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Wrist Actigraphy in Insomnia

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Summary: To assess the use of actigraphy in evaluating insomnia, 36 patients with a serious complaint of insomnia slept 3 nights each in the laboratory, where the usual polysomnograms (PSGs) were obtained as well as actigraphic assessments of their sleep. Patients also wore actigraphs for 7 days at home, were extensively interviewed and filled out psychometric tests. Based on all this information, the patients were then diagnosed according to the International Classification of Sleep Disorders.

Averaged over the 3 nights for each insomniac, the mean discrepancy between actigram and PSG was 49 minutes per night. In three-fourths of the cases, actigram and PSG agreed to within 1 hour on the total amount of sleep per night. Discrepancies, however, were not random: In patients with psychophysiologic insomnia and in insomnia associated with psychiatric disease, the actigram typically overestimated sleep when compared with the PSG. In patients with sleep-state misperception, the actigram was either quite accurate or it underestimated sleep when compared with the PSG. Comparing laboratory with home sleep, one-third of all insomniacs slept better in the laboratory and two-thirds slept better at home. In addition, night-by-night variability was higher at home than in the laboratory. Based on our study, we now recommend actigraphy as an additional tool in the clinical evaluation of insomnia, but we believe that in complex cases it should be combined with 1 PSG night in the sleep disorders center. **Key Words:** Actigraphy—Ambulatory sleep monitoring—Sleep state misperception—Psychophysiologic insomnia.

It is difficult to assess how insomniacs actually sleep. They are highly variable sleepers (1), often alternating excellent nights with very poor ones in an unpredictable sequence. In addition, the variables of interest for the sleep of insomniacs such as sleep latency, total sleep, sleep efficiency and number of awakenings are highly susceptible to the first night effect, which is unpredictable in insomniacs (2). Because of the high variability of insomniac sleep and because of the problems with the first night effect, one would need many laboratory nights to validly describe by polysomnographic measures how an insomniac truly sleeps. This would be an extremely expensive undertaking. However, even that would be unsatisfactory because the laboratory environment, with its lack of distractions, its remoteness from the tensions at home and its safety often results in improved sleep in insomniacs, whereas other, more anxious, insomniacs may sleep consistently worse in the laboratory than at home.

Clearly, if insomnia is ever to be assessed objectively, methods other than polysomnography in the sleep laboratory are needed. An objective assessment of sleep in insomnia is crucially important, however, because many insomniacs seriously misperceive how much they actually do sleep (3).

Wrist actigraphy offers a possible solution to the problem of objectively assessing how an insomniac sleeps. Wrist actigraphy is based on the fact that, in general, considerably fewer limb movements occur during sleep than during wakefulness. Most current wrist actigraphs consist of a movement detector and considerable memory storage, both packed into a small box that can be worn on the wrist like an oversized watch. No applications of electrodes are necessary, and the patient can wear this equipment continuously for a number of days during routine daily functioning and sleeping at home.

Although there were earlier reports of using wrist actigraphy successfully (4–6), the first report involving a self-contained unit came from Kripke's laboratory (7). In a pilot study with five subjects, Kripke et al. reported a 0.98 correlation between sleep duration estimated from wrist actigraphy and from polysomnography. This is a high correlation which, however, may be inflated by the fact that it was based on 24 hours of recording per day. In a follow-up study, Mullaney et al. (8) reported data from 63 good sleepers and from

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39 hospitalized patients with psychiatric problems and alcoholism. Each slept in the laboratory for 1–2 nights while both PSG and wrist actigraphy were recorded. On a minute-by-minute basis, actigraphy recordings agreed with PSG recordings in 94.5% of the epochs. Correlations between actigraphy and PSG were found to be 0.89 for total sleep, 0.70 for wake after sleep onset but only 0.25 for mid-sleep awakenings. By 1982, the same group had developed a better algorithm for hand scoring the wrist actigram, as well as a capability to computer-score wrist actigrams (9).

In 1987, a reliable wrist actigraph became commercially available. This actigraph contains piezoelectric transducers, 16-byte storage capacity and a reliable battery, making it possible to record wrist actigrams in 1-minute episodes over a minimum of 7 consecutive days (less time if shorter episodes are selected). The use of this equipment was then explored in studies differentiating adapting from nonadapting shift workers (10), in screening for apneas (11), in assessing narcolepsy (12), in differentiating insomniacs from normals (13) and in assessing daytime somnolence after treatment with a monoamine oxidase inhibitor (MAOI) (14). Wrist actigraphy seems to be useful not only in adults, but also in assessing the sleep of infants and children (15). For a review of technical issues and most recent findings relating wrist actigraphy and sleep, see Tryon (16).

Throughout the literature on wrist actigraphy runs the theme that this technique correlates very well with PSG data in normals and less well in those who have disturbed sleep. Perhaps Levine et al. (17) put it most succinctly: "As the probability of sleep decreases, actigraphic accuracy decreases." Pollmaecher and Schulz (18) found the agreement between PSG and actigraph excellent in the deeper stages of sleep but poor in the transition between waking and sleeping. Stampi and Broughton (19) found that ultrashort sleep/wake schedules reduced the accuracy of the wrist actigraph in estimating sleep. These findings suggest that data obtained from normal sleepers are not sufficient to support the use of wrist actigraphy in insomniacs, because insomniacs have short sleep/wake alteration cycles and excessive amounts of transition between sleep and wakefulness.

The current study was designed to assess the validity of actigraphic sleep evaluations in insomniacs, both for research and for clinical work. Reviewing the literature on wrist actigraphy, it seemed that the reliability of this method had been adequately established, but that the validity of its use in insomnia was questionable. Specifically, we were interested in the following three issues:

1. In insomniacs, how does wrist actigraphy compare with PSG, which is the current "gold standard"?
2. Could wrist actigraphy expand our research understanding of insomnia and its various subtypes?
3. Is wrist actigraphy clinically useful in the diagnosis and treatment of individual insomniac?

METHODS

Subjects

Subjects for this study were 36 insomniacs (mean age 45, range 24–69) who volunteered for a research study on insomnia that was described in the local media. There were 23 females and 13 males in the study. All volunteers were free of hypnotics, sedatives, anxiolytics and other sleep-affecting medications for at least 2 weeks before the onset of the study.

Volunteers were first screened by a telephone interview. They were accepted if they reported sleeping poorly on at least 3 nights per week and if their insomnia had lasted for a minimum of 6 months. To pass this screen, volunteers also had to report that their insomnia clearly affected their daytime functioning, that it was not caused by chronic pain or any known medical disease and that the volunteer did not use either alcohol or drugs that might affect sleep (an occasional alcoholic drink was accepted). Volunteers were then sent a number of questionnaires including a 1-week sleep log, a 1-week Stanford sleepiness scale and a Minnesota multiphasic personality index (MMPI).

Following the return of the questionnaires, patients were interviewed by the senior author. They were accepted for the next step of the study if sleep logs indicated either a sleep latency of more than 1 hour or more than 90 minutes of wakefulness during the night on at least 3 nights per week; if the Stanford sleepiness scale indicated significant daytime sleepiness and this was attributed by the patients to their poor sleep; if the insomnia did not seem secondary to a sleep/wake schedule disorder or a parasomnia (e.g. fear of nightmares); and if, according to the patient's medical history or according to a physical examination, there was no medical illness that might interfere with sleep. Sixty-two insomniacs were interviewed, and 36 were accepted.

Procedures

Subjects were first given a wrist actigraph to be worn continuously for 1 week at home, plus a 1-week sleep log and a 1-week Stanford sleepiness scale. Patients were then scheduled for 3 consecutive nights in the laboratory. They typically arrived at the lab around 8:30 p.m., had the standard Rechtschaffen and Kales (20) electrodes applied and then watched television until they felt like going to bed. On 2 of the 3 nights,

a full clinical PSG was done, including thermocouples in front of nose and mouth, respitrace (chest and abdomen), electrocardiogram and measures of anterior tibialis electromyogram. Subjects were also observed over a video monitor to assess sleeping position.

In an effort not to interfere with the usual sleep behavior of our volunteers, it was decided to leave their total time in bed (TIB) ad libitum, except that, in the laboratory, they had to stay in bed for a minimum of 6 hours per night. The TIB in the laboratory and at home is reported in Table 1. As reported there, TIB did not vary significantly among the three diagnostic groups. However, all three groups stayed in bed significantly longer when at home than when in the laboratory. This may be partly artifactual because short times out of bed (e.g. to the bathroom) were subtracted from TIB in the laboratory but not at home.

PSGs were scored by a trained technician using the Rechtschaffen and Kales (20) criteria. Initially, actigrams were hand scored from the printout of the data. However, as various scoring programs became available, they were evaluated (see Results). Finally, the scoring program of Sadeh et al. (21) was selected. All data reported in this paper are computer scored using that program.

TABLE 1. *Time in bed (minutes)*

	Insomnia associated with mental disorder	Psychophysiologic insomnia	Sleep state misperception
In laboratory	410	432	424
At home	487	500	442

ANOVA	df	*F*	p
Diagnosis (A)	2	2.24	0.13
Subjects within diagnostic groups	28	—	—
Laboratory vs. home (B)	1	25.22	0.001
Interaction A × B	2	2.15	0.14
B × subjects within diagnostic groups	28	—	—

Diagnostics

At the end of the 3-night sleep laboratory evaluation, each patient was assigned an International Classification of Sleep Disorders (ICSD) diagnosis (22), using all the information that had been collected during the 3 nights of sleep in the laboratory, the interview and the psychological testing. Only one major diagnosis was coded, however. For example, if, in the opinion of the investigators, somebody's insomnia was caused mainly by depression, although there were some periodic leg movements (PLMs) that mildly disturbed sleep as well, only a diagnosis of insomnia associated with psychiatric disorder was given.

This study was initiated before the ICSD (22) was published. To operationalize the diagnosis of sleep state misperception (SSM), the following rules were used:

1. Persistent complaint of insomnia, as indicated by the intake procedures discussed above.
2. Sleep efficiency >85% and sleep latency <40 minutes on at least 2 out of the 3 laboratory nights.
3. On the post-sleep questionnaire, the nights that fulfilled criterion 2 above were rated as "average" or "worse than average."

Rule 3 was designed to separate psychophysiologic insomniacs from those with SSM. Both may sleep quite well in the laboratory but for different reasons. When the psychophysiologic insomniac sleeps well in the laboratory, he/she is aware of having slept well and rates the laboratory sleep as better than average, whereas the patient with SSM sleeps well in the laboratory but rates this sleep as average or worse.

Because we used a sleep efficiency of 85% and a sleep latency of 40 minutes as cutoff scores for SSM (rule 2), whereas ICSD now uses a total sleep time of 6½ hours, our selection criteria were not the same as those of the ICSD. Of the eight volunteers whom we classified as SSM, two slept more than 6½ hours per night, three slept more than 6 hours and three slept more than 5½ hours. Thus, the findings of this study may not entirely apply to those rare SSM patients described in ICSD, but they do apply to the more commonly encountered patient who sleeps relatively well (over 5½ hours per night) while bitterly complaining about insomnia.

Among the 36 insomniacs in our sample, 13 had insomnia associated with a mental disorder, 10 carried a diagnosis of psychophysiologic insomnia, 8 had SSM, 3 had idiopathic insomnia and 2 had PLM disorder. Obviously, these figures are not related to incidence rates of insomnia in the general population; our intake procedures had carefully selected against transient insomnia and against the insomnias associated either with drugs and alcohol, or with sleep-induced respiratory impairment or associated with other medical, toxic and environmental conditions.

RESULTS

Selection of a scoring program

There are currently a number of ways to score actigraphy. The first systematic rules were Webster et al.'s 1982 algorithims for hand scoring (9), as follows:

A. After at least 4 minutes scored awake, the first 1 minute that looks like sleep is rescored awake.

B. After at least 10 minutes scored awake, the first 3 minutes that look like sleep are rescored awake.

C. After at least 15 minutes scored as awake, the first 4 minutes that look like sleep are rescored awake.

TABLE 2. *Comparison of different scoring methods*[a]

	Hand score	Sleepest zero	Sleepest one	Sleepest two	ASA Sadeh
Mean deviation from polysomnogram (minutes)	50	63	63	64	60
% Patients with errors over 1 hour	25	45	45	45	30
% Patients with errors over 2 hours	5	10	10	10	10

[a] For description of scoring programs, see text.

D. Six minutes or less scored as sleep surrounded by at least 10 minutes (before and after) scored awake are scored as awake.

E. Ten minutes or less that look like sleep surrounded by at least 20 minutes (before and after) scored awake are scored as awake.

Recently, a computer scoring program called Sleepest has become available. This program has three options: Sleepest 0 scores each epoch as either awake or asleep independent of what proceeds or what follows it. Sleepest 1 adds Webster's rule A to Sleepest 0. Sleepest 2 adds Webster's rules A and B to the program. A different program, developed through stepwise discriminant analysis of data obtained from nine normal sleepers, has been developed by Sadeh et al. (21) and is called Actigraphic Scoring Analysis (ASA).

To select a scoring method for this study, the first 20 insomniacs in this study were scored according to each of the above methods. (The mix of this subsample was similar to that of the total sample.) The results of this analysis are reported in Table 2. Clearly, hand scoring is best, mainly because artifacts can more easily be eliminated. The currently available computer programs are each able to score insomniac sleep within an average error of about 1 hour, which is not that much worse and considerably more efficient than hand scoring the actigraphic output. Among the programs we compared, the three Sleepest programs performed about equally, suggesting that Webster's rules add no increased precision when insomniac sleep is scored. The ASA program seemed to have a slight edge in our data, and was, therefore, used for the current study.

To verify our selection of the ASA programs, we replicated the computations in Table 2 for the remaining set of 16 insomniacs except that no hand scoring was done. Agreement between PSG and ASA scored wrist actigraphy was considerably better in this second set. For unknown, apparently random reasons the discrepancy between PSG and ASA-scored wrist actigraphy was only 35.5 minutes in the last 16 volunteers (whereas it had been 60 minutes for the first 20 volunteers). Again, the ASA program showed a slight, nonsignificant edge over the three Sleepest programs.

Sleep in the laboratory

Data averaged over 3 laboratory nights, rank ordered according to the discrepancy in total sleep between somnogram and actigram, are shown in Table 3. Overall, the average disagreement between the two measures of sleep is 49 minutes. More importantly, the two measures of total sleep agreed to within 30 minutes in 44% of our subjects. They agreed to within 1 hour in 75%, and, in 94% of the cases, the amount of disagreement was less than 2 hours. Overall, the actigraph overestimated sleep in 20 patients (56%), and it underestimated sleep in 15 patients (42%).

It is theoretically possible that the polygraph and the actigraph agree well in overall sleep time, while agreeing poorly in evaluating individual epochs as either sleep or awake. Therefore, an epoch-by-epoch analysis was carried out using the 59 nights of the first 20 subjects (equipment failure on 1 night). Overall, 52,530 epochs were analyzed, and the actigraph agreed with the polygraph on 44,127 epochs, for an overall epoch-by-epoch agreement of 82.1%. Agreement ranged from 96.8% in a patient with psychophysiologic insomnia to only 41.3% in a patient with severe PLMs. Inspecting the raw data, Levine et al.'s (17) rule held: The more fragmented sleep is, the poorer is the agreement between actigraph and polygraph.

Inspecting the data in Table 3 more clearly, it appears that the discrepancies between polysomnogram and actigram are not random. Splitting the data at the median according to how much the actigraph overestimated sleep, of the 18 patients in the top half (most overestimation), 17 were diagnosed as having either psychophysiological insomnia or insomnia associated with mental disorder. None had SSM. Among the bottom 18 patients, only 6 had either psychophysiological insomnia or insomnia associated with mental disorder, and 8 had SSM ($\chi^2 = 12.5$, $p > 0.001$). Using the PSG as the standard, the actigraph apparently tends to overestimate the amount of sleep in patients with psychiatric and behavioral problems, who apparently may lay in bed for long time periods motionless, but not sleeping. Actigraphy tends to be more exact or possibly to underestimate sleep in patients with SSM. Actigraphy also underestimated sleep in the three volunteers with idiopathic insomnia and in our patients with serious PLM, but the numbers there were too small for chi-square analysis.

Because a possible systematic bias in the discrepancy between PSG and wrist actigraphy is of research and of clinical importance, a two-factor fixed factor ANOVA was carried out using the five diagnostic classifi-

TABLE 3. *Comparison of actigraphy with polysomnography in the laboratory (mean of the nights)*[a]

No.	Age	Sex	Diagnosis	A	B	C
1	58	F	Psychophysiologic insomnia	−105	66.2	90.5
2	53	F	Insomnia associated with mental disorder	−75	63.7	78.5
3	53	F	Insomnia associated with mental disorder	−70	80.4	95.1
4	60	F	Psychophysiologic insomnia	−60	61.4	79.1
5	59	F	Psychophysiologic insomnia	−54	79.3	88.6
6	42	M	Insomnia associated with mental disorder	−52	81.4	94.9
7	43	F	Insomnia associated with mental disorder	−51	82.5	94.8
8	50	F	Insomnia associated with mental disorder	−43	72.8	74.9
9	52	M	Periodic limb movement disorder	−43	85.6	96.2
10	58	F	Insomnia associated with mental disorder	−38	67.8	58.6
11	43	M	Insomnia associated with mental disorder	−30	72.8	81.1
12	46	F	Psychophysiologic insomnia	−29	84.9	90.5
13	33	M	Insomnia associated with mental disorder	−28	70.0	54.5
14	59	F	Psychophysiologic insomnia	−28	73.3	80.3
15	61	F	Insomnia associated with mental disorder	−27	75.1	79.6
16	45	F	Psychophysiologic insomnia	−27	86.8	93.0
17	24	M	Insomnia associated with mental disorder	−20	79.9	85.3
18	30	F	Insomnia associated with mental disorder	−20	84.0	88.9
19	24	F	Psychophysiologic insomnia	−12	85.6	81.6
20	57	F	Sleep state misperception	−9	89.8	94.2
21	39	F	Sleep state misperception	0	92.8	93.0
22	54	F	Sleep state misperception	+1	88.3	87.7
23	52	M	Sleep state misperception	+5	88.7	87.9
24	54	F	Psychophysiologic insomnia	+19	86.1	82.6
25	52	M	Psychophysiologic insomnia	+22	85.7	83.1
26	43	M	Psychophysiologic insomnia	+24	69.6	62.4
27	36	F	Sleep state misperception	+32	92.9	81.7
28	26	F	Idiopathic insomnia	+38	90.3	80.1
29	38	F	Insomnia associated with mental disorder	+47	76.2	64.7
30	58	F	Insomnia associated with mental disorder	+48	82.9	70.2
31	45	M	Sleep state misperception	+50	91.9	83.8
32	34	M	Sleep state misperception	+94	94.6	71.6
33	37	M	Idiopathic insomnia	+106	88.2	62.8
34	34	M	Sleep state misperception	+113	87.5	60.7
35	32	F	Idiopathic insomnia	+129	94.3	66.6
36	60	M	Periodic limb movement disorder	+217	62.4	21.6

[a] A: Discrepancy (minutes) in total sleep: Polysomnogram minus actigram. B: Sleep efficiency (%) according to polysomnogram. C: Sleep efficiency (%) according to actigram. A, B and C are all means of 3 laboratory nights.

cations as one fixed factor and the three measures of sleep in the laboratory (PSG, actigraphy and subjective estimate) as the other (Table 4). This ANOVA indicated no statistical significance for the diagnosis factor: none of the five diagnostic categories consistently slept worse or better than the others on all three measures of sleep duration. There was a significant main effect for sleep duration, which appears to simply reiterate the well-known fact that most insomniacs subjectively underestimate how long they slept when compared to the PSG. Of interest to this study was a significant interaction effect, which means that, depending on their diagnosis, patients performed differently on the three measures of sleep duration. This interaction effect is evaluated in Table 5, where differences are analyzed by row ANOVAS and, if significant, by pairwise Scheffe F test comparisons.

Both for insomnia associated with mental disorder and for psychophysiologic insomnia, statistically significant differences were found when comparing actigraphy with subjective evaluations. Actigraphy reported longer sleep in these diagnostic categories than did the subjective report. Sleep duration assessed by PSG held a middle ground, not statistically significant from either actigraph or subjective reports.

The data are quite different for SSM. There were no statistically significant differences between the actigraph and the subjective evaluation by the patient, but both were significantly lower than the PSG.

Concerning idiopathic insomnia and PLMs, the n was simply too small to evaluate statistical differences with confidence. However, it is of some interest that in the three cases of idiopathic insomnia, actigraphy

TABLE 4. *Two-factor ANOVA of laboratory results for five diagnostic groups vs. three measures of sleep duration (PSG, actigraph, subjective estimation)*

Source	df	F	p <
A) Diagnosis	4	1.83	0.16
B) Sleep duration	2	10.97	0.0001
A × B interaction	8	2.43	0.02

TABLE 5. *Analysis of three measures of sleep duration by diagnostic group*[a]

Diagnosis	n	Sleep duration			Scheffé F tests, p <		
		Polysomnogram	Actigraph	Subjective	P/A	A/S	P/S
Insomnia associated with mental disorder	13	313	341	272	NS	0.05[b]	NS
Psychophysiologic insomnia	10	339	364	306	NS	0.05[b]	NS
Sleep state misperception	8	373	337	316	0.05[c]	NS	0.05[c]
Idiopathic insomnia	3	369	278	333	0.05[d]	NS	NS
Periodic limb movements	2	325	238	288	NS	NS	NS
Overall	36	344	311	291	NS	NS	NS

[a] For a description of the statistical procedures, see text. All row ANOVAS were significant except for the one involving periodic limb movements. P/A: polysomnogram (PSG) compared with actigraphy. A/S: actigraphy compared with subjective estimates. P/S: PSG compared with subjective estimates. Raw data are means of three laboratory nights.

[b] Subjective estimates are significantly lower than actigraphy estimates, but neither is significantly different from PSG data.

[c] PSG is significantly higher than either actigram or subjective estimates, but actigraphy is not significantly different from subjective estimates.

[d] PSG is significantly different from actigraphy.

considerably underestimated sleep when compared with PSG.

Comparing the ability of actigraphy to assess sleep to that of subjective estimates by inspecting the raw data in Table 5, we find that for insomnia associated with mental disorder, for psychophysiologic insomnia and for SSM, the actigraph comes considerably closer to the data obtained from the PSG than does the sleep log. For idiopathic insomnia and for PLMs, this does not seem to be the case, but these two latter categories do not contain a high enough n to draw firm conclusions.

Finally, a note concerning reliability: During the 108 nights of laboratory sleep involved in this study (36 patients at 3 nights), we experienced 4 lost nights. Twice, an error was programmed into the actigraph when setting it up for the study; once, there was a mechanical failure in the movement sensing apparatus; and once, we lost a night because of a low battery that had not been checked.

Home sleep and laboratory sleep

The ultimate goal using actigraphy is, of course, to assess sleep at home, away from the distorting influences of the laboratory. The comparison of home sleep versus laboratory sleep using only data from actigraphy is reported in Table 6. Only the three main diagnostic categories of insomniac sleep are assessed because of the low n in idiopathic insomnia and PLM. Obviously, data reported in Table 6 are subject to the systematic distortions discussed in the previous section: overestimation of sleep for insomnia associated with mental disorder and psychophysiologic insomnia and possible underestimation of sleep in SSM. In Table 6, we analyzed not only average length of sleep at home and in the laboratory, but also its night-by-night variability. There are persistent speculations in the insomnia literature that sleeping regularly in the laboratory (e.g. during placebo drug studies) consistently improves insomniac sleep because bedtime is much more regular.

For total sleep, the data in Table 6 indicate a significant overall ANOVA and a near-significant interaction effect. The main effect of home versus laboratory sleep was not significant: In general, patients slept about the same in the laboratory as they did at home. The overall group effect, however, was significant. Paradoxically, in the laboratory as well as at home, patients with SSM slept consistently worse than the other two groups when their sleep was assessed by actigraphy. Following up on the near significant interaction effect with appropriate Scheffé F tests, we found that both insomniacs associated with mental disorder and psychophysiologic insomniacs slept better at home than

TABLE 6. *Comparison of home sleep with laboratory sleep using actigraphy data only*

	Insomnia associated with mental disorder (n = 13)	Psychophysiologic insomnia (n = 10)	Sleep state misperception (n = 8)	Overall ANOVA	Main effects[a]		Interaction
					Home/laboratory	Diagnostic groups	
Laboratory sleep (minutes)	341	364	338	0.05	NS	0.03	0.07
Sleep at home (minutes)	398	403	331				
Variability in laboratory (SD)	44	35	30	0.03	0.04	NS	NS
Variability at home (SD)	74	63	77				

[a] NS = not significant (p > 0.10).

in the laboratory, whereas no such effect was observed in SSM.

Inspecting the raw data summarized in Table 6, we determined that the average discrepancy between laboratory sleep and home sleep was 73 minutes. Two-thirds of our insomniacs slept worse in the laboratory than at home and one-third did not. More importantly, home sleep was within 30 minutes of laboratory sleep in only one-fourth of our insomniacs. The discrepancy was within 1 hour in slightly more than half of our insomniacs, and in close to one-fifth of our insomniacs, average home sleep differed from average laboratory sleep by more than 2 hours, when assessed by actigraphy.

Concerning the night-by-night variability in laboratory sleep and home sleep, a main effect was found: Variability was considerably larger at home than in the laboratory. Although a slight increase in variability would be expected because 7 nights were assessed at home and only three in the laboratory, doubling the standard deviations from laboratory sleep to home sleep cannot be explained by this small statistical effect alone.

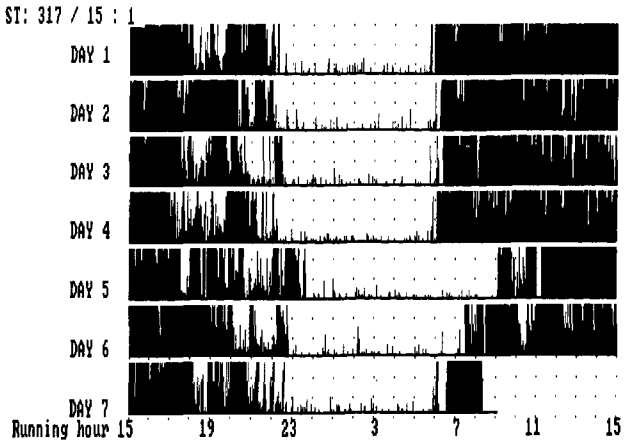

FIG. 1. A normal sleeper, a 38-year-old laboratory assistant. Typically, she got up at 6 a.m. except on Saturday (day 5) and Sunday (day 6). She worked actively until about 6 p.m. when she started to relax and watch television. Typically, she fell asleep between 10 and 11 p.m.

DISCUSSION

Insomnia research

As the results in Tables 3–5 indicate, wrist actigraphy has difficulties assessing with precision how long an insomniac actually is sleeping. The mean error when comparing wrist actigraphy with PSG in insomnia is 49 minutes, an error that is probably too large for most research studies. In addition, in two of our cases (6% of the subjects), the error was larger than 2 hours, which is clearly outside the acceptable range for most research studies. Nevertheless, as the data in Table 5 document, for insomnia associated with psychiatric disorder, for psychophysiologic insomnia and for SSM, the error committed by the wrist actigraph is only about half as large as the error committed by sleep logs. Thus, for studies that heretofore were forced to use only sleep logs, the wrist actigraph may be a considerable improvement.

A clear research strength of the wrist actigraph lies in its assessment of small wrist movements, a sleep parameter that is very different from the ones assessed on the PSG. This opens up new research avenues that could not be pursued by polysomnography alone.

Of interest in this context is the fact that wrist actigraphy typically overestimates sleep in psychophysiologic insomniacs and in those associated with mental disorders, whereas it assesses more accurately or even underestimates sleep in those with SSM (Table 5). It appears that psychiatric and psychophysiologic insomniacs may often lie in bed motionless but not asleep according to their EEG, whereas some patients with SSM apparently show excessive wrist activity while still remaining asleep.

Another advantage of wrist activity is that it can assess home sleep in a relatively unintrusive way. Although it cannot document the exact amount of sleep, it is a reliable assessor of such issues as regularity of sleep times, naps during the day and follow-through in sleep curtailment procedures. Therefore, it is likely to play a significant role in research on habitual sleep/wake patterns in insomniacs and in the research evaluation of follow-through after treatment with sleep hygiene measures.

Clinical applications

In the clinical evaluation of a specific insomniac, an average error of 49 minutes in total sleep time might be more easily tolerated than in rigorous research studies because the exact amount of sleep per night is rarely a crucial issue. However, except for the tendency of the actigraph to overestimate sleep in psychiatric and psychophysiological insomnia, we do not know whether the error in any given case is positive or negative. Thus, if the wrist actigraph measures, say, 5¾ hours of sleep, on average the actual sleep time could range from about 5 hours to about 6½ hours.

The strength of the actigraph for clinical work lies not in measuring exactly how long a person sleeps, but in evaluating patterns of sleeping and their stability over time, observing discrepancies between weekday and weekend sleeping, occasional nights of extremely little or extremely long sleep, etc. Major computer programs for the scoring of wrist actigraphy now have good display options that let the clinician assess at a glance the above parameters for an entire week. Figures

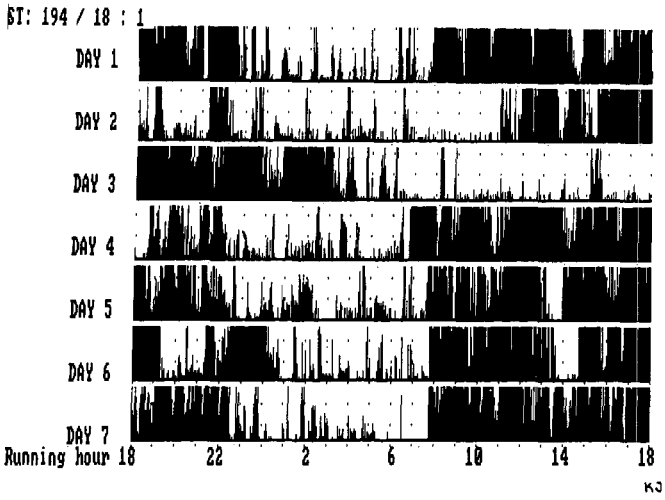

FIG. 2. A 42-year-old female insomniac who aggravated her problem by her weekend sleep/wake behavior (days 2–4). On Fridays (day 2) she went to bed at about 7 p.m. and slept almost continuously until 11 a.m. on Saturday. She then remained awake until about 3 a.m. on Sunday. From then until Monday at 6 a.m. (15 hours) she slept almost continuously except for some awake time around 7 p.m. to 11 p.m. on Sunday (day 4). During the rest of the week, the patient tried to get up at 7:30 a.m. but was prone to take a nap after lunch.

1–3 illustrate this clinical use of wrist actigraphy. Also, a rough level of daytime alertness can be obtained from the wrist actigraph as demonstrated in Fig. 1, whereas resting in the evening can clearly be differentiated from daytime alertness on the job (23).

As documented, occasionally the discrepancy between wrist actigraphy and PSG-evaluated sleep can become quite large, over 2 hours. Such a discrepancy would become clinically significant. Also, the wrist actigraph in its usual mode of collecting data in 1-minute intervals is no assessor of PLMs and disordered breathing events, and it has no way of assessing alpha intrusion into sleep or other EEG-derived phenomena. Therefore, if an organic component is suspected in a given insomnia, or if the discrepancy between the sleep log and the wrist actigraph are extreme, a laboratory PSG would seem indicated. Optimally, it appears that insomniac patients should be assessed by a minimum of 1 week of wrist actigraphy at home, plus a minimum of 1 night of polysomnography in the laboratory.

In summary, wrist actigraphy is relatively inexact when assessing the duration of insomniac sleep, although in most insomniacs wrist actigraphy seems to

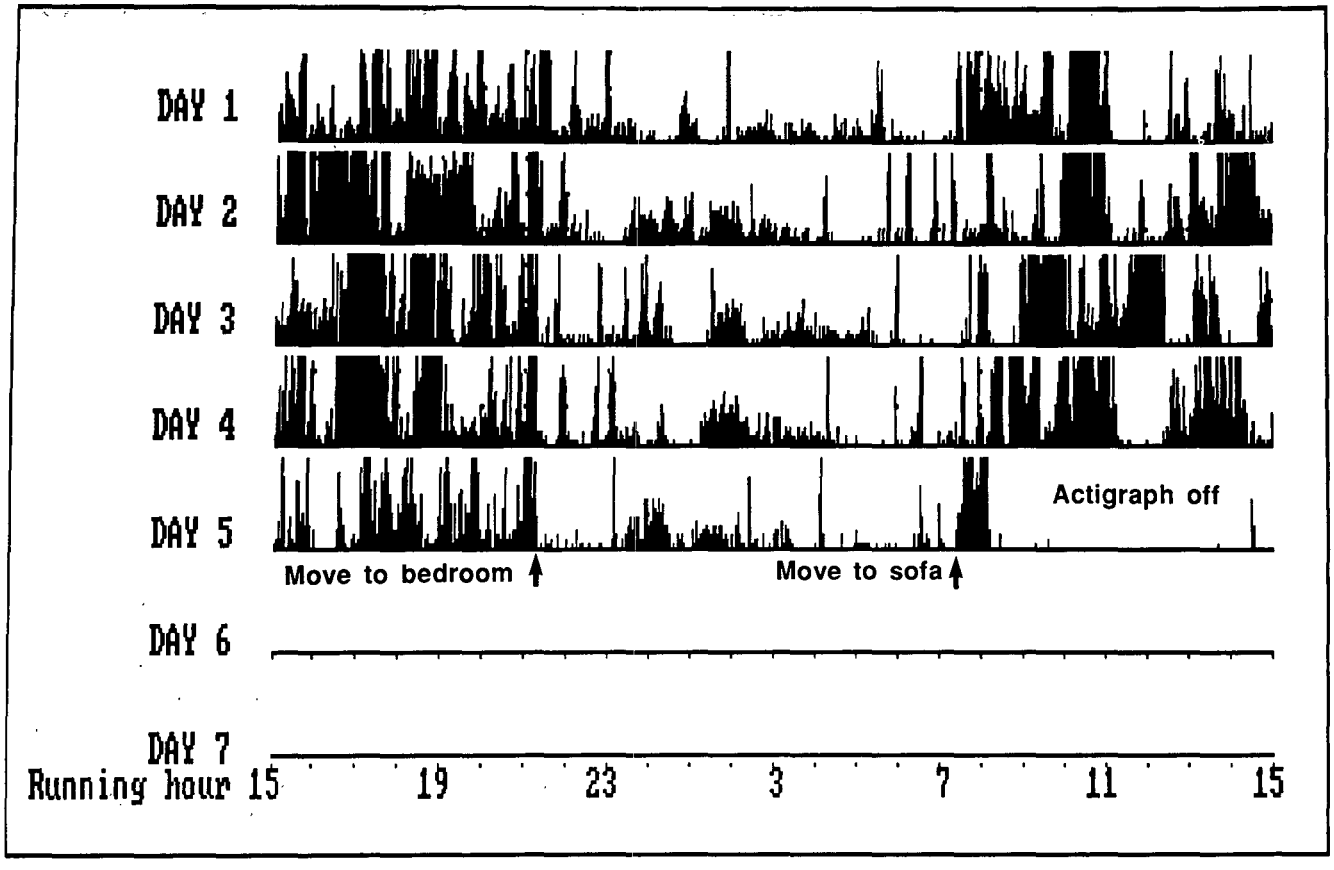

FIG. 3. A 65-year-old serious insomniac. Retired, this man spent most of his time "resting" with long naps during the day and long periods of wakefulness at night. A circadian rhythm is only faintly discernable.

be more exact than sleep logs. Its main research strength lies in its ability to measure a different aspect of sleep (small wrist movements) that is not assessed by the PSG but may lead to new research insights. For clinical work, its main asset lies in the fact that many nights of insomniacs' sleep can be quickly and inexpensively scanned on wrist actigraphy, leading to clinical insights concerning the pattern of sleeping and waking at home, which are not available from laboratory polysomnography. Thus, wrist actigraphy occupies its own niche in research and clinical work on insomnia. It is not simply a poor man's polysomnography.

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