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Actigraphy Reliability with Normal Sleepers

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Abstract

Introduction: Actigraphy has gained popularity as an objective method for measuring sleep in a home setting. We evaluated whether missing data affects the utility of actigraphy for the measurement of sleep parameters in normal sleepers.

Methods: We evaluated actigraphy data from 60 normal sleepers who participated in a study of the effects of changes in setting on sleep. Participants were asked to wear a Mini Mitter Actiwatch actigraph for 35 days and to use event markers to record bedtime and arising time. Counts of nights on which participants failed to supply usable data were computed using the following criteria: missing nights, missing bedtime markers, missing arising time markers, and multiple markers supplied at bedtime or arising time. A night on which any of these problems occurred was counted as unscorable.

Results: We evaluated a total of 2100 nights, of which 559 (27%) nights were deemed unscorable due to missing data. Missing markers at bedtime (206) and arising time (172) accounted for the majority of missing data. Trends over the five weeks indicated that incidence of missing data increased over the assessment period.

Conclusion: We found that missing data was a significant problem for long-term assessment of sleep using actigraphy. We suggest that researchers consider compensatory strategies, such as extending the assessment period and using adjunctive measures, in order to obtain sufficient data for analysis. We also recommend that future improvements in actigraphy instruments should aim to address the sources of missing data.

INTRODUCTION

Actigraphy is a method for assessing sleep that uses a small wrist-watch like device equipped with a highly sensitive accelerometer to measure limb movement and produce activity counts over a 24-hour period. A computerized algorithm is used to convert activity counts to infer sleep and wakefulness, which provides researchers and clinicians with information about sleep parameters such as sleep onset latency, wake time after sleep onset, terminal wake time, sleep efficiency, and total sleep time.

Over the course of the past twenty years actigraphy has gained popularity as an objective method for measuring sleep in both clinical and research applications (Sadeh, 2011). Compared to the other major approach for objective sleep measurement, polysomnography (PSG), actigraphy enables researchers to measure sleep in a home setting more easily, monitor sleep and wake continuously over a 24-hour period, and evaluate sleep over extended periods of time (Ancoli-Israel et al., 2003). Actigraphy has been validated for use in normal sleepers and found to have agreement rates of greater than 90% with PSG (Sadeh, Hauri, Kripke, & Lavie, 1995). Actigraphy has also proved useful in the long term assessment of sleep patterns in people with insomnia. However, scoring algorithms have been documented to have a systematic tendency to underestimate sleep onset latency and overestimate sleep duration compared to PSG in this population (Lichstein et al., 2006; Natale, Plazzi, & Martoni, 2009).

Reliability of actigraphy has been evaluated by relatively few studies based on mean values aggregated over one to seven nights of recording. Tworoger, Davis, Vitiello, Lentz, and McTiernan (2005) found that one night of actigraphy provided insufficient information about sleep in young women. The overall interclass correlation was low for total sleep time, sleep onset latency, and time in bed, and using the Spearman–Brown

formula the authors estimated that five nights of data collection are needed to obtain reliability greater than 0.70. Acebo et al. (1999) found that for young children, five or more nights of actigraphy should be recorded, whereas teenagers may require more than seven nights due to high intra-individual variability in their sleep schedules. These authors report that reliability for values aggregated over five nights was adequate (>0.70) for sleep onset, wake time during the night, and sleep efficiency.

The convergent validity of actigraphy with PSG and self-report measures of sleep has been extensively evaluated (for a review, see Sadeh, 2011), and the reliability of actigraphy has been found to be acceptable, as long as data are aggregated over a sufficiently long assessment period. However, a critical aspect of reliability for instrumentation concerns the consistent performance of the instrument aside from the data it returns. An unreliable instrument will fail to collect data or collect incomplete data. Little attention has been given to the practical issues of actigraphy use in sleep research, with regard to sources and frequency of missing and unusable data produced during long term actigraphic measurement of sleep.

Most actigraphs in use today are equipped with an event marker which allows participants to indicate bedtime and out-of-bed time, thus allowing researchers to evaluate sleep onset latency after entering bed and morning wake time prior to arising. Both of these parameters are essential for computing sleep efficiency, which is the ratio of total sleep time to time spent in bed, and may be helpful in calculating waking periods at the beginning and end of the sleep period as well as total sleep time. There are several sources of missing actigraphy data that would prevent the researcher from deriving the variables of interest. First, a participant may forget to activate the bedtime event marker signaling the beginning of the sleep period, and thus preventing the researcher from

computing sleep onset latency. Second, a participant may fail to supply an arising time marker signaling the end of the sleep period, preventing the researcher from computing terminal wake time. Third, participants may depress the event marker multiple times at bedtime or arising time, thus precluding the researcher from knowing their actual bedtime and arising time. Fourth, participants may fail to wear the actigraph during the assessment period, for example because they took the actigraph off to bathe and forgot to replace it. Finally, data loss can result from equipment failure.

The degree to which a missing data problem exists with actigraphy is difficult to estimate from the existing literature because the subject has never been systematically addressed. Some studies make no mention of how bedtime and arising time were captured or any problems with missing actigraphy data (e.g., Edinger et al., 2007), and in our informal survey of actigraphy articles, this is by far the most common approach taken by authors. Some studies make no attempt to use the event markers to record bedtime and arising time, relying entirely on diaries to determine the sleep period (e.g., Rowe et al., 2008). Additionally, some studies report they revert to the diary to replace missing actigraphy data (e.g., Palermo, Fonareva, & Janosy, 2008). We identified two studies which reported rates of missing data in actigraphic assessment of sleep. Acebo et al. (1999) reported high rates of data loss in samples of children and adolescents, with up to 28% of week-long recordings being insufficient for analysis due to participant non-compliance with data collection procedures or equipment problems. They further report that 44% of participant who provided acceptable data still had one or more unsorable nights during a seven-day assessment period. Tworoger et al. (2005) reported that in a sample of young women 14% of nights had some missing data, and these authors

identified the participants forgetting to put on the actigraph at bedtime as the primary cause of data loss.

In the current study we evaluated whether missing or compromised data affect the utility of actigraphy for the measurement of sleep parameters in adult normal sleepers.

METHODS

Participants

The data used in this study were collected as part of a separate research program that evaluated the effect of changes in the bedroom environment on sleep quality. Participants were 60 normal sleepers, who were recruited through media advertisements in the Tuscaloosa, Alabama area. In order to qualify for this study participants had to be 35 to 65 years old, have a Body Mass Index lower than 30, and had to have a score of less that 10 on the Epworth Sleepiness Scale (Johns, 1991). A brief investigator-designed interview was used to screen out participants who endorsed the presence of sleep disorders including insomnia, sleep apnea or its symptoms (e.g. heavy snoring, gasping for breath), restless legs, and periodic limb movements. Additionally participants who reported using a prescription sleep medication or any medication known to significantly affect sleep were excluded. Participants that endorsed a medical or psychiatric condition that was affecting their sleep were also excluded.

Measures

Actigraphy

Participants were asked to wear a Mini Mitter Actiwatch actigraph (AW-64)for a total of 35 days and to use event markers to record bedtime and arising time. Participants wore the actigraph on whichever wrist they preferred 24-hours a day for 14 consecutive days during baseline and 21 consecutive days after changes in the bedroom environment. The baseline and post change period were separated by a break of 7 to 25 days. The actigraph used in this study was equipped with an event marker that participants used to indicate the time they entered bed and got up in the morning. The epoch length was set at

30 seconds. Sleep and wake during the night were scored based on the presence or absence of movement using the Actiware – Sleep 3.4 software package at the medium sensitivity setting.

Sleep diaries

In addition to actigraphy, sleep diaries were used to assess participants' sleep during the assessment period. Sleep diaries are self-report questionnaires that gather information about sleep parameters by asking participants to record bedtime, time to fall asleep, wake time during the night, final wake up time, and final arising time. Several variables of interest can be derived from the raw sleep diary data, including time spent in bed, total sleep time, and sleep efficiency.

Procedures

If either the nighttime or morning markers were missing, we deemed this night unscorable. Additionally, nights on which multiple markers were supplied at bedtime or arising time were deemed unscorable, because it was unclear which of the markers indicated actual times to enter and exit the bed. If the participant removed the actigraph this also resulted in data loss. Finally, if a technological problem prevented us from collecting or extracting the data we counted this data as unscorable. We considered all of these sources of missing data and evaluated their rate of occurrence. Counts of nights on which participants failed to supply actigraphy data were computed using the following criteria: missing nights due to not wearing the actigraph, missing bedtime markers, missing arising time markers, multiple markers supplied at bedtime or arising time, and missing data due to technological problems. If multiple sources of unscorable data occurred on the same night, that night was only counted once.

Sleep diary data, collected concurrently within our sample, were also evaluated for incidence of missing data as a benchmark for comparison. If any of the variables necessary for computing sleep efficiency on a given night were missing that night was deemed unsocrable. As with the actigraphy data, we computed the number of nights on which diary data proved unscorable, counting nights with multiple sources of missing data only once. This allowed us to compare the frequency of missing data resulting in unscorable nights that occurred on sleep diaries to rates for actigraphy.

RESULTS

Participants

Data from 60 participants were analyzed. The sample was composed of 26 males and 34 females. The age range in the sample was 35 to 65 years with a mean age of 47.7(8.9). The mean body mass index was 25.5(2.3) for men and 25.4(3.3) for women. Mean sleep efficiency for the sample was 85.1(5.5)% and total sleep time was 403.6(44.3) minutes based on actigraphy measures.

Actigraphy

We evaluated 35 nights of sleep assessment for each participant for a total of 2100 nights of diary and actigraphy data. Of the actigraphy nights evaluated, we deemed 559 (27%) as unscorable due to missing data. Missing markers which occurred at bedtime (206) and arising time (172) accounted for the majority of missing data. Missing nights due to participants not wearing the actigraph occurred on 97 occasions. Occurrence of multiple markers at bedtime (37) and arising time (67) also contributed to unscorable nights (see Figure 1). The sum of these missing data events exceeds 559 because more than one event occurred on some nights.

The mean number of missing nights per participant was 9.1(6.2) out of 35, and the mode number of missing nights was 8. For men the average number of missing nights was 8.6(5.7) and for women the average was 9.7(6.6). The difference in missing data rates between genders was not significant $t(58) = 0.48$, $p = .66$. The correlation between age and missing data rates was not a significant predictor in our sample (r=.11, ns.).

Trends over the five week assessment period indicated that incidence of missing data increased as the study went on. During the 1st week 20% of nights were unscorable,

whereas 37% of nights during the 4th and 5th weeks were unscorable (see Figure 2). The rate of missing nights due to failure to wear the actigraph showed a particular increase over the assessment period with only one missing night during the 1st week and 55 during the 5th week. Interestingly, we did not identify a single instance in which a technological malfunction was the cause of data loss.

Sleep Diaries

We also evaluated nights deemed as unscorable on sleep diaries as a benchmark comparison for the actigraphy data. Compared to actigraphy, sleep diaries yielded relatively few missing data nights. We deemed a total of 31 (1.5%) of nights as unscorable. Missing nights, on which participants did not provide any diary data (26) were the leading cause of data loss. Missing data for sleep onset latency, wake time after sleep onset, and final wake-up time each occurred on two occasions, and missing arising time occurred on three occasions. The majority of missing nights occurred later in the assessment period, six took place in the 4th week and 16 in the 5th week.

DISCUSSION

Missing data were a significant problem for long-term assessment of sleep using actigraphy. The high frequency of missing data nights on actigraphy, compared with the relatively minor loss of sleep diary data, suggests that the participants were generally motivated to supply accurate and complete data, but had genuine difficulty complying with the necessary actigraph procedures. Our data indicated that participants became more likely to remove the actigraph without replacing it, and were less consistent with using event markers the longer the assessment period. This may be particularly problematic because extended assessment periods are necessary to attain sufficient reliability, to assess changes in sleep over time, and to evaluate the effects of interventions on sleep quality.

We have generated several recommendations that may help researchers cope with the problems of missing activity and event marker data. First, the use of adjunctive measures of bedtime and arising time, such as sleep diaries, should be used in conjunction with actigraph event markers to increase the likelihood that a participant will record this information on a given night, as has been recommended by other researchers (Berger, 2008). However, this solution has major limitations because it cannot be used in cases where actigraphy is utilized due to participants' inability or unwillingness to supply sleep diaries, or when the goal is to validate self-report with an objective measure. Second, participants should be encouraged to wear the actigraph continuously during the assessment period to minimize the chance that they will forget to put it back on. Most actigraphs are water and impact resistant so this should not affect their performance. However, we found some participants in our sample were resistant to wearing the

actigraph when bathing or had jobs that required them to remove the device while in the workplace. Third, it may be helpful to assist participants with creating a reminder system, or to determine points in their nighttime and morning routines that would cue them to depress the event marker. For example, activities which individuals are likely to do at set daily times, such as setting and turning off the alarm clock, bathing, or turning lights on and off, could serve as reminders to press the event marker. Fourth, researchers should adjust their a priori sample size calculations and assessment period durations with the expectation that data loss will occur.

In the future, designers of actigraphs should consider alternatives to participant supplied event markers for bedtime and arising time and attempt to move toward an automated method for capturing this information. One possibility would be to use weight sensors or radio frequency identification technology to record when a participant is in his/her bed. An alternate strategy would be to equip the actigraph with an automated prompt system, that would remind participants to depress the event marker at the appropriate time, for example by detecting changes in activity suggestive of getting into bed or exiting the bed. Such advances would reduce the data collection burden on both research participants and researchers.

Future research is needed to determine if the above findings can be replicated within other samples of normal sleepers. Additionally, it is important to evaluate whether our data will generalize to older and younger individuals. Another topic for further study is to evaluate the missing data rates with special populations, such as individuals with disturbed sleep or psychiatric problems. It is also important to assess whether other actigraphy technology has similar missing data problems. We suspect that existing data

sets available to a number of researchers from previously conducted actigraphy studies could help to answer many of these questions.

Research will also be needed to evaluate the effectiveness of the above suggestions for reducing the rates of missing data. For example, the effectiveness of a reminder system for the participants to depress the event markers at bedtime and arising time can be systematically evaluated. It would also be informative to compare the missing data rates for participants who are instructed to wear the actigraphs continuously compared with rates for those who are asked to wear them only at night. Any technological improvements that allow for automatic capture of bedtime and arising time will also need to be empirically tested against participant supplied event markers to evaluate their reliability and utility in reducing missing data.

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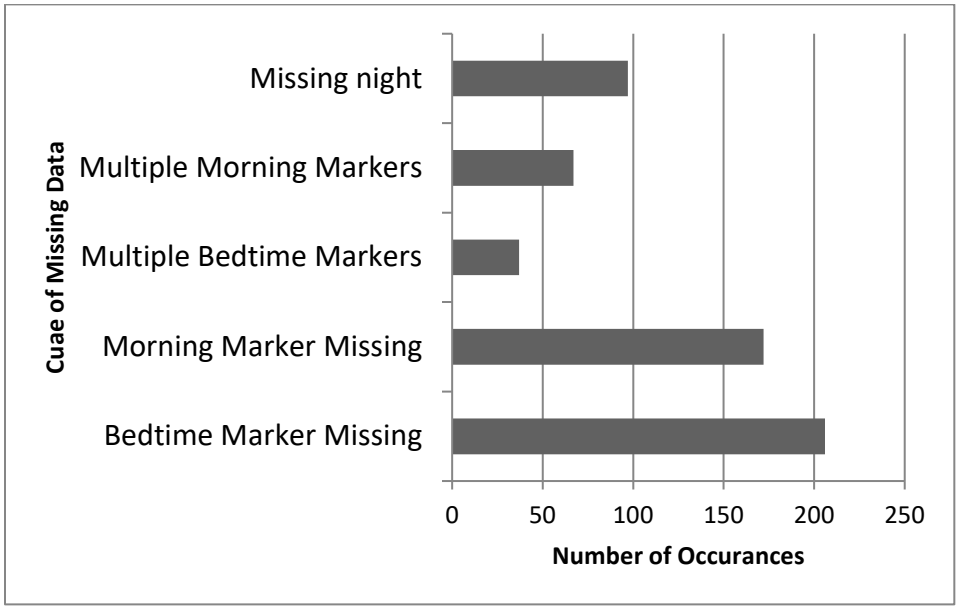

Figure 1. Actigraphy nights deemed unscorable due to various sources of missing data.

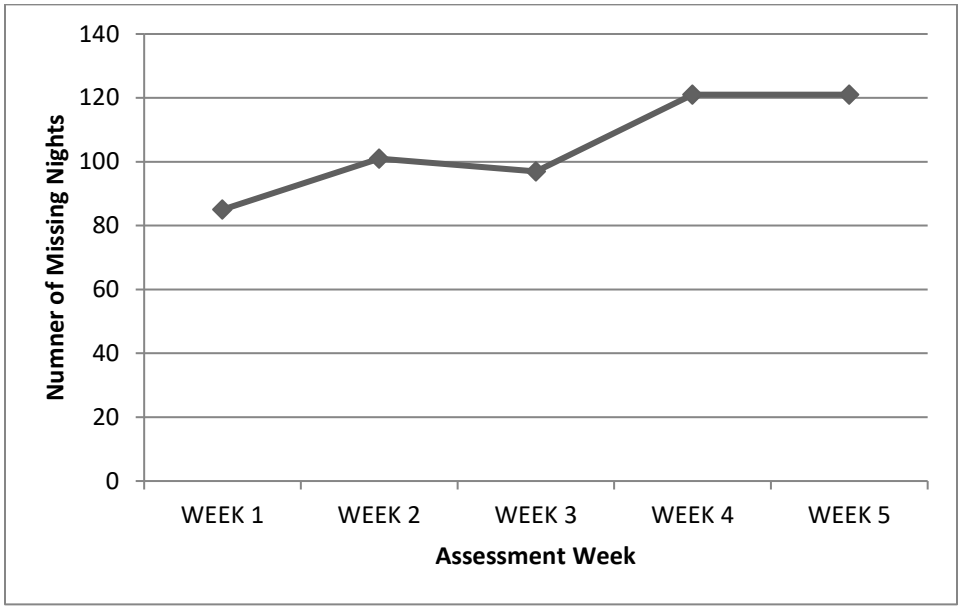

Figure 2. Trends in missing data rates over a five-week assessment period.