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A Pilot Study of Shoulder Placement for Actigraphy in Children

Karen W. Adkins, Suzanne E. Goldman, Diane Fawkes, and Kyla Surdyka

Sleep Disorders Division Department of Neurology Vanderbilt University School of Medicine

Lily Wang and Yanna Song

Department of Biostatistics Vanderbilt University School of Medicine

Beth A. Malow

Sleep Disorders Division Department of Neurology Vanderbilt University School of Medicine

Abstract

Children with neurodevelopmental disorders may have difficulty tolerating devices that monitor sleep, presenting challenges in measuring sleep disturbances in this population. Although wrist actigraphy has advantages over polysomnography, some children remain unable to tolerate wrist placement. This study piloted an alternative site for actigraphy in 8 children with autism, ages 6–10 years. Results are presented from the 2 locations (custom pocket shoulder location and wrist location) using Bland–Altman limits of agreement and other statistical measures to compare sleep onset latency, total sleep time, sleep efficiency, and wake after sleep onset. The use of an alternative actigraphy site for children with autism, who have difficulty tolerating actigraphy placement, appears promising and worthy of further study.

Pediatric sleep disturbances are a major parental concern, especially in children with neurodevelopmental disorders. For example, the prevalence of sleep disturbance in children with autism spectrum disorder (ASD) is approximately 40% to 80% of children compared to 9% to 50% in typically developing (TD) children, with insomnia being the most common parental concern (Couturier et al., 2005; Krakowiak, Goodlin-Jones, Hertz-Picciotto, Croen, & Hansen, 2008; Richdale & Schreck, 2009; Souders et al., 2009).

Behavioral and pharmacologic interventions are greatly needed to treat these sleep concerns (Mindell et al., 2006; Morgenthaler et al., 2007). However, measuring the success of these interventions requires the development of tools that are low cost, wireless, home based, noninvasive, and easily tolerated by children. Although polysomnography (PSG) has been the “gold standard” to measure sleep patterns and their response to treatment, children with neurodevelopmental disorders may not tolerate the PSG and the laboratory environment in which it is performed. Furthermore, repeated nights of PSG during an intervention may not be feasible or cost-effective.

Actigraphy, widely used in sleep research and clinical practice, is an objective and reliable method that measures sleep patterns by differentiating sleep from wake states (Ancoli-Israel et al., 2003; Sadeh & Acebo, 2002) based on the detection of movement and rest. Actigraphy devices are small, computerized, wristwatch-like devices that contain accelerometers which detect movement. Actigraphy and PSG have been validated in the literature (Kushida et al., 2001; Lichstein et al., 2006). In prior work, we showed comparability between actigraphy and PSG in children with ASD (Goldman et al., 2009).

Others have used actigraphy to measure sleep–wake patterns in autism and attention deficit hyperactivity disorders (ADHD) (Goodlin-Jones, Tang, Liu, & Anders, 2008; Gruber, Sadeh, & Raviv, 2000; Wiggs & Stores, 2004). Actigraphy has also been used to document improvement in sleep onset latency in clinical trials of melatonin in these disorders (Gruber et al., 2000; Paavonen, Nieminen-von Wendt, Vanhala, Aronen, & von Wendt, 2003).

Although actigraphy is well tolerated in most children, those with neurodevelopmental disorders may not tolerate the device when placed on the wrist. In our studies of sleep and ASD, 26 of 102 participants between the ages of 3 and 10 years (25%) were unable to tolerate the actigraphy device on the wrist (unpublished data). When the actigraphy device is placed on the wrist, data are recorded as sleep or wake based on movement of the wrist. Shoulder stability is required for wrist mobility as they move in the same plane of motion. For this reason, we selected the shoulder placement as an alternative site for children who are unable to tolerate wrist placement of the device. We hypothesized that our children had adapted to the use of a shirtsleeve as part of their daily living skills and would tolerate the shoulder placement with greater ease than wrist placement. To increase data collection in children with ASD participating in our sleep intervention studies, we piloted the use of the shoulder location for the actigraphy device.

METHOD

Participants

This actigraphy comparison study was approved by the Vanderbilt University institutional review board. All children, ages 6 to 10 years, met the criteria for the clinical diagnosis of ASD, based on a clinical interview that incorporated the Diagnostic and Statistical Manual of Mental Disorders (4th ed., text rev.; American Psychiatric Association, 2000), with confirmation by the Autism Diagnostic Observation Schedule (Lord et al., 2000). Seven of the eight children had a history of sleep disturbances, and had participated in a pilot trial of supplemental melatonin. One child participated in an observational study of sleep, which was conducted at Vanderbilt University, and had no reported history of sleep problems. None of the children had difficulty wearing a wrist actigraph on their non-dominant wrist during their prior research study. Each of these 7 children continued on their melatonin dose after study completion, and parents reported no further difficulty falling asleep. None of these children had a history of epileptic seizures, and all were screened to exclude comorbidities that affect sleep.

After completion of these studies, parents gave consent for their children, and their children gave assent, to participate in the actigraphy comparison study, which involved wearing the devices simultaneously in two locations. The two locations were the (a) non-dominant wrist location (with an adjustable wristband), which had been used in the pilot study; and the (b) non-dominant shoulder location (with the wristband removed). For the shoulder location, the device was inserted into a custom pocket. The pocket was sewn into a snug-fitting short-sleeved shirt, just below the shirt's shoulder seam. The pocket was sewn onto each shirt by the study investigator to assure uniform placement and fit for each child's needs.

Inclusion criteria for the actigraphy comparison study required that children tolerated the wrist actigraphy placement during the pilot trial. In addition, the study required that parents successfully completed a daily sleep diary form during the pilot trial. This form documented the times the interval button was activated for “lights out” each night (e.g., when the child first attempted to fall asleep). The rationale for including only children who could tolerate the wrist device and whose parents were able to complete the diary form was to ensure successful data collection in this study.

Data Collection

All children wore the AW-64 Actiwatch device (Phillips Respironics, Bend, OR). Each device contains an accelerometer, which is able to detect motion > 0.01 G-force in all directions, and translates it into an electrical signal. This information is subsequently stored in memory within the devices as actigraphy counts. Actigraphy counts express the largest of all measured accelerations over a predefined measurement epoch. Both devices were configured using a 1-min epoch with medium threshold for 7 consecutive days, and the validated MiniMitter software (Phillips Respironics, 2010) algorithm was used to estimate sleep parameters, based on thresholds for wake and sleep, as described in prior work (Kushida et al., 2001; Lichstein et al., 2006; Mezick et al., 2009).

The parents were oriented to the two collection methods in a face-to-face training session using verbal and written instructions, and hands-on demonstration with both procedures. The parents were asked to activate the interval button on both device methods at lights out and again the following morning when the child arose from sleep for the day. Parents recorded these activation times on sleep diary forms on each day of actigraphy data collection. The interval button was used to score actigraphy data with reference to the parent diary to confirm accuracy. At the end of the 7 consecutive days of data collection, devices and sleep diary forms were returned to investigators for centralized scoring of collected data.

Data Analysis

Data from the actigraphs were downloaded to a personal computer where all sleep intervals were manually placed on the actogram for visual representation of the actigraphy data. The sleep measures of total sleep time, sleep onset latency, sleep efficiency, and wake after sleep onset were calculated based on the recommendations of Buysse, Ancoli-Israel, Edinger, Lichstein, and Morin (2006). Total sleep time was defined as actual time slept, which is the sum of all sleep epochs, measured in minutes, within the interval between the time set on the actogram for nighttime sleep and morning wake time. Sleep-onset latency was defined as the number of minutes it took the child to fall asleep when the parent turned the lights out and expected the child to fall asleep. This time was documented by the parent using the device event marker and the sleep diary. Sleep efficiency was defined as the percentage of total sleep time/time in bed. Wake after sleep onset was defined as the total time the child was awake during the night after the sleep-onset latency was excluded. Wake after sleep onset was measured as the sum of all wake epochs during the sleep period. The participants in our study got out of bed for the day upon awakening, and this time was designated by the parent pushing the event marker and documenting this same information onto the sleep diary form. Wake after sleep onset did not include wake time in bed before the final arising, and we did not encounter terminal wakefulness.

For each child, the 7 nights of actigraphy data for the wrist and shoulder placements were averaged separately. This approach was chosen as it reflects what is done in clinical practice. We also performed a random effects model that uses all nightly measurements from each child, and obtained similar results (data not shown). In the following, wrist and shoulder values refer to the average of measurements over 7 nights. Linear associations between wrist and shoulder values were assessed using Spearman correlation coefficients, and the mean differences of wrist and shoulder were tested (for departure from 0) using the Wilcoxon signed rank test. These nonparametric tests were used due to the small sample size. Although correlation analysis in the comparison of two methods is useful in demonstrating the strength of their relationship, it does not necessarily demonstrate concordance or describe how concordance varies with the absolute values of the parameters (DeSouza et al., 2003). Signed rank tests are useful in assessing the significant mean difference in two measures, although limited in that the absence of a significant difference in

two measures does not demonstrate their concordance. To assess the agreement between the wrist and shoulder measurements, the method of Bland–Altman was used (Bland & Altman, 1986). This method plots the differences of 2 sets of measurements (e.g., shoulder subtracted from wrist in this study) against their averages, and also shows the limits of agreement, or the mean difference with 2 *SDs* above and below the mean. Data were analyzed using the statistical software *R* (see <http://www.r-project.org/>).

RESULTS

Participants

Eight children (7 boys and 1 girl; mean age = 8.3 ± 1.1 years) were enrolled in the study, and all completed 7 days of data collection, with scorable data for both the wrist and shoulder placement on all nights. All children tolerated both placements well, and there were no nights with missing data. Medications were not changed during the week of collection (see Table 1).

Actigraphy Data

Table 2 presents actigraphy values, including Spearman correlations (*r*) for wrist and shoulder values by individual participants. The highest correlations were observed for sleep-onset latency (0.67–1.00), total sleep time (0.79–0.98), and sleep efficiency (0.79–0.98); and the lowest correlations were observed for wake after sleep onset (0.19–0.93). Table 2 presents summary statistics that include signed rank tests; sleep onset latency showed the most consistency between the two placements, and wake after sleep onset showed the least consistency. The Bland–Altman limits of agreement for the wrist and shoulder measurements are presented in Figure 1. The wrist and shoulder measurements agreed well for sleep onset latency, with limits of agreement (corresponding to a 95% confidence interval for the mean difference) being within ± 4 min. For total sleep time, the differences (wrist value – shoulder value) ranged from –100 min to 50 min; for efficiency, the differences ranged from –17 to 8 percentage points; and for wake after sleep onset, the differences ranged from –16 to 41 min, except for one outlier. We observed no apparent systematic bias for sleep onset latency and total sleep time, meaning that there was no relation between the values for these parameters (low vs. high) and the differences. For the other sleep parameters, the differences between wrist and shoulder values (i.e., wrist value – shoulder value) tended to increase for higher sleep parameter values. In other words, the wrist and shoulder values agreed better when values of these sleep parameters were smaller.

DISCUSSION

In this pilot comparison study, we demonstrated in our sample of eight children with ASD between the ages of 6 and 10 years that shoulder placement for actigraphy was feasible and well tolerated. In considering all of our analyses together (Bland–Altman, Spearman correlations, and signed rank tests), sleep onset latency was the parameter that showed the highest agreement between the two placements. Sleep onset latency and total sleep time did not show systemic bias in contrast to sleep efficiency and wake after sleep onset in which agreement was best at lower values of sleep efficiency and lower values of wake after sleep onset. Although we acknowledge the limitations of our work and that our findings need to be interpreted conservatively, we believe that this alternative placement shows promise for measuring sleep parameters (particularly sleep latency and total sleep time) in children who are unable to tolerate wrist actigraphy placement. Future studies should (a) obtain simultaneous wrist and shoulder data in larger samples and (b) compare the shoulder placement's performance to wrist actigraphy in measuring variability of sleep parameters over time and response to interventions.

Sensory sensitivities are commonly reported in ASD, and a recent meta-analysis emphasized the contributions of autism diagnosis and age (6–9 years) to the presence of sensory modulation symptoms (Ben-Sasson et al., 2009). We identified the need for alternate placement of the actigraphy device, as 25% of the children in our prior research were unable to tolerate wrist placement. The contributing factors that cause this intolerance bear further study. We are also continuing to examine predictors of tolerance, including obtaining standardized measures such as the Sensory Profile (Dunn, 1999).

Some of the strengths of our work are our well-defined sample of children with a rigorous diagnosis of ASD, who had previously participated in studies of actigraphy and sleep. The parental familiarity for completing a daily sleep diary and the child's familiarity with the use of the actigraphy device in the prior studies contributed to our complete data collection during this comparison study. Limitations of our work are a small sample size and that our population was limited to ASD. However, we believe that our results are generalizable to other neurodevelopmental disorders, as well as to the TD pediatric population. As a result of this work, we have begun using the shoulder placement in children with ASD, who have not tolerated the wrist placement, and each has tolerated the shoulder placement with scorable data for all nights worn. We also included children with a range of ages (6–10 years), which introduced heterogeneity in developmental stages. However, all of these children were school-aged and had similar bedtime-waketime schedules due to school activities.

In prior work, an alternative placement for actigraphy devices was piloted (using the MicroMini-Motionlogger actigraph [AMA-32; Ambulatory Monitoring, Inc., Ardsley, NY]) in a TD cohort (Souders et al., 2009). The investigators placed the devices in a pajama sleeve pocket, and reported no statistically significant differences between the two placements (pocket and wrist) for similar parameters to those reported in this study (e.g., sleep onset latency, total sleep time, and sleep efficiency). Our work expands their observation to children with ASD, uses a different commercially available device, and compares the two device placements using the Bland–Altman method for limits of agreement across a spectrum of values for these parameters. One limitation is that the ASD children in our sample did not exhibit tactile sensitivity. It will be important to study this alternate placement in those with tactile sensitivities, who may have different motility patterns. In addition, it may be worthwhile to validate the alternative placement against PSG in this population, although one of the challenges of doing this will be that PSG may not be tolerated in children with tactile sensitivities. It will be important to demonstrate, however, that the alternative placement measures show change in response to an intervention.

Actigraphy has potential as an objective measure of sleep patterns in children with neurodevelopmental disorders, as well as the TD population, given its ease of measurement in the home setting. Our methodology provides baseline data to demonstrate the validation of an alternate method for actigraphy data collection in a sample of 8 children with ASD. Further actigraphy-based studies should focus on validation of this method in children with tactile sensitivities across a range of neurodevelopmental disorders. Results of this methodology from these larger and more heterogeneous studies can be better generalized to the overall population of ASD and other disorders of neurodevelopment.

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FIGURE 1.

Bland–Altman agreement plots for sleep parameters. *Note.* The Bland–Altman agreement plots (see Bland & Altman, 1986) are illustrated for the two placements—wrist and shoulder—which measure the parameters of sleep onset latency, total sleep time, sleep efficiency, and wake after sleep onset across the measured range (average of wrist and shoulder values). Perfect agreement between the two placements is indicated by a mean of zero (wrist – shoulder; y axis). Positive values indicate that the wrist value is higher than the shoulder value, and negative values indicate that the wrist value is lower than the shoulder value.

TABLE 1

Participant Characteristics

Participant	Age (in Years)	Gender	DSM-IV-TR Diagnosis	Medications Affecting Sleep
1	6	Male	Autistic disorder	Melatonin
2	9	Female	Autistic disorder	Melatonin; amphetamine-dextroamphetamine
3	9	Male	Asperger's disorder	Melatonin
4	6	Male	PDD-NOS	Melatonin
5	8	Male	Autistic disorder	Melatonin
6	10	Male	Autistic disorder	Melatonin
7	7	Male	Asperger's disorder	Melatonin
8	7	Male	PDD-NOS	None

Note. *DSM-IV-TR* = *Diagnostic and Statistical Manual of Mental Disorders* (4th ed., text rev.; American Psychiatric Association, 2000); PDD-NOS = pervasive developmental disorder—not otherwise specified.

TABLE 2

Mean (Standard Deviation) Actigraphy Values and Daily Correlations

Participant	Sleep Onset Latency (in Minutes)			Total Sleep Time (in Minutes)			Sleep Efficiency (%)			Wake After Sleep Onset (in Minutes)		
	Shoulder	Wrist	r	Shoulder	Wrist	r	Shoulder	Wrist	r	Shoulder	Wrist	r
1	31.3 ± 9.1	32.0 ± 8.2	0.93	465.9 ± 47.3	421.6 ± 29.9	0.79	85.4 ± 4.7	77.4 ± 4.5	0.55	21.0 ± 14.2	62.3 ± 14.6	0.19
2	17.9 ± 6.0	19.4 ± 8.1	0.95	516.7 ± 39.1	472.0 ± 35.0	0.98	88.8 ± 4.5	81.2 ± 4.2	0.81	26.7 ± 11.3	67.1 ± 14.1	0.88
3	11.1 ± 8.6	13.0 ± 7.7	0.67	438.6 ± 57.2	468.7 ± 58.4	0.90	82.9 ± 6.1	88.6 ± 4.3	0.81	49.0 ± 17.1	32.6 ± 12.0	0.57
4	58.1 ± 46.9	54.1 ± 46.7	0.95	435.3 ± 63.5	402.1 ± 52.4	0.98	71.3 ± 8.0	65.9 ± 5.8	0.98	37.9 ± 10.5	63.3 ± 17.9	0.83
5	23.7 ± 11.9	23.9 ± 11.7	1.00	430.4 ± 35.0	415.1 ± 33.9	0.98	83.1 ± 7.9	80.3 ± 7.8	0.95	26.9 ± 10.1	41.7 ± 13.0	0.56
6	18.7 ± 13.0	19.7 ± 13.1	0.98	520.0 ± 30.1	493.9 ± 30.4	0.98	85.7 ± 4.9	81.4 ± 4.9	0.95	47.9 ± 21.7	73.1 ± 19.8	0.93
7	9.1 ± 6.4	10.0 ± 6.2	0.88	463.4 ± 46.9	365.6 ± 35.9	0.86	78.3 ± 7.2	61.9 ± 6.6	0.76	75.2 ± 33.5	172.3 ± 48.8	0.90
8	16.7 ± 15.0	15.1 ± 15.6	0.86	478.0 ± 28.1	491.1 ± 29.8	0.88	88.5 ± 3.1	90.9 ± 3.5	0.88	36.1 ± 9.5	22.3 ± 7.8	0.66
All	23.3 ± 15.7	23.4 ± 14.2 ^a		468.5 ± 35.0	441.3 ± 46.7 ^b		83.0 ± 5.8	78.5 ± 10.1 ^c		40.1 ± 17.4	66.8 ± 46.3 ^d	

^aDifference in sleep onset latency (wrist vs. shoulder), $p = .58$ (signed rank test).^bDifference in total sleep time (wrist vs. shoulder), $p = .07$ (signed rank test).^cDifference in sleep efficiency (wrist vs. shoulder), $p = .09$ (signed rank test).^dDifference in wake after sleep onset (wrist vs. shoulder), $p = .05$ (signed rank test).