Measuring Treatment Outcomes in Comorbid Insomnia and Fibromyalgia: Concordance of Subjective and Objective Assessments

Jennifer M. Mundt, MS; Earl C. Crew, MS; Kendra Krietsch, MS; Alicia J. Roth, MA; Karlyn Vatthauer, MS; Michael E. Robinson, PhD; Roland Staud, MD; Richard B. Berry, MD; Christina S. McCrae, PhD

1Clinical and Health Psychology, University of Florida, Gainesville, FL; 2Rheumatology and Clinical Immunology, University of Florida, Gainesville, FL; 3Pulmonary, Critical Care and Sleep Medicine, University of Florida, Gainesville, FL; 4Health Psychology, University of Missouri, Columbia, MO

Study Objectives: In insomnia, actigraphy tends to underestimate wake time compared to diaries and PSG. When chronic pain co-occurs with insomnia, sleep may be more fragmented, including more movement and arousals. However, individuals may not be consciously aware of these arousals. We examined the baseline concordance of diaries, actigraphy, and PSG as well as the ability of each assessment method to detect changes in sleep following cognitive behavioral therapy for insomnia (CBT-I).

Methods: Adults with insomnia and fibromyalgia (n = 113) were randomized to CBT-I, CBT for pain, or waitlist control. At baseline and posttreatment, participants completed one night of PSG and two weeks of diaries/actigraphy.

Results: At baseline, objective measures estimated lower SOL, higher TST, and higher SE than diaries (ps < 0.05). Compared to PSG, actigraphic estimates were higher for SOL and lower for WASO (ps < 0.05). Repeated measures ANOVAs were conducted for the CBT-I group (n = 15), and significant method by time interactions indicated that the assessment methods differed in their sensitivity to detect treatment-related changes. PSG values did not change significantly for any sleep parameters. However, diaries showed improvements in SOL, WASO, and SE, and actigraphy also detected the WASO and SE improvements (ps < 0.05).

Conclusions: Actigraphy was generally more concordant with PSG than with diaries, which are the recommended assessment for diagnosing insomnia. However, actigraphy showed greater sensitivity to treatment-related changes than PSG: PSG failed to detect any improvements, but actigraphy demonstrated changes in WASO and SE, which were also found with diaries. In comorbid insomnia/fibromyalgia, actigraphy may therefore have utility in measuring treatment outcomes.

Keywords: insomnia, fibromyalgia, chronic pain, assessment, actigraphy, polysomnography, cognitive behavioral therapy, clinical trial


INTRODUCTION

Chronic insomnia is a primarily subjective disorder that is defined by self-reported difficulty falling asleep, staying asleep, awakening too early, or experiencing sleep that is routinely non-restorative and accompanied by at least one of many possible daytime impairments (e.g., mood disturbance, daytime sleepiness, fatigue or malaise). The high prevalence of chronic insomnia among patients with chronic pain has been well-established, with reported rates of insomnia as high as 88% in this population. Independently, sleep and pain are known to be associated with a host of negative consequences including decreased quality of life, mood disturbance, impaired quality of social interactions, dependence on medication, and cognitive dysfunction. However, these consequences are often exacerbated in chronic pain patients with comorbid insomnia. In light of these findings, an understanding of effective measurement of sleep in the context of comorbid chronic pain and insomnia warrants consideration in order to effectively assess and treat impairments associated with both conditions.

In research settings, insomnia is typically evaluated using several methods, including objective (polysomnography [PSG], actigraphy) and subjective (sleep diaries) measurements. During nighttime sleep. Despite their ubiquity in research, it is generally considered that objective methods of sleep measurement are less sensitive and specific than self-reports for identifying insomnia. Because insomnia is defined by the presence of subjective complaints, daily sleep diaries are the primary measurement tool used to diagnose insomnia and evaluate treatment effects in research and clinical contexts. Although...
American Academy of Sleep Medicine guidelines recommend that individuals' perceptions of insomnia symptoms be relied upon for a diagnosis, objectively derived data nonetheless have utility for understanding other aspects of sleep, and researchers routinely collect both types of data. Additionally, objective measures of insomnia are important in light of recent evidence that negative health outcome are most strongly linked to the subtype of insomnia with objective short sleep duration. Because PSG monitoring is relatively expensive and cumbersome for participants and therefore difficult to utilize over an extended measurement period—even when it is conducted as an ambulatory procedure—more economical measurements of objective sleep have been developed that provide comparable sensitivity and specificity to PSG.

Among these technologies, wrist actigraphy has emerged as an alternative to PSG that reliably measures sleep and wake parameters. Modern actigraphs can record for long durations before requiring battery replacement or data download and are recommended for conducting several days or weeks of continuous monitoring. Actigraphic estimates of total sleep time (TST) correlate well with PSG in normal sleep populations, with agreement coefficients ranging from 0.72 to 0.97. However, in individuals with chronic insomnia, the discrepancies between PSG and actigraphy estimates of TST are typically greater, with agreement coefficients for TST ranging between 0.70 and 0.88. This is partially attributed to the tendency of actigraphy to underestimate sleep onset latency (SOL) and wake time after sleep onset (WASO) relative to diaries of individuals with insomnia, who may lie in bed motionless for extended periods of time while attempting to fall asleep.

Due to these measurement concerns, actigraphy is only recommended by the American Academy of Sleep Medicine as an optional screening measure for clinical evaluation of chronic insomnia and is recommended as a guideline measure for research on sleep-related treatment outcomes. This is based on the evidence that actigraphy is able to detect treatment response in patients with chronic insomnia following pharmacological and cognitive behavioral interventions. However, these prior treatment studies examined chronic insomnia in individuals without comorbid medical conditions, and it is therefore unknown whether the sensitivity of actigraphy to detect treatment response also generalizes to comorbid populations.

Given that 50% of all patients with chronic insomnia suffer from comorbid chronic pain, validation of actigraphy as a convenient, less-invasive, and more ecologically valid objective measure of sleep-related treatment outcomes within this clinical population is warranted. More than half of all patients with fibromyalgia—a condition characterized by widespread musculoskeletal pain, poor sleep, fatigue, somatic complaints, and cognitive symptoms—have comorbid insomnia. Nearly all report some level of sleep disturbance. Studies of sleep in fibromyalgia patients have routinely employed actigraphy as a measure of sleep and activity (see examples), and these patients represent an ideal population of chronic pain patients in which to assess the sensitivity of actigraphy monitoring to detect treatment effects.

While some studies have not found that the presence of chronic pain changes sleep characteristics among individuals with insomnia (e.g., Tang et al.), there is evidence that sleep disturbance in chronic pain patients may present differently than in individuals with primary insomnia. PSG studies on patients with rheumatic conditions have indicated that their sleep is highly fragmented with increased arousals and periodic leg movements, lower sleep efficiency (SE), and more frequent shifting between stages of sleep relative to individuals without chronic pain. Studies have also demonstrated that these patients experience increased NREM sleep alpha-rhythm intrusions during slow wave sleep as assessed via electroencephalography (EEG). These intrusive patterns of increased alpha-EEG activity have also been associated with more frequent microarousals from sleep, which have the potential to result in increased movement relative to poor sleepers without chronic pain. These findings, in conjunction with objective investigations on sleep in chronic pain patients, indicate that patients with chronic pain may generally experience greater sleep fragmentation, movement, and time spent awake at night. These differences in sleep characteristics may in turn result in differential levels of concordance among sleep measures.

Despite the need to validate actigraphy, there have been no published studies examining the concordance of actigraphy relative to both PSG and sleep diaries in the assessment of insomnia comorbid with chronic pain. Furthermore, it remains to be established whether actigraphy can detect sleep-related treatment response following cognitive behavioral therapy for insomnia (CBT-I) in this population. Therefore, we aimed to (a) evaluate the baseline concordance of wrist actigraphy relative to diaries and ambulatory PSG and (b) investigate whether treatment effects were detected by all three assessment methods. Our analyses were in part modeled after those described by Vallières and Morin, who evaluated the sensitivity of actigraphy as an outcome measure in the treatment of chronic insomnia.

Given that the presentation of insomnia in individuals with comorbid chronic pain may be characterized by greater movement during the night relative to individuals with insomnia and no comorbid pain, we anticipated that estimates of SOL, WASO, TST, and SE would be comparable between actigraphy and PSG. Moreover, actigraphy and PSG were expected to show equivalent sensitivity to treatment-related changes (reduced WASO and SOL, increased TST and SE). Given that chronic pain patients may not consciously perceive pain-related microarousals during the night as wakefulness, we predicted that actigraphy would overestimate WASO, equivalently estimate SOL, and underestimate TST and SE compared to sleep diaries. Accordingly, we expected actigraphy to be less sensitive than sleep diaries to treatment response on these parameters.

**Methods**

**Participants**

This analysis used data from a clinical trial (NCT02001077) investigating the efficacy of CBT-I and CBT-P (cognitive behavioral therapy for pain) for comorbid fibromyalgia and insomnia. Individuals were recruited from the community and...
were eligible to participate if they reported suffering from fibromyalgia for ≥ 6 months. The presence of fibromyalgia was confirmed by tender point testing, using guidelines established by the American College of Rheumatology (with application of 4 kg force, participants reported pain in ≥ 11 of 18 points, including points in all 4 body quadrants). The presence of insomnia was determined based on standard research and diagnostic criteria: (a) individual reported insomnia (sleep onset or awake time during night > 30 min) ≥ 3 nights per week for > 6 months; (b) sleep diary confirmed insomnia (sleep onset or awake time during night > 30 min) ≥ 6 nights during 2-week baseline period; and (c) daytime dysfunction due to insomnia (mood, cognitive, social or occupational impairment). Pre-
scription and over-the-counter sleep medications were allowed provided the participant had been stabilized on the medication for ≥ 6 months. Pain medications were also allowed regardless of duration or frequency of use.

Individuals were excluded from participation in the parent study for the following reasons: (a) sleep disorder other than insomnia, specifically sleep apnea (apnea-hypopnea index > 15/h or between 10–15/h with oxygen saturation < 88%) or periodic limb movement disorder (PLMS > 15/h); (b) bipolar disorder or seizure disorder (due to potential risk of sleep restriction treatment); (c) significant medical (e.g., cancer) or neurological disorder (e.g., dementia); (d) severe untreated psychopathology (e.g., schizophrenia, substance abuse); (e) cognitive impairment based on Mini-Mental State Examination score < 26; and (f) concurrent participation in other nonpharmacological sleep treatment.

The final sample for the present analysis included the 113 participants who completed the baseline assessment and were randomized to a treatment condition (individual CBT-I = 39, individual CBT-P = 37, waitlist control = 37). Participants were predominantly female (97%), with an average age of 52.7 years (SD 10.9). Further descriptive data of the sample are shown in Table 1.

**Procedures**

All study procedures were approved by the University of Florida Institutional Review Board. Informed consent was obtained from all participants. Participants completed an initial baseline assessment, 8 weeks of treatment, posttreatment assessment, and 6-month follow-up assessment. Assessment periods lasted 2 weeks and included the following: tender point testing, questionnaires, single night ambulatory PSG, 2 weeks of actigraphy, and 2 weeks of sleep diaries.

**Sleep Diaries**

Participants were instructed to complete a daily sleep diary for 2 weeks at each assessment point.

**Actigraphy**

Participants wore an actigraph, the Actiwatch 2 (Phillips Respironics, Bend, OR), on their nondominant wrist 24 h/day for the 2 weeks coincident to completing the sleep diaries. The Actiwatch 2 records data on gross motor activity using a solid-state, piezo-electric accelerometer. The accelerometer continuously measures the intensity and frequency of wrist movement at a sampling rate of 32 cycles per second. The sum of all wrist movements in a 30-sec interval is recorded as an activity count. The activity counts are downloaded onto a computer and analyzed using Actiware Sleep Analysis Software v.5.3.2 which classifies each 30-sec epoch as a sleep or wake state using validated algorithms. The high sensitivity setting in the Actiware software was used. Initial bedtime and final wake time from sleep diaries were used to establish the period for scoring.

**Ambulatory PSG**

A single night of in-home PSG was conducted at the beginning of each assessment period using a 25-channel AURA Portable Recording System (Grass Technologies). Consistent with ambulatory PSG recommendations, monitoring consisted of 10 EEG measures (F2, C2, O2, ground, reference, M1, M2), 2 electro-oculography (EOG), and 3 chin electromyography (EMG) according to standard placements. Other standardized PSG monitoring included respiratory inductance plethysmography (thoracic and abdominal effort), oximeter (pulse and oxygen saturation), electrocardiogram (ECG), and right and left anterior tibialis EMG, oral-nasal airflow thermocouple, and nasal cannula pressure transducer. Studies were scored by a registered polysomnographic technologist who was blinded to treatment condition assignment. Our PSG scoring procedures were based on those described by the Sleep Heart Health Study.33

---

**Table 1**—Sample demographic characteristics (n = 113).

<table>
<thead>
<tr>
<th>Demographic Variables</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years, mean (SD)</td>
<td>52.68 (10.91)</td>
</tr>
<tr>
<td>Female (%)</td>
<td>97.3</td>
</tr>
<tr>
<td>Race (%)</td>
<td></td>
</tr>
<tr>
<td>Caucasian</td>
<td>79.6</td>
</tr>
<tr>
<td>African-American</td>
<td>17.7</td>
</tr>
<tr>
<td>AI/AN</td>
<td>1.8</td>
</tr>
<tr>
<td>More than one</td>
<td>0.9</td>
</tr>
<tr>
<td>Ethnicity (%)</td>
<td></td>
</tr>
<tr>
<td>Latino</td>
<td>7.8</td>
</tr>
<tr>
<td>Education level (%)</td>
<td></td>
</tr>
<tr>
<td>No high school</td>
<td>1.8</td>
</tr>
<tr>
<td>High school</td>
<td>21.2</td>
</tr>
<tr>
<td>Some college</td>
<td>21.2</td>
</tr>
<tr>
<td>Associate’s</td>
<td>22.1</td>
</tr>
<tr>
<td>Bachelor’s</td>
<td>13.3</td>
</tr>
<tr>
<td>Master’s</td>
<td>5.3</td>
</tr>
<tr>
<td>Doctoral</td>
<td>15.0</td>
</tr>
<tr>
<td>Employed (%)</td>
<td>37.2</td>
</tr>
<tr>
<td>Marital status (%)</td>
<td></td>
</tr>
<tr>
<td>Married</td>
<td>43.4</td>
</tr>
<tr>
<td>Single</td>
<td>25.7</td>
</tr>
<tr>
<td>Divorced</td>
<td>22.1</td>
</tr>
<tr>
<td>Widowed</td>
<td>5.3</td>
</tr>
<tr>
<td>Separated</td>
<td>2.7</td>
</tr>
<tr>
<td>Cohabitng</td>
<td>0.9</td>
</tr>
</tbody>
</table>

AI/AN, American Indian/Alaskan Native.
RESULTS

Sleep Variables

The three assessment methods each provided the following sleep variables: time in bed (TIB), TST, SOL, WASO, and SE. Vallières and Morin included total wake time (TWT) because their actigraphy software did not compute WASO. However, we chose to examine WASO instead of TWT because though TWT overlaps with SOL, WASO provides unique information about sleep fragmentation during the night after initial sleep onset.

Data Analysis Plan

In order to compare values obtained for the 3 sleep measurement methods, we used data gathered from all methods on a single night during the baseline period of the study. Although diary and actigraphy data were collected for 2 weeks, PSG was conducted on only one night. Although PSG was conducted at the beginning of the assessment period for most participants, this was not always possible. For the present analyses, we limited our sample to individuals who completed PSG on day one of the assessment period, to coincide with the beginning of diaries/actigraphy.

To assess the concordance of the three assessment methods at baseline, we conducted repeated measures analyses of variance (ANOVAs) with method as a within-subjects factor. A separate ANOVA was conducted for each of the 5 sleep parameters listed above. Significant omnibus tests were examined with simple contrasts in order to determine which pairs of methods differed significantly from one another. Next, we conducted Pearson product-moment correlations between the 3 methods as another way of assessing concordance. Finally, we examined each method’s sensitivity to detect change by conducting repeated-measures ANOVAs with 2 within-subject effects (2 times, 3 methods). We limited this analysis to the CBT-I group only in order to illuminate the utility of each method for evaluating outcomes of a treatment with demonstrated efficacy in improving sleep.

Discrepancies between Methods

Baseline means for each sleep variable as measured by diaries, actigraphy, and polysomnography are listed in Table 2 and depicted in Figure 1. The omnibus test for differences among the methods was significant (p < 0.05, full results in Table 3). Means sharing a superscript are significantly different from one another (p ≤ 0.05). TIB, time in bed; TST, total sleep time; SOL, sleep onset latency; WASO, wake time after sleep onset; SE, sleep efficiency; SD, standard deviation.

Table 2—Baseline means by assessment method.

<table>
<thead>
<tr>
<th>Assessment Method</th>
<th>Diary</th>
<th>Actigraphy</th>
<th>Polysomnography</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIB</td>
<td>507.22</td>
<td>504.89</td>
<td>484.95</td>
</tr>
<tr>
<td>TST*</td>
<td>361.52</td>
<td>400.39</td>
<td>380.83</td>
</tr>
<tr>
<td>SOL*</td>
<td>65.22</td>
<td>46.93</td>
<td>25.73</td>
</tr>
<tr>
<td>WASO*</td>
<td>58.64</td>
<td>45.77</td>
<td>78.54</td>
</tr>
<tr>
<td>SE*</td>
<td>71.84</td>
<td>79.46</td>
<td>78.57</td>
</tr>
</tbody>
</table>

With the exception of sleep efficiency (%), all numbers are given in minutes. *Omnibus test for repeated measures ANOVA was significant (p < 0.05, full results in Table 3). Means sharing a superscript are significantly different from one another (p ≤ 0.05). TIB, time in bed; TST, total sleep time; SOL, sleep onset latency; WASO, wake time after sleep onset; SE, sleep efficiency; SD, standard deviation.

Figure 1—Baseline means for sleep variables as measured by sleep diaries, actigraphy, and polysomnography.
recorded significantly higher SOL but significantly lower TST and SE (ps < 0.05). The comparisons diverged for WASO, however, with diary estimates being higher than actigraphy (p = 0.05) and lower than PSG (p < 0.01). Complete results of the ANOVAs for each sleep variable are given in Table 3.

**Correlations between Methods**
Pearson product-moment correlation analyses revealed significant, positive correlations among all 3 methods for TIB, TST, WASO, and SE (rs = 0.26–0.66, ps < 0.01; see Table 4). For SOL, diaries correlated with actigraphy (r = 0.27, p < 0.01) and PSG (r = 0.41, p < 0.01), but the relationship between actigraphy and PSG was not significant (r = 0.08, p = 0.45).

**Sensitivity of the Three Methods to Treatment Effects**
Repeated-measures ANOVAs with two within-subject effects (2 times, 3 methods) were performed using data from only the CBT-I group (n = 15), as explained above. Mauchly’s
tests indicated that the assumption of sphericity was met for all variables, \( p > 0.05 \). Means and standard deviations for sleep variables as measured with sleep diary, actigraphy, and PSG at baseline and posttreatment are presented in Table 5. A comparison of the sleep and pain outcomes of all randomized groups will be the subject of a forthcoming paper on the main outcomes of the study. For the present analyses, we were interested only in examining the time by method interactions within the CBT-I group in order to determine if treatment effects on sleep parameters were detected by all measurement methods.

There were no significant main effects of time or method for TIB, nor was there a significant time by method interaction.

### Evidence for Treatment Effect Varying by Method

For WASO, there was only a main effect of time such that, across all measurement methods, WASO decreased from baseline to posttreatment, \( F_{1,14} = 8.03, p = 0.01, \eta^2_p = 0.37 \). Although the method by time interaction was not significant, inspection of pairwise comparisons (Bonferroni correction applied here and in all subsequent instances) found that only actigraphy (\( p = 0.001 \)) showed a significant change from baseline to posttreatment, while the change captured by diaries approached significance (\( p = 0.06 \)). The change in PSG failed to reach statistical significance (\( p = 0.20 \)). **Figure 2A** depicts the baseline and posttreatment WASO values for each method.

Significant method by time interactions emerged for TST, SOL, and SE, indicating differential sensitivity of the methods to treatment-related changes in these outcomes. In the case of TST, there was a significant method by time interaction, \( F_{2,28} = 6.96, p = 0.004, \eta^2_p = 0.33 \), but no main effects of either method or time. Pairwise comparisons demonstrated that the difference in TST as measured by diary and PSG approached statistical significance at baseline (\( p = 0.07 \)) but was no longer significant at posttreatment (\( p = 1.00 \)). This interaction is seen clearly in **Figure 2B**, which shows the comparatively large increase in diary TST relative to other methods.

The ANOVA for SOL (**Figure 2C**) found significant main effects of measurement method, \( F_{2,28} = 4.34, p = 0.02, \eta^2_p = 0.24 \), and time of measurement, \( F_{1,14} = 12.73, p = 0.003, \eta^2_p = 0.48 \), as well as a significant method by time interaction, \( F_{2,28} = 4.50, p = 0.02, \eta^2_p = 0.24 \). Post hoc comparisons for the main effect of method indicated that—across both time points—diary values for SOL were significantly higher than those obtained through PSG (\( p = 0.01 \)). Pairwise comparisons for the interaction showed that at baseline, diary values differed significantly from PSG (\( p = 0.03 \) and actigraphy (\( p = 0.04 \)), but this difference was not maintained at posttreatment (\( p > 0.50 \)). Accordingly, pairwise comparisons demonstrated that diaries registered a larger and statistically significant change over time (\( p = 0.001 \)), while the changes measured by actigraphy (\( p = 0.31 \)) and PSG were not significant (\( p = 0.24 \)).

For SE, there was a significant main effect of time, \( F_{1,14} = 13.81, p = 0.002, \eta^2_p = 0.50 \), and a significant method by time interaction, \( F_{2,28} = 4.31, p = 0.02, \eta^2_p = 0.24 \) (see **Figure 2D**). As was the case with TST, pairwise comparisons demonstrated that diary values approached being significantly different from PSG values at baseline (\( p = 0.06 \)) but not at posttreatment (\( p = 1.00 \)). Comparisons also showed that SE as measured by actigraphy (\( p = 0.02 \)) and diary (\( p = 0.001 \)) increased significantly over the course of treatment, while PSG did not (\( p = 0.16 \)).

### DISCUSSION

The present study evaluated discrepancies between commonly used sleep assessment methods—sleep diaries, actigraphy, and

---

**Table 5**—Diary, actigraphy, and polysomnography data for CBT-I group before and after treatment (n = 15).

<table>
<thead>
<tr>
<th></th>
<th>Diary</th>
<th>Actigraphy</th>
<th>Polysomnography</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td><strong>TIB</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>494.60</td>
<td>54.55</td>
<td>494.60</td>
</tr>
<tr>
<td>Posttreatment</td>
<td>472.93</td>
<td>97.00</td>
<td>452.20</td>
</tr>
<tr>
<td><strong>TST</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>370.27</td>
<td>91.44</td>
<td>413.80</td>
</tr>
<tr>
<td>Posttreatment</td>
<td>409.40</td>
<td>89.11</td>
<td>396.00</td>
</tr>
<tr>
<td><strong>SOL</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>52.67</td>
<td>37.36</td>
<td>23.50</td>
</tr>
<tr>
<td>Posttreatment</td>
<td>20.53</td>
<td>10.07</td>
<td>17.90</td>
</tr>
<tr>
<td><strong>WASO</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>55.33</td>
<td>46.70</td>
<td>47.07</td>
</tr>
<tr>
<td>Posttreatment</td>
<td>32.87</td>
<td>33.80</td>
<td>31.97</td>
</tr>
<tr>
<td><strong>SE (%)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>74.70</td>
<td>15.27</td>
<td>83.62</td>
</tr>
<tr>
<td>Posttreatment</td>
<td>86.67</td>
<td>8.69</td>
<td>87.72</td>
</tr>
</tbody>
</table>

With the exception of sleep efficiency, all numbers are given in minutes. TIB, time in bed; TST, total sleep time; SOL, sleep onset latency; WASO, wake time after sleep onset; SE, sleep efficiency; SD, standard deviation.
ambulatory PSG—among a sample of patients with comorbid insomnia and fibromyalgia. This investigation highlights the utility of subjective and objective data collection when measuring sleep in persons with fibromyalgia.

**Baseline Concordance of Methods**

As expected, the three methods produced estimates of sleep that were significantly related to one another. Across sleep parameters, the methods provided estimates that were generally moderately correlated with one another ($r_s = 0.26–0.66$, $p < 0.01$), with the exception of a nonsignificant correlation between PSG and actigraphy estimates of SOL. Despite this overall pattern of similarity among methods, repeated measures ANOVAs revealed differences, particularly with regard to the assessment of wake time (i.e., SOL and WASO). These measures of wake time are involved in the derivation of TST and SE, and on both of those parameters, participants’ subjective reports were significantly lower than the values obtained with objective assessment methods.

**Comparison to Non-fibromyalgia Samples**

Similar to Vallières and Morin, we found higher concordance between objective methods than between diaries and objective methods. As in previous studies of insomnia, we found that diaries provided the lowest estimates of TST. Our findings indicate that, dependent on the sleep measure, diaries did not uniformly over- or under-report wake compared to objective measures. Similar to prior research, we found that diaries underestimated WASO compared to PSG. Also in keeping with prior studies, diaries provided higher estimates of SOL than both actigraphy and PSG. However, whereas Vallières and Morin replicated the common finding that actigraphy underestimates SOL compared to PSG, we found the opposite pattern. This difference would seem to indicate that, among individuals with insomnia, those with fibromyalgia have more movement at sleep onset. However, in comparing our results to those of prior studies, it should be noted that it is unclear whether those studies excluded individuals who reported chronic pain. Given the high prevalence of chronic pain in the general population,
it is likely that these prior studies included some individuals with chronic pain unless it was an explicit exclusion criterion.

Regardless of the specific population under study, there seems to be a pattern of objective-subjective discrepancies in individuals with insomnia. For insomnia in general, a number of possible factors have been proposed to account for this difference, including misperception of sleep as wake, worry, brief awakenings, and alpha-delta sleep. These explanations likely also apply to individuals with comorbid fibromyalgia, in whom patterns of frequent NREM alpha intrusions and greater sleep fragmentation have been noted.

**Sensitivity to Treatment Effects**

Similar to Vallières and Morin, we observed decreases in unwanted wake time and increases in SE across all devices in response to treatment. However, we did not replicate a time main effect for TST in our study sample. Instead, we found a method by time interaction, with diaries showing an increase, actigraphy showing a reduction, and PSG remaining stable. There were also significant method by time interactions for SOL and SE, indicating differences in the degree to which diaries, actigraphy, and PSG detected treatment-related changes in these parameters. Post hoc analyses indicated, intriguingly, that although diaries were significantly different from objective measures (particularly PSG) at baseline, these differences were nonsignificant by posttreatment due to larger improvement in diary outcomes relative to other methods. Over the course of treatment, PSG values did not change significantly for any sleep parameter. However, diaries showed significant improvements for SOL, WASO, and SE, and actigraphy detected improvement in WASO and SE. Thus, while improvements from treatment were unlikely to be evident in PSG, diaries and—to a slightly lesser degree—actigraphy both appeared capable of detecting changes in key sleep outcomes. This pattern of changes indicates that CBT-I was most successful in altering subjective perceptions of sleep, thereby diminishing the difference between subjective and objective measures.

The narrowing of the gap between subjective and objective measurements of wake time may reflect the use of the techniques learned during the course of CBT-I. Participants randomized to CBT-I engaged in therapy targeting their reactivity to sleep fragmentation (e.g., using cognitive techniques and relaxation strategies), thereby minimizing the impact of nighttime awakenings. It is possible that the larger changes seen on sleep diaries compared to objective measures following treatment is a result of altered perceptions of the impact of insomnia, which in this case could be considered a positive treatment gain.

Few investigations of interventions for individuals with chronic pain have employed actigraphy to measure sleep, and none have assessed the degree to which actigraphy—compared to diaries and PSG—is able to detect sleep improvements in this comorbid population. We are aware of one study that used both diaries and actigraphy as outcome measures. In that small pilot study of a hybrid sleep/pain intervention, diaries detected improvements in all sleep parameters, whereas actigraphy captured gains only in TIB, SOL, and WASO, but failed to show improvement in either TST or SE. Similarly, in our study, actigraphy data supported some (WASO, SE), but not all (SOL), of the improvements detected by diaries.

**Limitations and Future Directions**

The results of this study should be interpreted with several limitations in mind. The conclusions drawn from this research may not generalize to other chronic pain populations, and future research should examine individuals who have insomnia comorbid with other conditions. Additionally, the sample was primarily female, potentially limiting its applicability to males with fibromyalgia. Furthermore, study participants were recruited from the community to participate in a clinical trial at an academic medical center, and it is unknown whether data obtained from a clinically referred sample would yield comparable results.

**Conclusions**

In companion with prior research, the results of this study indicate that—in both insomnia and comorbid insomnia and fibromyalgia—discrepancies between measures are greatest when comparing sleep diaries with PSG. Our analyses suggest that the concordance of sleep assessment methods differs across sleep variables in a pattern that is largely similar in individuals with and without fibromyalgia, with the exception of actigraphic estimates of SOL. Although actigraphy typically underestimates SOL in individuals with insomnia, we found that actigraphic estimates exceeded PSG estimates of SOL in our sample of individuals with comorbid fibromyalgia.

Improvements in sleep over the course of treatment were not uniformly reflected by these different assessment methods. Sleep diaries captured the greatest improvements in all parameters, though actigraphy also detected improvements in several key outcomes. The differential sensitivity to detecting change in sleep parameters may reflect increased movement at sleep onset in this population as well as the ability of CBT-I to modify the subjective experience of poor sleep. These findings suggest that future investigations of sleep in individuals with fibromyalgia should consider utilizing multiple measurement approaches, as each provides unique contributions to the understanding of this population. From a patient perspective, subjective improvements in sleep are vital to determining the success of an insomnia intervention, and this study demonstrates that subjective perceptions are the outcome most likely to improve with CBT-I. However, it also demonstrates that, in terms of objective measures, actigraphy is more likely than PSG to detect treatment-related changes.

**Abbreviations**

ANOVA, analysis of variance
CBT-I, cognitive behavioral therapy for insomnia
CBT-P, cognitive behavioral therapy for pain
EEG, electroencephalography
NREM, non-rapid eye movement
PSG, polysomnography
SE, sleep efficiency
SOL, sleep onset latency
TIB, time in bed
TST, total sleep time
TWT, total wake time
WASO, wake after sleep onset

REFERENCES


ACKNOWLEDGMENTS
The authors thank and acknowledge the efforts of the study coordinator, Christine Towler; study therapists Ryan Anderson, Daniela Roditi, and Jacob Williams; the registered polysomnographic technologist, Susan Purdy; and the undergraduate research assistants in the UF Sleep Research Lab.

SUBMISSION & CORRESPONDENCE INFORMATION
Submitted for publication March, 2015
Submitted in final revised form July, 2015
Accepted for publication August, 2015
Address correspondence to: Christina S. McCrae, PhD, University of Missouri, One Hospital Drive, DC116.88, Columbia, MO 65212; Tel: (573) 882-1561; Fax: (573) 884-1889; Email: mccraec@health.missouri.edu

DISCLOSURE STATEMENT
This was not an industry supported study. This research was supported by a grant from the National Institute of Arthritis and Musculoskeletal and Skin Diseases (R01AR055160; Christina McCrae, PI; Michael Robinson, Co-PI). Dr. Staud has received research support from Pfizer. The other authors have indicated no financial conflicts of interest. Work was performed at the University of Florida, Gainesville, FL.