Actigraphy, Sleep Diaries and Polysomnography in College Students with Insomnia

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Fall 2007

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Abstract

Actigraphy (ACT), a wrist worn activity sensor, is an inexpensive and objective measure of sleep. Actigraphy use has been previously validated for older adults with insomnia in measuring the number of awakenings (NWAK), wake after sleep onset (WASO), total sleep time (TST), and sleep efficiency (SE). However, actigraphy has not been studied in the college population suffering from insomnia and has not been validated against ambulatory polysomnography (PSG).

Sleep diaries, PSG and ACT were obtained from 18 college students ($M = 19.47$) with chronic insomnia. ACT was significantly correlated with PSG on sleep onset latency (SOL) ($r = .759$), WASO ($r = .617$), SE ($r = .709$), and TST ($r = .985$). Absolute values were also equivalent for SOL, WASO, SE and TST. These results indicate that ACT may serve as a valid measure of general sleep variables in young adults with insomnia.
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It is necessary to obtain accurate data if we are to advance the science of sleep and the treatment of sleep disorders. Patient self-report of sleep can be inaccurate; therefore, it is generally necessary to use some sort of objective measure (Buysse, Ancoli-Israel, Edinger, Lichstein, & Morin, 2006). Polysomnography (PSG) is considered by most to be the gold standard of objective sleep measurement. The process, however, can be inconvenient, time-consuming and expensive. Actigraphy can provide a cheaper and less invasive measurement of sleep variables. Although partially validated in adults with and without insomnia, actigraphy has never been evaluated in college students. The current study fills this gap and also contributes to the overall body of literature concerning the use of actigraphy in people with insomnia.

The following have been suggested as a research diagnostic criteria for chronic insomnia: sleep-onset latency or wake time after sleep onset of more than 30 minutes, a frequency of at least 3 times a week, lasting for more than 6 months (Lichstein, Durrence, Taylor, Bush & Riedel, 2003). It is estimated that chronic insomnia affects approximately 10% of the adult population (Ohayon, 1997) and 17% of college students (Bramoweth, 2006). Aside from sleep impairments, insomnia has also been linked to daytime cognitive deficits and decreased quality of life (Riedel & Lichstein, 2000). Insomnia also may be a risk factor for mood, anxiety, and substance abuse disorders, and is most strongly linked as a risk factor for major depression (for a review, see Taylor, Lichstein, & Durrence, 2003).

When treating insomnia it is necessary to have an ongoing accurate assessment of sleep to assess effectiveness of the intervention and determine if changes in treatment protocol are necessary. Sleep diaries are used by clinicians and scientists as a standard means of gaining insight into the individual’s ongoing sleep behavior by asking them to record the events as they
occur. This use of ecological momentary assessment is relatively error free as long as the events are recorded as soon as they occur. However, if the patient is engaging in retrospection then there are possible problems with the use of sleep diaries alone. The errors could be the result of a number of problems including memory decay, memory replacement, or memory interference (Bolger, Davis, & Rafaeli, 2003). These effects are particularly likely if patients attempt to record a week’s worth of sleep diary data from memory in the few minutes in the waiting room before they meet with their clinician (Bolger, Davis, & Rafaeli).

The previously mentioned method of PSG involves recording electroencephalographic activity of the brain, electro-oculography and mental/submental electromyography using conductive electrodes on the skin. While PSG is an effective objective measure of sleep, it is generally not a good means of assessing sleep over the long term. No patient would be willing to undergo a PSG every night during the often weeks long treatment of insomnia.

Measurement with actigraphy utilizes a motion sensor called an “accelerometer” to measure the intensity and frequency of body movement. Devices are about the size of a wrist watch and are typically worn on the non-dominant wrist. It does not measure sleep directly as does PSG but instead assumes sleep based on the lack of body movement. The variables given by PSG are estimated from actiwatch data using sophisticated logarithms (Morgenthaler et al., 2007). Actigraphy may serve as a more appropriate means of measuring sleep over extended periods of time due to its minimally invasive nature and the relatively low cost. The minimally invasive nature would be particularly significant when collecting data among individuals with sleep problems.

The use of actigraphy in normal populations has been widely studied and has been validated as an effective measure of sleep variables. Previous studies have found that when
Actigraphy comparing actigraphy to PSG, the actigraphy is valid and reliable when measuring sleep in normal, healthy adult populations but becomes less reliable as sleep becomes more disturbed (Cole, Kripke, Gruen, et al., 1992; Jean-Louis, von Gizycki, Zizi et al., 1996; Kripke, Mullaney, Messin et al., 1978).

The issues concerning the validity of actigraphy in measuring sleep in patients with insomnia are due to long periods of motionlessness that are common among these individuals when trying to fall asleep (Ancoli-Israel, 2005). This can make the assessment of sleep variables particularly difficult. A number of studies have attempted to address these issues. These studies have provided somewhat mixed results but have supported the use of actigraphy in measuring total sleep time (TST) and/or sleep efficiency (SE) in people with insomnia (Hauri & Wisbey, 1992; Jean-Louis, Zizi, von Gizycki, & Hauri, 1999; Lichstein et al., 2006; Vallières & Morin, 2003). A study by Hauri and Wisbey compared PSG with actigraphy and sleep dairy on TST in 36 individuals with insomnia. This study concluded that actigraphy did provide an "a considerable improvement" over sleep diaries when measuring TST but overestimated the value by an average of 49 minutes. This position was challenged on methodological and statistical grounds (Chambers, 1994) but the conclusions were justified and reasserted by the authors (Hauri & Wisbey, 1994). The data from the study by Hauri and Wisbey was later reanalyzed using a new computer algorithm (Jean-Louis, Zizi, Von Gizycki, & Hauri). This reanalysis yielded an average error of 25 minutes and a correlation of 0.86 on TST between actigraphy and PSG. The study also found a significant correlation between the measures on SE. More recent research by Vallières and Morin found actigraphy to be more accurate than sleep diaries in predicting sleep variables in individuals with insomnia. The study included 17 individuals between the ages of 30 to 50 ($M = 41.6$), and compared the measures on TST, total wake time
Actigraphy recording provided close to a perfect correlation with PSG on TST and SE. Smaller but still significant correlations were found on TIB and TWT. There was no significant difference between actigraphy and PSG for absolute or relative discrepancies on any of the variables except SOL. The study by Lichstein et al. provided convincing support for the use of actigraphy in mature adults (predominantly over 40 years of age) for the measurement of the number of awakenings in a night (NWAK), wake time after sleep onset (WASO), TST and SE. The research to date suggests that actigraphy is likely a better predictor of global variables, such as SE and TST, than more specific variables such as SOL, WASO, and NWAK. The literature also suggests that actigraphy serves as a more accurate measure than sleep diaries but just how much more accurate remains to be seen.

These studies have dealt with the use of actigraphy in primarily older populations and it may be that insomnia in younger individuals manifests itself differently than insomnia in older populations that were previously studied. This necessitates the validation of the use of actigraphy in young adults suffering from insomnia. This population is known to have heightened levels of stress as well as highly irregular sleep schedules as compared to the general populous (Jensen, 2003). It has been reported that older adults with sleep problems tend to have greater difficulty maintaining sleep, while young adults tend to have greater difficulty in falling asleep (Giesecke, 1987). While it seems unlikely that these differences will have a significant impact on the validity of actigraphy, it is necessary to validate the measure for this population to be certain that no significant differences exist. The current study attempted to show that actigraphy will serve as an accurate measure with college students suffering from insomnia for TST and SE, and may be effective in measuring NWAK and WASO but will not be effective in measuring SOL, in congruence with previous studies of older adults.
Method

Participants

Participants were recruited from the general college population through undergraduate psychology courses, using flyers on campus and in the community. Eleven women and seven men, ranging in age from 18 to 23 ($M = 19.47$) participated in the study. Three participants were excluded from the study due to a lack of PSG or actigraphy data. One participant did not complete the experiment due to schedule conflicts making it unfeasible to complete the PSG study. The only inclusion criterion for this study was documentation of chronic insomnia (see definition below). Exclusion criteria included pregnancy, medical disorders or medications that might affect sleep patterns (including sleep medications), and psychotic or manic psychiatric disorders. This study was approved by the University of North Texas institutional review board.

Apparatus

Sleep Diaries. One night sleep diaries were obtained from all of the participants for the night of the PSG study. People with insomnia tend to consistently underestimate total sleep time and to overestimate sleep onset latency on nightly sleep diaries (Tang & Harvey, 2004a; Tang & Harvey, 2006). Despite this, correlations between PSG and sleep studies have been found to be relatively high ($r = .46-.59$) and this method of data collection is better than a single point retrospective estimate of sleep for a week to two week long period (Lichstein et al., 2006).

Actigraphy. Actigraphy data was obtained using AW64 Actiwatches produced by MiniMitter Company, Inc. and scored using the software provided by the manufacturer. This unit collects data on gross motor activity using an accelerometer. Sleep and wake patterns are determined by comparing activity counts for a given epoch of time (30 seconds in the current study) and the epochs surrounding that sample. A wake threshold value is determined by the
researcher and if the total activity value is less than or equal to the threshold then the epoch is scored as sleep. Actiwatch data was scored using a 20, 40, and 80 wake threshold value to determine which level would be most effective. These values are the minimum number of activity counts (as detected by the accelerometer) that are necessary for the epoch to be determined as wake. Sleep onset and sleep offset were determined using a five epoch sample and is the manufacturer prescribed setting. Data was visually inspected prior to entry and before analyses were run. The participants for whom there was significant missing data were excluded prior to analysis.

While actigraphy does not directly measure physiological sleep it does seem to provide a fairly reliable correlation to PSG. The reliability of actigraphy when compared to PSG varies somewhat ($r = .89 - .98$) among normal sleepers (Cole, Kripke, Gruen, et al., 1992; Jean-Louis, von Gizycki, Zizi, et al., 1996; Kripke, Mullaney, Messin et al., 1978). Reliability of the measurement among individuals with sleep disorders ranged from .78 to .88 (Ancoli-Israel, 2005). Given the obvious restriction of range, it is understandable that correlations are consistently smaller for sleep disordered populations than the normal population as a whole. The same is likely true for the accuracy of PSG in people with and without sleep disorders.

*Polysomnography (PSG).* Ambulatory polysomnographic recordings were obtained using Siesta wireless recording devices manufactured by Compumedics. PSG recordings were done using a standard montage of two electroencephalograph channels, two electroculagram channels, and two chin electromyogram channels. The montage also included channels for oxygen saturation, bilateral anterior tibialis electromyogram, thoracic and abdominal respiratory effort bands and nasal-oral thermistor. Recordings were scored for sleep stages, respiratory disruptions and limb movements using the standard criteria (Rechtschaffen & Kales, 1968) on ProFusion 2
software. PSG studies were scored by two lab assistants and then compared for concordance and discrepancies were corrected. To ensure synchronicity between actigraphy and PSG the two measures were housed on the same computer. Actigraphy was analyzed beginning at the initiation of the PSG recording and continued until awakening and cessation of PSG recording.

**Structured clinical interviews.** All patients who entered the study underwent two concurrent structured clinical interviews to ensure diagnostic integrity. To determine comorbidity with psychiatric disorders, patients completed the Structured Clinical Interview for the DSM-IV Axis I and Axis II disorders (SCID-I and SCID-II) (First, Spitzer, Gibbon & Williams, 1997; First, Gibbon, Spitzer, Williams & Benjamin, 1997). The Duke Structured Interview for Sleep Disorders was used as a sleep screening and diagnostic tool. The measure uses diagnostic criteria from the DSM-IV and ICSD-II.

**Procedure**

The participants were originally recruited to participate in a randomized clinical trial comparing cognitive-behavioral therapy of insomnia to wait-list-control in college students with insomnia. As part of this randomized clinical trial, all participants were asked to complete a polysomnographic study, while recording was also completed with actigraphy and sleep diaries. They were offered extra credit in psychology courses for their participation in the study along with monetary compensation.

Participants were asked to come to the psychology department where they signed an informed consent form and underwent a structured clinical interview to affirm the presence of insomnia and to assess for psychiatric disorders using the SCID-I, AUDIT, and the MPS. Participants were required to meet the established research diagnostic criteria for primary insomnia: a sleep-onset latency (SOL) or wakefulness after sleep onset (WASO) of more than 30
minutes, frequency of at least 3 times a week, and duration of at least 6 months (Lichstein, Durrence, Taylor, Bush & Riedel, 2003)

Following the initial structured clinical interview screening and the completion of informed consent forms, approved participants were asked to wear the actigraphy unit and complete one week of sleep diaries prior to the PSG study to validate sleep complaints. On the night of the PSG, participants came into the lab at approximately 8:00 PM and had PSG electrodes attached, which were then attached to a wireless home monitoring system. Participants were shown how to turn on the PSG unit and sent home to sleep, with the instructions to turn on the unit just before getting into bed and turn it off when they got out of bed in the morning, then return it to the sleep and health research lab. This was done in attempt to attain a more naturalistic observation of sleep compared to studies conducted in a hospital or laboratory. The participants simultaneously wore the actigraphy unit on their non-dominant wrist. They were also given a single night sleep diary (SD) to be filled out in the morning.

Results

Analysis Plan

The PSG served as the objective standard against which both a single night of actigraphy (ACT) and the single night of SD were compared. The three measures were compared on the sleep variables for sleep onset latency (SOL), number of awakening (NWAK), wake after sleep onset (WASO), total sleep time (TST), and sleep efficiency (SE). Following successful completion of this study, participants received treatment for insomnia in the form of cognitive behavioral therapy. Based on previous research, it was hypothesized that ACT would be significantly correlated with PSG on NWAK, WASO, TST, and SE but would not measure SOL effectively.
The three measurement tools were compared using a bivariate correlation yielding significance values as well as correlation values. This was done in an attempt to determine if separate measures covaried together significantly. Separate measures were also compared using one way repeated-measures analyses of variance (ANOVA) for each sleep variable: SOL, NWAK, WASO, TST, and SE, with post hoc pair-wise repeated measure comparisons between the individual measures. This was done to ensure that in addition to covarying together, that separate measures also gave equivalent measures of central tendency. Three levels of ACT sensitivity were analyzed: high, medium, and low sensitivity. These levels were based on the number of movement counts within an epoch of 30 seconds to determine wake: high or 80 counts, medium or 40 counts, and low or 20 counts. Preliminary analysis indicated that the high sensitivity level on actigraphy was most strongly correlated with the PSG data, therefore only this level will be reported.

**Correlations.** The data obtained showed that ACT was significantly correlated with PSG at the .01 level on SOL \( r = .759 \), WASO \( r = .617 \), SE \( r = .709 \), and TST \( r = .985 \). Sleep diaries were significantly correlated with PSG at the .05 level on SOL \( r = .566 \), NWAK \( r = .546 \), and TST \( r = .574 \).

**Mean Differences.** As can be seen in Table 1, the repeated measures ANOVA showed significant differences among the means for the three different measures on SOL, \( F(2, 15) = 11.19, p < .01 \), NWAK, \( F(2, 15) = 66.42, p < .01 \), and SE, \( F(2, 15) = 7.07, p < .01 \). Post hoc pair-wise repeated measure comparisons showed that for SOL there was a significant difference between SD and PSG, and between SD and ACT. For NWAK there were significant differences between SD and PSG, SD and ACT, and between ACT and PSG. For SE significant differences
were found between SD and PSG, and between SD and ACT. There were no significant differences between ACT and PSG on any sleep variable other than NWAK.

Discussion

As predicted, ACT was a more effective predictor than SD of TST and SE as measured by the gold standard of PSG. Results for the NWAK showed that the SD has a stronger correlation with PSG than the ACT, but the means for NWAK shows that the SD and PSG were still discrepant (2.17 vs. 6.2, respectively). There was also a trend for ACT to be more strongly correlated than the SD to PSG on WASO.

This data supports the use of actigraphy in measuring more global variables such as SE and TST and highlights some of the difficulties of measuring more specific variables such as NWAK and WASO. It should be noted that generally, middle of the night wake time (i.e., NWAK and WASO) is accounted for by SE (i.e., TIB/TST), which is accurately measured by ACT. Further, SE is often the target used to guide behavioral interventions of insomnia. Thus, actigraphy provides a reasonably good objective measure of sleep for use in both treatment and clinical research of individuals in young adults with insomnia. When assessing broad variables such as TST and SE there is a greater margin of error afforded to the measurement devices and in such cases actigraphy proves to be quite effective.

The low correlations between ACT and PSG on the number of awakenings highlight one of the downfalls to this system of measurement. While actigraphy is significantly more effective at detecting the wake time, it seems to partition these wake periods, which are likely continuous episodes, into separate events, thus exaggerating the total number of awakenings. Potential problems may arise when a clinician is trying to assess whether awakenings are more transient or whether the individual awakens once and simply lies relatively motionless but is still awake.
Another difficulty arises in determining whether wake time should be added to SOL or WASO when very shortly after falling asleep. If the individual is asleep for one and a half or more minutes this may be designated sleep onset but if they awaken after this one and a half minute period, then the sleep is left in a gray area for designation.

The correlation results should be interpreted with caution, since studying people with insomnia restricts the range of the variables measured. This restricted range is analogous to the use of a general intelligence test in measuring “genius” individuals. Significant correlations between the scores might be lost since the pattern of correlation might only be noticeable when compared with a full range of scores. The same scenario holds true for these results. It is possible that relationships that are currently non-significant would be significant if compared to a general sample.

Based on what was learned in this study it is recommended that sleep diaries be used to accompany actigraphy when more accurate sleep data is desired. Thus, the clinician will be able to confirm bedtimes and events as they occur throughout the day and night. With some actigraphy devices it is possible to have the patient use the event markers to designate in and out of bedtimes. However, patients are prone to overuse, accidental use, and none-use of event markers so scoring actigraphy based solely on event markers should be avoided. Easily quantifiable variables like in and out of bedtime are generally reported accurately as long as they are reported within a short period of time after the event. Scoring the actigraphy based on these numbers should not be problematic. Despite this there is still the risk of inaccurate reporting.

This study looked only at a comparison of sleep diaries, actigraphy, and PSG over a single night and, as a result, the potential effects of retrospective error in the reporting of the data should be minimized. This data represents the ideal, where the patient only self reports for a
single night and returns the data the next day. It would be optimal if the patient would do the
same for the entire week of data prior to their next clinical visit. However, this may not always
be the case. Based on literature concerning the errors in retrospective reporting the quality of the
data obtained would only degrade from the data obtained in the current study as the likelihood of
retrospective error increases (Bolger, Davis, & Rafaeli, 2003). Future research will compare the
effectiveness of sleep diaries and actigraphy over a longer period to determine to what degree the
quality of the data does degrade as time progresses. The sample in the study was exclusively
younger individuals and thus the ability to generalize to the general population is uncertain.
References


Table 1

Means (M), Standard Deviations (SD), and significance of sleep onset latency (SOL), wake after sleep onset (WASO), number of awakenings (NWAK), total sleep time (TST), and sleep efficiency (SE). Differences between polysomnography (PSG), Actigraphy (ACT), and Sleep Dairies (SD).

<table>
<thead>
<tr>
<th>Variable</th>
<th>PSG M (SD)</th>
<th>ACT M (SD)</th>
<th>SD M (SD)</th>
<th>PSG v ACT F</th>
<th>p</th>
<th>( \eta^2 )</th>
<th>PSG v SD F</th>
<th>p</th>
<th>( \eta^2 )</th>
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<tr>
<td>SOL</td>
<td>30.93 (20.39)</td>
<td>38.87 (23.26)</td>
<td>71.83 (50.38)</td>
<td>3.98</td>
<td>.066</td>
<td>.22</td>
<td>15.16</td>
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<td>.50</td>
</tr>
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<td>WASO</td>
<td>31.03 (22.42)</td>
<td>27.67 (19.91)</td>
<td>33.80 (27.94)</td>
<td>.48</td>
<td>.49</td>
<td>.03</td>
<td>.12</td>
<td>.72</td>
<td>.008</td>
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<td>NWAK</td>
<td>6.20 (3.00)</td>
<td>27.53 (11.48)</td>
<td>2.17 (1.33)</td>
<td>56.84</td>
<td>&lt; .001</td>
<td>.80</td>
<td>40.54</td>
<td>&lt; .001</td>
<td>.73</td>
</tr>
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<td>TST</td>
<td>402.20 (112.20)</td>
<td>407.57 (109.42)</td>
<td>364.83 (94.77)</td>
<td>1.11</td>
<td>.30</td>
<td>.07</td>
<td>1.92</td>
<td>.18</td>
<td>.11</td>
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<td>SE</td>
<td>83.13 (6.43)</td>
<td>84.78 (5.75)</td>
<td>75.43 (11.05)</td>
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