclusion: Known sleep disorders, psychotropic meds, blindness, deafness / NS	pre-hospital endogenous variables, age, gender, & New York Heart Association functional classification and pre-hosp sleep loss all related to SE & dur of wakes once hospitalized. Pre-hosp severity of cardiac disease greatest correlate	
Redeker (155) 4C-b	Case series / Out-of-lab hospital bed / Entire 24-hs; Continuous for hospital stay	22 (NS) / Grp1 57.12±6.6 (47-65), Grp2 72.36±4.1 (66-77) / Coronary artery bypass	None / MML / ndom / 1 min / NS / ACTION 3	ACT: activity counts, cosinor parameters; Sickness Impact Profile	Exclusion: H/o of psychiatric disorder, neuromuscular disorder, chronic renal failure, blindness, deafness / Small Sample	Activity levels & strength of CRs increased over Ds 2-5 post-operative. In older adults it took longer (at a slower rate)	Examined the effect of age
Reyner (147) 4C-b	Unblinded, nonrandomized, observational study / Home / Nocturnal only for NS hs; 15Nt ACT	NS (400) / Grp1 (20-34), Grp2 (35-49), Grp3 (50-70) / Sleep normal Community dwelling people living near 4 UK airports	log / "Swiss-type" Gaehwiler electronics / wrist / 30 sec / NS / Horne et al, "SOn algorithm"	log; ACT: time of SOn, SQ	door-to-door survey / sleep-promoting meds or excessive alcohol / NS	Time of SOn was effected by gender & age; and differed from log and ACT; Average movement declined w/ age, and men had more movement than women	
Sadeh (172) 4C-b	Observational., longtitudinal / home / nocturnal, 5N	135/135 / M, 69, F, 66, NS (7.2-12.7) / normal, NS	None / Mini-motionlogger (AMI) / non-dom wrist / 1-min / NS / Sadeh actigraphic scoring algorithm	ACT; SO, morning up time, total sleep period, % sleep, # awakes, longest sleep period, quiet sleep %, neuropsych tests	NS / NS	Kids fragmented sleep had lower performance and more behavior problems	

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Sadeh (206) 4C-b	Case-control study / Home / Entire 24 hs 3-4D	NS (NS) / Grp1 12.1 (8.2-15.4), Grp2 12.4 (8.9-14.7) / asthma	None / AMA-32 (AMI) / ndom / 1 min / NS / ASA program	ACT: SOL, TST, s1eep percent, longest SP, % quiet sleep; activity level; Pulmonary function, asthma severity, sleep Q by child & parent	NS / NS / NS	Asthma kids were more active during sleep & had less % quiet sleep; boys w/ asthma fell asleep faster than girls; control girls fell asleep faster than boys; %sleep & mean activity correlated w/ evening & morning Pulmonary peak expiratory flow measures & poor sleep associated w/ more severe asthma	Was first home-based evaluation of asthma & sleep in children
Sadeh (207) 4C-b	Observational study / out of lab hospital bed / Entire 24 hrs; 3D	39 (NS) / Grp1 9.51±1.9 (7-14) / Severe psychiatric problems	None / AMA-32 / non-dom / 1 min / NS / ASA	ACT: SO, TSP, % sleep, true sleep time, longest sleep percent, % quiet sleep; WISC - R, Depression scale, psychological tests, Abuse history	NS / NS / NS	Lower SQ during hospitalization strongly associated w/ self report on depression, hopelessness & low self esteem in children w/ severe behavior disorders	
Sakakibara (207) 4C-b	Unblinded; Randomized; cross-over design / Home / Entire 24-hs; 5Nt ACT, PSG last 2Nt	10 (10) / 59.7 (50-69) / Normal	NS / MML / ndom / NS / NS / Cole et al	log; PSG; ACT: mean activity, movement index, daytime activity level	Exclusion: On meds, mentally ill, physically ill / Small sample	60 mins of bright light in the morning reduced nocturnal activity	
Scherder (114) 4C-b	Randomized / NS / Entire 24-hs; 4D ACT BL 1, 4D ACT after 6wk Tx; 4D ACT after 6wks no Tx	16 (15) / Grp1 81.7 (70-91) / Alzheimer's Disease	NS / No info	ACT: is (interdaily stability); IV interdaily variability; RA relative amplitude	Exclusion: Alcoholism, Psych illness, cerebral trauma, Cerebrovascular dis, Epilepsy, etc. / Not enough info	TENS increased IS	
Schlesinger (208) 4C-b	Unblended, nonrandomized, observational study /home / nocturnal only for NS h / 3 Nt After whiplash injury and 3 Nt f/u (3-5 months later	NS (34) Grp 1, M, 4, F, 14; Grp 2, M, 5, F, 11 / Grp 1, 36.5, (20-48, SD = 8.5) Grp 2, 33.2, (20-50, SD = 8.0) , normal, Grp 1; acute whiplash injury in traffic accident, Grp 2, normal controls	None / AMI / wrist / NS / NS / Actigraph Statistical analysis	Sleep diary, log; ACT, SL, total cumulative S dur, SE and num arousals	Exclusion Grp 2: no meds, no sleep problems, no h/o whiplash injury	No significant differences in ACT measured sleep between whiplash pts and controls. In sleep logs, whiplash pts had prolonged SL, and impaired SQ. In whiplash pts, greater signs/symptoms of whiplash correlated with greater num arousals and lower SE.	
Schnelle (209) 5D-b	Controlled clinical trial, unblinded, nonrandomized, cross-over design / NH / Nocturnal for 10 hs; 5Nt ACT	267 (184) / No info / NS	NS / NS	ACT: Peak activity; mean activity		Noise & light reduced correlated w/ change in % sleep but no change in D sleep (by observation) or actual sleep variables	Measured noise levels, used ACT only at Nt, used observation of sleep during D
Schwietzer (210) 5D-b	RCT; DB; comparative Tx / Laboratory / 3D ACT	NS (12) / 31.3±8.1 / Normal; Hypersensitivity to environmental allergen	MSLT / (AMI) / NS / 1 min / NS / NS	Log: VAS; MSLT, simulated assembly line task		No ACT results reported. after 3 Ds amount of sleepiness reported and on MSLT, same in all Grps	Not given any info on actigraph results
Shamir (211) 4C-b	RCT; DB; cross-over design; comparative Tx / NS / 3Nt ACT during each Tx phase 2mg mel vs. placebo	27 (19) / 42±5 (24-67) / Insomnia; Schizophrenia	NS / Somnitor / NS / NS / NS / NS	ACT: SE, SOL, TST, WASO, Fragmentation index, num wakes	Exclusion: Liver or renal disease or other psych disorders, severe physical illness / Much information missing on ACT	SE improved w/ mel compared to placebo in those who started out w/ poor sleep	Analyzed those w/ poor sleep to start out w/ separately
Shilo (212) 4C-b	Observational study / Out-of-lab hospital bed / Entire 24-hs; 72 hs ACT	NS (14) / Grp1 61±11 (39-76) Grp2 59±11 (49-74) / All on ICU	NS / Somnitor / NS / NS / NS / NS	Melatonin; ACT: TST		Very little sleep in a 72-h period 6-SMT abnormal in all w/ no nocturnal rise	
Shilo (213) 4C-b	Comparative Tx (mel/placebo) / Out-of-lab hospital bed / Entire 24-hs; 3D ACT	NS (8) / 62±14 (30-72) / On pulmonary ICU-COPD	NS / Somnitor / ndom wrist / 1min / NS / NS	ACT: TST, num awakenings	NS / NS / Small sample but understated population	Melatonin improved sleep-both duration & quality	

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Shinkoda (214) 4C-b	Observational study / Home / Entire 24-hs; ~4 mos ACT	NS (4) / (26-31) / Normal; pregnant or post-delivery	NS / AMA-32CL (AMI) / ndom wrist / 1 min / NS / NS	log / ACT: TST, SE, SOL, Naps, WASO	NS / NS / Low sample but unusual population	After delivery, sleep became irregular & WASO went up	
Shirota (215) 4C-b	Observational study / Home / Entire 24-hs; 10-14D ACT	NS (28) / Grp1 74.1±4.9, Grp2 73.0±5.0 / Normal	NS / NS / ndom / NS / NS / NS	log / ACT: mean activity, TST, SOL, TST-nap	NS / NS / NS	Hi volitional aged pts had well structured sleep and most took 1400h nap; low volitional had poor structured sleep & tool time-dependent nap ~ 8h after awakening	
Stein (216) 5D-b	Controlled clinical trial; DB; cross-over design / Home / Nocturnal only for 16 hs; 2-18h periods during each of 4 wks of protocol	NS (25) / 8±1.8 (6-12) / ADHD	NS / NS / NS / NS / NS / NS	log; ACT: activity level, SOL, TST, num awake, duration of wakes	NS / NS / NS	Slept less when Rx given TIB than in placebo	
Thessing (104) 5D-b	Cross-sectional study / Laboratory / Diurnal only for 8 hs; 1D ACT (while asleep in lab during D)	30 (24) / 21 (18-29) / Normal	NS /(AMI) / wrist / 1 min / NS / NS	log; ACT: TST, WASO	NS / NS / NS	No difference in sleep between the different light conditions	Tested shift workers during the D after a night w/ bright light Tx
Usui (217) 4C-a	ACT compared with other techniques/home/entire 24 h, 5-7 D ACT & Logs	18 (18) M, 11, F, 7/ 30.1 (NS) normal	Sleep log, diary /Motionlogger-AMI/ non-dom wrist / 1 min /0.01 g/rad/s / NS	Sleep diary, log, ACT: sleep minutes, wake minutes	NS/NS/ low sample size	Sensitivity (sleep) between ACT and log was 86.7% and specificity (wake) was 97.04%	Used ACT as gold standard to validate sleep log in healthy adults
Usui (218) 4C-a	ACT compared with other techniques/home/ 2-7D ACT & log	35 (35) Grp 1; 27.6 , (NS) Grp 2; 74.3, (NS) Grp 3, 42.1; (NS) normal, narcolepsy, other; sleep state misconception, idiopathic hypersomnia, DSPS	Sleep log, diary /Motionlogger – AMI / non-dom wrist / 1 min / 0.01g/rad/s / Cole	Sleep diary, log , ACT: sleep & wake minutes	NS/NS/NS	Sleep log does not always detect sleep state. Agreement dropped during sleep-wake transition periods. Sensitivity was lower in patients with sleep disorders than normals.	Used actigraphy as gold standard to validate sleep logs in healthy vs. elderly vs. sleep disordered patients
Usui (219) 5D-a	Unblended, randomized, cross-over design, case series / home / entire 24 h 3D ACT BL, 4 D ACT Tx 1, 3 D ACT washout, 4 D ACT Tx 2. Tx = 2 h bright light 2500 lux at BT or triazolam .125 mg	4 (3) / NS (64-80) / normal, NS	Sleep log, diary, VAS-sleepiness / Motionlogger, AMI / non-dom wrist / NS / .01 g / Cole et al	Sleep diary, log; ACT; day TST, night TST; Others: sleep log variables: Son time, SOff time, day TST in maps	NS/NS/ low sample size, no placebo	Decreased D and Nt TST (by ACT) with bright light. Increased NT TST (by ACT with triazolam. Findings lessened over the 4 D for both Tx.	
Van Londen (220) 4C-b	Observational study / NS / Entire 24-hs; 5D ACT	NS (78) / Grp1 45.2±14.4 (22-77), Grp2 42.2±16.3 (19-73) / Depression	NS / Gaehwiler / ndom / 30 sec / NS / NS	log / ACT: mean activity during W & sleep; immobility during sleep; fragmentation	NS / NS / NS	During W: pts < mean activity than controls; pts lower fragmentation & lower TST; During sleep: pts had higher activity	
Van Someren (115) 4C-b	Observational study / Home 18=Nt; NH 16=Nt / Entire 24-hs; 155 hs ACT	42 (34) / 72±1.2 / Alzheimer's	NS / NS / wrist / NS / NS / EEPROM	ACT: IS (interdaily stability), IV (intradaily variability)	NS / NS / NS	Rhythm disturbance in most Alzheimer's Disease pts, no sundowning, rhythms in NH less stable than home particularly in IS	
Vercoulen (221) 5D-b	RCT; DB; parallel design / NS / Entire 24-hs; 12D ACT	NS (96) / Grp1 38.5±10.1, Grp2 39.9±8.6, Grp3 37.8±11.9, Grp4 39.8±7.4 / Chronic fatigue syndrome; depression	NS / Actometer / ankle / NS / NS / NS	log; ACT: mean activity; Mood: Beck, SIP (SIP-sickness impact profile)	Exclusion: Other psych disorders	No difference in any outcome measures between the 4 Grps	
Wallace-Guy (222) 4C-b	Unblended, nonrandomized, observational study / home / entire 24 h 7D ACT	NS (154) F, 154 / 66.7 (51-81) / normal, postmenopausal women	None / Actillume (AMI) / wrist / 1 min /10 sec / NS / NS	ACT: lux, in-bed sleep, out of bed sleep, SE, SL, wake within sleep, TST, sleep timing, amount of daytime napping; Mood: depression brief screening questionnaire	Inclusion: participants in womens' health initiative observational study / Exclusion/ physically unable to participate or not likely to survive few months / NS	Greater 24-h illumination correlated with shorter SL, reduced wake within sleep, and greater depressed mood. Evening light exposure was not associated with these variables.	

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Wolter (223) 4C-b	RCT; DB; parallel design / Home & out-of-lab hospital bed / Entire 24-hs; 7D ACT in hospital, 7D ACT last wk patch Tx, 7D ACT off patch, 7D ACT @ 6mos f/u	71 (NS) / 47.5 (23-66) / Smoker	NS / (AMI) / wrist / 1min / NS / (AMI)	log; ACT: mean activity, SE, inact index during D	Exclusion:OSA, EDS, PLMS, narcolepsy, parasomnia / NS	1. NS diff in SE between different patch doses; 2. At all phases of Tx mean act less than BL	
Yesavage (224) 4C-b	Unblended, non-randomized, observational, longitudinal/ home / entire 24 h 5D ACT every 6 mo for an average 2.2 yrs	NS (42) 61.9% M, 38.1% F / 70.8 (SD = 7.5) / normal	None / AMI / non-dom wrist / 30 sec / NS / Action software version 1.32	Sleep diary, log, ACT : SE, amplitude of rest, activity CR; Others; MMSE	Probably Alzheimer's disease and MMSE = 15./ major medical illness / NS	Between subjects differences explained over 55% of variance over time in SE and CR. MMSE state explained only 5 % of variance over time.	
Zhdanova (225) 4C-b	Case-control study / Home / Entire 24-hs; 7D ACT prior to mel. Tx, 5D ACT on mel 0.3mg	13 (NS) / 6.5 (2-10) / Insomnia; Angelman syndrome	NS / mini-logger 2000 / pocket on back of vest / 1min / NS / MIT algor.	log; Endocrine Measures; ACT: num body movements, TSP	NS / NS / Not blinded, no placebo control	Sleep improved w/ mel	