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Wrist Actigraph Versus Self-Report in Normal Sleepers: Sleep Schedule Adherence and Self-Report Validity

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This study compared the accuracy of reporting adherence to sleep instructions in participants who were informed that adherence would be verified with an actigraph (aware group) to participants not informed the actigraph would be used to assess adherence (unaware of group). Participants were college students ($N = 68$), who were screened for psychiatric or sleep disorders or extremes in circadian tendency. The UG had later actigraph estimates of bedtime than the AG, but the two groups did not differ on their self-report of adherence to the sleep rules. Only the UG had later actigraphic estimates of bedtimes that violated the sleep rules. These findings have implications for the accuracy of sleep diary self-reports as well as for the use of actigraphs in studies requiring people to follow specific sleep schedule instructions.

The term *adherence* refers to compliance with medical or treatment advice (Spilker, 1991). Frank and colleagues (1992) have suggested that the term *adherence* may be more appropriate than the term *compliance,* because adherence distributes responsibility between the clinician and the patient. Thus, clinicians

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should have an interest in creating situations to increase the likelihood of patient adherence to their treatment recommendations.

Adherence to treatment is a serious challenge to clinicians (DiMatteo & Lepper, 1998). The failure to follow treatment recommendations and the failure of the patient to report nonadherence have economic and health costs and can result in unnecessary alterations in treatment regimens (Paykel, 1995). Nonadherence with an experimental study's instructions and failure to detect nonadherence in outcome studies interfere with the results and the ability to interpret treatment effects (Frangakis & Baker, 2001).

Relatively little attention has been paid to adherence to sleep schedules. An investigation of adherence to sleep schedule changes in school-age children found that participants were able to maintain imposed sleeps schedules (Fallone, Seifer, Acebo, & Carskadon, 2002). In a study on adherence to sleep restriction, Riedel and Lichstein (2001) reported that some patients may not adhere to sleep restriction instructions because spending less time in bed when the complaint is insomnia seems counterintuitive. In the Riedel and Lichstein study, the ability to accurately monitor adherence was important because measures of sleep schedule consistency were better predictors of treatment response than was the degree of bedtime reduction. Those undergoing sleep restriction may also experience sleepiness during the early stages of the treatment (Glovinsky & Spielman, 1991), which may contribute to nonadherence.

Within the past decade, wrist actigraphs have become a widely used and relatively inexpensive method of objectively monitoring activity over 24-hr periods. A wrist actigraph is a portable instrument, worn like a wristwatch, that measures body movement. Actigraph data are used with a computer algorithm program to estimate rest and activity. Because it is less invasive and far less costly than polysomnography (PSG), actigraph use is a promising method of monitoring rest and activity behaviors (Ancoli-Israel, 2000).

Although applications of actigraphs for the field of sleep disorders medicine are numerous (Ancoli-Israel, 2000), the use of actigraphs to assess and influence adherence to sleep recommendations has not been investigated formally. Because adherence to treatment recommendations is problematic for clinicians, support for the use of actigraphs in combination with a specific instruction that the actigraph data will be used to verify adherence could be very important.

The aim of this investigation was to evaluate whether participants who were told that their actigraph data would be used to verify adherence to specific bedtime, wake time, and time-in-bed instructions would increase both adherence and the accuracy of reporting their adherence to sleep rules. The unaware group (UG) and aware group (AG) were expected to differ on actigraph estimates of bedtime, wake time, and time in bed but were not expected to differ in their reported adherence to sleep rules on sleep diary bedtime, wake time, and time in bed. More specifically, we expected that participants in the AG would have less discrepancy between the study-required bedtime and wake time and their actual bedtime and wake time than would participants in the UG.

METHOD

Participants

Participants were Louisiana State University undergraduate psychology students, age 18 to 28 years, who were given extra course credit for their participation. Screening measures excluded participants with habits, medication, or disorders that potentially could affect sleep, thus making adherence more difficult. Exclusion criteria were: (a) a current mood or anxiety disorder or alcohol abuse on the Primary Care Evaluation of Mental Disorders diagnostic questionnaire and interview (Prime-MD; Spitzer et al., 1994), (b) current use of psychoactive medications, (c) a probable sleep disorder diagnosis according to self-report responses on the Sleep Disorders Inventory (Waters & Tucci, 1989), or (d) extreme morning (scores in the range of 70–86) or extreme evening tendency (scores in the range of 16–30) on the Morningness Eveningness Questionnaire (MEQ; Horne & Östberg, 1976).

Of the 169 people screened for participation, 68 met the study inclusion criteria and were assigned to either the monitoring aware group (AG, $N = 31$) or the monitoring unaware group (UG, $N = 37$). No participants dropped out from the study; however, 19 people (11.5%) who initially met inclusion criteria later declined participation because of scheduling conflicts.

Procedures

After approval was obtained from the Louisiana State University Institutional Review Board, participants were recruited online from psychology classes. Prospective participants were scheduled for a 60-min screening appointment during which they completed the aforementioned questionnaire measures (i.e., Prime-MD, Sleep Disorders Inventory, MEQ, and demographic questionnaire).

For a 48-hr period, participants wore wrist actigraphs and were instructed to maintain an 8-hr sleep schedule with bedtime at 23:00 and wake time at 07:00. Participants were instructed that if they had difficulty sleeping during this time, they were still required to stay in bed and attempt to sleep or rest for the 8-hr period. Each morning, participants completed a sleep diary to track their subjective report of sleep quantity and quality. To minimize potential deleterious effects on sleep, participants were instructed to refrain from daytime napping and from the following activities within 2 hr of bedtime: smoking, vigorous exercise, and consumption of caffeine, alcohol, or large meals or snacks. This 2-hr period from the scheduled bedtime was used as a cutoff for simplicity's sake, so that remembering and adhering to the rules would be more likely. Adherence to the sleep–wake schedule rules was the specific adherence variable of interest to the study. Adherence to the nonsleep schedule rules was tracked using a Sleep Hygiene Monitoring Form.

Prior to the self-monitoring phase, participants were randomly assigned to one of two groups. Those in the AG were told the actigraph unit would be used to verify their adherence with the sleep rules, whereas those in the UG were told the actigraph unit would provide movement data for the experiment but were not explicitly told that this could provide adherence information. Participants were given a follow-up appointment to return their self-report measures and actigraph equipment and to receive their earned course credit for participation.

Measures

The Prime-MD was used as a brief screening instrument for *Diagnostic and Statistical Manual of Mental Disorders* (4th ed.[DSM–IV]; American Psychiatric Association, 1994) mood or anxiety disorders and alcohol abuse (Spitzer et al., 1994). The Sleep Disorders Inventory (Waters & Tucci, unpublished) is a 60-item self-report questionnaire that assesses symptoms of sleep disorders and dysfunction. It is based on International Classification of Sleep Disorders (ICSD; American Sleep Disorders Association, 1997) criteria and covers major ICSD classifications. Any response that indicated a possible sleep abnormality was queried with a brief interview by an advanced doctoral student to assess if the participant met non-PSG ICSD criteria for a given sleep disorder.

The MEQ is a self-report measure consisting of 19 items to assess extreme morningness or extreme eveningness (Horne & Östberg, 1976). Participants who exhibited extreme morningness or extreme eveningness (scores between 16–30 or 70–86) were excluded. The following three items of the Daily Sleep Diary (SD; modified from Lacks, 1987) were used in the statistical analyses: (a) “What time did you go to bed” (SDBED), (b) “What time did you wake-up to start the day” (SDWAKE), and (c) “What was the total number of hours and minutes you spent in bed last night” (SDTIB). A Sleep Hygiene Monitoring Form, which consisted of a list of the nine rules of the study, was completed each morning. The form required participants to indicate whether they followed the study’s sleep schedule and hygiene rules. A *no* response was given a score of 1, and a *yes* response was scored as a 0. A score of 0 indicated perfect self-reported adherence.

The actigraph used in this study was an ActiTrac 3.15C (ActiTrac, IM Systems Incorporated). Participants were instructed to wear the actigraph on the dominant wrist. Sensitivity was set at 0.3125 mG, and the data sampling rate was 120 per hr (every 30 sec). A complete formal validation study of this particular actigraph model has not been published to date, although validation studies have been presented at national conferences and published in proceedings abstracts for earlier models of this unit (see Gorny, Allen, Krausman, Cammarata, & Earley, 1997).

Many actigraph sleep–wake scoring algorithms rely on sleep diary information to set scoring periods for sleep onset and offset. In this study, we hypothesized that there would be a discrepancy between these two measures, so we devised a priori criteria that would determine what values would be entered into the scoring windows for bedtime and wake time. To determine bedtime (ACTBED), we visually examined the actigraph data for a dip in activity counts in the evening and used the last value before the dropoff as a comparison point. This single value was multiplied by 90% to determine whether the subsequent activity count values constituted a 90% reduction in activity. The bedtime scoring window value was determined by the presence of 30 epochs (15 min) that contained a 90% reduction in average activity counts from the preceding 10 epochs (the 90% reduction was calculated by hand). Once the bedtime criteria were met, the first epoch that contained the 90% decrease in activity was used in the scoring window. This made sense visually because it corresponded to the value in the evening where there was a large, sustained period during which activity was dramatically reduced for the night.

Similarly, to determine wake time (ACTWAKE), we visually inspected the data for a large increase in morning activity and then looked for the presence of 10 consecutive 30-sec epochs of a 75% increase in activity counts from the last low-activity data point. Once the wake time criteria were met, the time corresponding to the first epoch that contained a 75% increase in activity was used in the scoring window. The participants' total time in bed (ACTTIB) was calculated by the scoring program of the actigraph, after ACTWAKE and ACTBED variables were entered into the scoring windows of the program. Only data between 21:00 and 09:00 were used for scoring to avoid the scoring of possible naps and times when the participants indicated they took the actigraph unit off to bathe.

RESULTS

Group Comparisons of Demographic Variables

The AG and UG were compared on demographic variables; see Table 1. Chi-square tests for gender, $\chi^2(1) = 1.92$, and ethnicity, $\chi^2(3) = 1.87$, proved nonsignificant. Group comparisons (e.g., *t* tests) on age, $t(65) = .89$, $p = .38$, and MEQ scores, $t(66) = 1.19$, $p = .24$, also proved nonsignificant.

Group Comparisons of Sleep Variables

A multivariate analysis of variance (MANOVA) was conducted on 6 dependent variables (ACTBED, ACTWAKE, ACTTIB, SDBED, SDWAKE, SDTIB) with night-in-study as a repeated measure (TIME), and group (UG, AG) as a between-group factor. The MANOVA indicated a statistically significant effect for

TABLE 1
Descriptive Statistics for Demographic Variables

Variables	*Aware Group*[a]	*Unaware Group*[b]	χ^2	*t*
Gender				
Female	21	30		
Male	10	7	1.92	—
Ethnicity				
White	27	29		
Black	4	6		
Asian	0	1		
Other	0	1	1.87	—
Age (years)				
M	20.4	19.9		
SD	1.47	2.17	—	0.89
M-E-Q scores				
M	49.51	51.32		
SD	6.97	7.96	—	1.19

Note. All between-group analyses (chi-square and *t* tests) were nonsignificant.
[a]$N = 31$. [b]$N = 37$.

group (Wilks's $\Lambda = .8$, $F[6, 61] = 2.55$, $p = .03$), but there was no significant effect for TIME (Wilks's $\Lambda = .82$, $F[6, 61] = 2.19$, $p = .06$) and no significant interaction (Wilks's $\Lambda = .93$, $F[6, 61] = .76$, $p = .61$). Follow-up analyses of variance (ANOVA) on the dependent variables were conducted, and only the ANOVAs for actigraph bedtime and actigraph wake time were statistically significant. See Table 2 for the means, standard deviations, and *F* values for the two groups. Those in the UG had significantly later objective bedtimes than the AG. The UG actigraph wake times were also significantly later than the AG wake times.

TABLE 2
Means, Standard Deviations, and *F* Values for Sleep Diary and Actigraph Variables

	Aware Group		*Unaware Group*		
Variables	*M*	*SD*	*M*	*SD*	*F*
Diary bedtime	23.2	.66	23.48	0.65	3.22
Actigraph bedtime	23.2	.64	24.21	1.49	11.94*
Diary wake	7.28	.76	7.51	0.64	1.85
Actigraph wake	7.27	.76	7.51	0.64	11.55*
Diary time in bed	7.97	.24	7.97	0.29	0.09
Actigraph time in bed	7.63	.61	7.78	0.67	0.66

Note. Times were decimalized for analysis.
*$p = .001$.

Nonparametric Between-Group Analyses of Difference Scores

Difference scores were calculated for the following variables: (a) actigraph bedtime minus scheduled bedtime, (b) actigraph wake time minus scheduled wake time, (c) actigraph time in bed minus scheduled time in bed, (d) sleep diary bedtime minus scheduled bedtime, (e) sleep diary wake time minus scheduled wake time, and (f) sleep diary time in bed minus scheduled time in bed. The range of difference scores for the two groups are presented in Table 3.

A Mann–Whitney *U* test was conducted on actual signed difference scores to evaluate whether those participants who were told that the actigraph would be used to verify their adherence to sleep schedule rules (AG) would have lower difference scores than those participants who were not told (UG). The test results were significant for the actigraph bedtime minus scheduled bedtime difference score only, $z = -2.851$, $p = .004$. The AG had a lower difference score average rank (27.03) than the UG (40.76). Thus, there was a greater discrepancy between scheduled bedtime and actigraph estimates of bedtime in the UG than in the AG.

Adherence According to the Sleep Hygiene Monitoring Form

A repeated measures ANOVA was conducted to determine if groups differed on their self-reported adherence to all of the study's sleep rules on the Sleep Hygiene Monitoring Form. Night-in-study was the repeated measure (TIME), and the dependent variable was the Sleep Hygiene Monitoring Form score. There was no sig-

TABLE 3
Means and Standard Deviations for Difference Scores for Actigraph Minus Sleep Study Rules and Sleep Diaries Minus Sleep Study Rules

	Actigraph		*Sleep Diaries*	
Variables	*Aware Group*	*Unaware Group*	*Aware Group*	*Unaware Group*
Scheduled bedtime				
M	.20	1.20*	.20	.20
SD	.64	1.49	.66	.66
Scheduled wake time				
M	.28	0.51	.28	.28
SD	.76	0.64	.76	.76
Scheduled time in bed				
M	–.37	–0.22	.31	.31
SD	.61	0.67	.24	.24

Note. Times were decimalized for analysis.
*$p < .05$.

nificant effect of time, $F(1, 65) = .63$, $p = .80$, or group, $F(1, 65) = .55$, $p = .46$, and no significant interaction, $F(1, 65) = 1.12$, $p = .29$; thus, the groups did not differ in their report of adherence to all the rules in the study. In addition, the means indicated almost perfect reported adherence to the rules in UG ($M = 0.63$, $SD = 0.61$) and AG ($M = 0.62$, $SD = 0.64$).

DISCUSSION

As hypothesized, the results of this study found that individuals who are told the actigraphs will provide information on their adherence are more likely to follow sleep rules than those who are not explicitly told that the actigraphs will provide information on their adherence. Both groups reported adherence to the study instructions; however, the actigraph estimates revealed bedtime adherence only in the group told that adherence would be verified by their actigraph data (AG). Specifically, results indicate that those in the UG went to bed approximately 1 hr later than the AG and 1 hr later than the study instructions indicated, but reported bedtime adherence on the sleep diary. Although there were also group differences on actigraph wake times, the lack of significance in the difference score comparisons prevents firm conclusions on the reliability of this finding. Finally, the analyses revealed that the groups did not differ on self-reported adherence on sleep diary items or the Sleep Hygiene Monitoring Form.

The results suggest that studies requiring participants to follow a particular sleep–wake regimen may benefit from improved accuracy of reporting by instructing them that actigraphs will be used to verify adherence to sleep schedules. Another noteworthy finding is that the UG were inaccurate in reporting actual bedtimes. This finding suggests that self-report sleep diaries may have questionable validity in providing accurate information on actual sleep–wake behavior in college students. These data suggest that combining actigraph monitoring with diaries can increase the likelihood of adherence to sleep instructions.

Although this study has possible implications in both clinical and research settings, there are some methodological limitations. One limitation to this study was the short observation period. The protocol only permitted the collection of 48 hr worth of data, which may not adequately represent participants' actual sleep–wake behavior. Typically, in both research and clinical settings, individuals are required to adhere to bedtimes and wake times for much longer periods.

Also note that the method to set bedtime and wake time scoring windows for the actigraph algorithm in this study has not been validated. We were interested in bedtime and wake time and not in the sleep onset or offset estimate provided by the scoring program. We also hypothesized that the sleep diary variables may not be accurate, and thus we could not use the sleep diary to score. We do not suggest that this method should be adopted in lieu of validated scoring procedures, but the specifics of the study necessitated a novel approach to scoring. The criteria were established a priori, and the actigraph scorer was blind to the group status of each participant and did not have access to sleep diary data; thus, there is no reason to suspect that the data were in any way biased. In addition, as of this date, the particular model of actigraph used in this study has not been fully validated except in small sample studies presented at national conferences, though the relevant technology has been well tested and formally validated, and its use justified in studies such as this.

The majority of the sample comprised young White women without sleep, circadian, or psychiatric disorders; thus the results may not be generalizable to other groups of individuals (e.g., clinical populations). Future studies should replicate these results with clinical and more diverse populations before any definitive conclusions are drawn about the clinical utility of actigraphs as a means of increasing the accuracy of reporting and adherence to sleep rules as a component of treatment. Because clinicians are interested in evaluating and increasing adherence to sleep schedule instructions (Riedel & Lichstein, 2001), it would also be useful to determine if use of wrist actigraphs, combined with an instruction that the units would be used to verify adherence, would increase the accuracy of reporting in other sleep treatments, such as sleep restriction.

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