Toddler Behavior Following Polysomnography: Effects of Unintended Sleep Disturbance

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Study Objectives: Childhood sleep disorders are consistently shown to affect behavior and cognition, but first-night effects on these measures are generally unknown. We sought to examine how sleep in the home versus the laboratory differed among healthy toddlers and how such differences relate to standardized scores on assessments the morning following polysomnography.

Design, Setting, and Participants: Twenty healthy 14-month-olds wore actigraphs during nighttime sleep at home for 5 nights preceding and during standard overnight laboratory polysomnography. The Bayley Scales of Infant Development (BSID-II) were administered once the morning after polysomnography.

Measurements and Results: All subjects had normal polysomnography. Sleep-start times at home and during polysomnography did not differ, whereas, during polysomnography, subjects awoke earlier (p = .008, d = .58), their total sleep time (p < .001, d = 1.1) and sleep efficiency (p = .004, d = .57) were reduced, and they had shorter sleep-bout lengths (p = .004, d = .03), less immobility (p = .003, d = .62), and greater average activity during sleep (p < .001, d = .98). Standardized assessments were not affected by differences between home and polysomnography night sleep, but children with greater emotional regulation difficulty had a lower percentage of immobility (r = -0.67, p = .001) and increased sleep fragmentation (r = -0.60, p = .005) during polysomnography.

Conclusions: Although sleep-onset times were preserved, sleep in the laboratory was disrupted, compared with at home. These differences did not affect standardized scores, but the magnitude of the difference was associated with worse emotional regulation. The effects of sleep disturbance during polysomnography, or the influence of poor emotional regulation on sleep in the laboratory, should be considered in studies of young children.

Keywords: Actigraphy, pediatric, sleep deprivation, polysomnography, behavior, MDI, PDI, emotional regulation

Citation: Montgomery-Downs HE; Gozal D. Toddler behavior following polysomnography: effects of unintended sleep disturbance. SLEEP 2006;29(10):1282-1287.

INTRODUCTION

The cumulative evidence of deleterious effects from sleep-disordered breathing (SDB) during early childhood is substantial and compelling. Impairments in cognition and school performance associated with pediatric SDB have been shown repeatedly.4-6 Furthermore, pediatric SDB leads to greater utilization of healthcare resources,7 more-frequent dose-dependent cardiovascular morbidity,8 reversible failure to thrive,9 and comorbid chronic illnesses,10 as well as more psychiatric and behavioral comorbidities.4,5,11-13 Evidence from animal models5,11 and interventional studies16-19 suggest that treatment leads to at least partial reversibility of these morbidities, highlighting the importance of early detection.

In addition to SDB, “primary snoring” is increasingly recognized as not just innocent noise during sleep but, rather, a condition that may lead to reduced daytime functioning.20,21 Compared with nonsnoring controls, 5- to 8-year-old children who snore but have an obstructive apnea-hypopnea index of less than 1 per hour of total sleep time (TST) show impaired verbal and global IQ and

Disclosure Statement
This was not an industry supported study. Dr. Montgomery-Downs has participated in speaking engagements supported by Mini Mitter/Respironics. Dr. Gozal has indicated no financial conflict of interest.

Submitted for publication March 24, 2006
Accepted for publication July 31, 2006
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SLEEP, Vol. 29, No. 10, 2006

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University of Louisville.

Subjects wore an actigraph for each of 5 consecutive nights at home immediately preceding their scheduled polysomnogram and during 1 night in the sleep laboratory during polysomnography. The Bayley Scales of Infant Development (version II—BSID-II) were administered once the morning after the polysomnography night. A diagram of the study design is shown in Figure 1.

**Actigraphy**

Actigraphs that digitally record gross motor activity using highly sensitive accelerometry have proven useful for assessing sleep-wake cycles, sleep quality and maintenance, insomnia, and locomotor activity levels in children with sleep disturbances. For the present study, subjects wore an ankle actigraph (Activwatch AW-64, Mini Mitter, Inc., Bend, OR) during nighttime sleep in the home for the 5 nights preceding the polysomnography night and during polysomnography in the sleep laboratory. Parents were instructed to place the actigraph around their child’s ankle during the bedtime routine and to remove it after the final awakening in the morning. Parents maintained a sleep diary during home-recording nights, which was used to corroborate the actigraphy data. Nights when the actigraph was off the subject, or applied after sleep onset, were excluded from analyses. The 5 home nights were averaged and compared with the polysomnography night. Thus, the average actigraphy measures in the home were compared with the actigraphy measures in the sleep laboratory.

Standard analysis parameter settings were used. Actigraphs were set to record at 15-second epoch lengths. The wake threshold selection method was set to medium, with wake threshold value set to 40.00. The sleep-interval detection algorithm used immobile minutes, of which 10 minutes (5 epochs) were required for sleep onset and end. Using these analyses parameters, the following measures were derived from actigraphy signal: Sleep Start—the first epoch of sleep that was sustained for 5 minutes or longer; Sleep End—the last epoch of the final sleep bout preceding removal of the actigraph by the parent in the home or by the research staff in the laboratory; TST—the number of minutes spent in sleep between Sleep Start and Sleep End; Sleep Efficiency—the TST divided by the number of minutes from Sleep Start to Sleep End multiplied by 100; Sleep Bouts—the total number of blocks that were 1 or more epochs in length scored as sleep between Sleep Start and Sleep End; Mean Sleep Bout Time—the TST divided by the number of Sleep Bouts; Immobile Minutes—the total number of minutes, between Sleep Start and Sleep End, during which there was sufficient valid physical activity to be scored as nonsleep but during which the subject was not active; Immobile Percentage—the number of minutes during which the subject was immobile, divided by the time from Sleep Start to Sleep End, multiplied by 100; Activity in Sleep—the total number of epochs of nonwake mobility during Sleep Bouts; Mean Activity in Sleep—the Activity in Sleep divided by the number of Sleep Bouts; and Fragmentation Index—the sum of the Activity in Sleep and Immobile Minutes divided by the TST.

**Polysomnography and Scoring**

With the parent present in the same room as the child, overnight polysomnography was performed on the research unit of the Kosair Children’s Hospital Sleep Medicine and Apnea Center using commercially available computerized multichannel data-acquisition equipment (MedCare Diagnostics, Amsterdam, The Netherlands), including 4 channels of electroencephalography (O1/O2, C3/C4), chin electromyography, bilateral electrooculography, snore sensor, electrocardiogram, chest and abdominal inductance plethysmography, pulse oximetry and waveform, and thermistor-derived oronasal airflow. Simultaneous video monitoring was digitally recorded.

Sleep-stage scoring was performed using standard criteria. Time spent in sleep stages was calculated and expressed as a percentage of the TST. Central apneas were scored based on cessation of oronasal flow and chest wall and abdominal movement; obstructive apnea was scored in the absence of oronasal airflow with continued chest wall and abdominal movement; decreases in oronasal flow of 50% or more with continued effort were scored as hypopneas. A minimum duration of 2 breath lengths and an associated desaturation in the Spo2 of at least a 4% and/or an arousal was required to score obstructive apneas and hypopneas. Snoring was scored in the presence of a change in basal snore-sensor levels that was verified by the technologist via both in-room checks and microphone transmission. Cardiorespiratory variables were scored as indexes based on the number of events per hour of TST. The Spo2 nadir was calculated from valid Spo2 during sleep, with values during movement artifact excluded using automated identification and user validation.

Because criteria for arousals have not yet been established for children, arousals were defined as recommended by the American Sleep Disorders Association Task Force report and manually scored as spontaneous or respiratory related (occurring immediately subsequent to an apnea, hypopnea, oxyhemoglobin desaturation, or snore). Arousals and respiratory events were scored as indexes based on occurrence per hour of TST. Scoring of all respiratory events and oxyhemoglobin desaturations were initially automated and then visually verified.

Records were scored by a single blinded analyst. No study was performed on a night when a child had an acute illness such as fever or nasal discharge.

**Developmental Assessment**

The BSID-II was administered the morning following polysomnography by a tester blinded to the results of the polysomnography night. The BSID-II consists of the Mental Scale (MDI), a Motor Scale (PDI), and a Behavior Rating Scale that were originally standardized in the United States under the auspices of the National Institutes of Health in children from 1 to 42 months of age and renominated in 1993. The MDI is an assessment of sensory-perceptual acuity, discriminations, and response abilities, which tests acquisition of object constancy, as well as memory, learning, and problem-solving.
abilities. Vocalizations and the beginnings of verbal communication are measured as early evidence of the ability to form generalizations and classifications, which are a basis of abstract thinking. The PDI measures fine and gross motor skills relating to reaching, quality of movement, functional hand skills, and sensory integration.

The MDI and PDI are each expressed as a standard score ranging from 50 to 150 and encompassing 3 standard deviations (15 points) on either side of the mean (100 points). Higher scores indicate better performance. When administered at the same age, there is a correlation between the MDI and the Stanford-Binet IQ test. The MDI at 12 and 18 months is correlated with IQ at 2.5 and 3 years, and at 24 months, the MDI is correlated with IQ at 3 and 5 years.

The behavior rating scale consists of 30 child behaviors rated by the test administrator on a 4-point scale; the behaviors are scored as percentiles based on norms for children older than 6 months and 3 years, 34 and, at 24 months, the MDI is correlated with IQ at 3 and 5 years.

Statistical Analyses

Descriptive statistics were calculated. Repeated-measures analysis of variance was used for comparisons between home- and polysomnography-night actigraphy measures. The Cohen d was calculated to determine effect sizes. z Scores were calculated for the differences between home- and polysomnography-night actigraphy measures (home-night value minus polysomnography-night value). Regression analysis was used to examine the relationship between z scores for the differences between home- and polysomnography-night actigraphy measures in relation to BSID-II measures. Data were analyzed using SPSS version 13.0 (SPSS, Inc., Chicago, IL) and, due to the small number of subjects, a p value less than .01 was considered significant.

RESULTS

Twenty-two subjects were recruited for participation in the study and completed the protocol. Data from 2 subjects were dropped from analysis because the subjects’ sleep-wake schedules in the home were highly irregular; 1 subject had an average sleep onset of 01:32 AM and rise time of 13:04 PM; the other had an average sleep onset time of 12:51 AM and rise time of 07:58 AM. Data from the remaining 20 subjects were available for analyses.

Table 1—Demographics and Family Characteristics of the 20 Subjects

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, mo</td>
<td>14.5 ± .48 (13.7-15.9)</td>
</tr>
<tr>
<td>Females, %</td>
<td>40</td>
</tr>
<tr>
<td>White, %</td>
<td>85</td>
</tr>
<tr>
<td>Birth weight, lb</td>
<td>7.7 ± .92</td>
</tr>
<tr>
<td>Gestational age, wk at birth</td>
<td>38.4 ± 1.8</td>
</tr>
<tr>
<td>Primipara, %</td>
<td>40</td>
</tr>
<tr>
<td>Maternal age, y</td>
<td>30.5 ± 5.1</td>
</tr>
<tr>
<td>Maternal education, y</td>
<td>16.1 ± 2.9</td>
</tr>
</tbody>
</table>

Data are presented as mean ± SD or percentages; age includes range in parentheses.

aNon-White: Hispanic (5%), biracial (10%)
regulation when tested on the morning following polysomnography. Differences scores and standard deviations are in Table 3.

**DISCUSSION**

This study shows that, even when sleep-onset times are preserved during laboratory-based polysomnography, measures of children’s sleep are highly disrupted, as compared with during their sleep at home. These differences did not affect standardized development indexes (MDI and PDI) administered the morning following polysomnography but were associated with behavioral difficulty. In contrast, there were no significant relationships between sleep in the home and BSID-II indexes or behavior scales following polysomnography, indicating that the behavior difficulty was due to sleep on the polysomnography night rather than poor sleep in general. Indeed, the data indicate that, the larger the differences in sleep fragmentation and percentage of immobility between the home night and polysomnography night, the worse the percentile scores on emotional regulation.

Interestingly, difference scores for TST and sleep efficiency were unrelated to behavior, suggesting that altered or interrupted sleep architecture, rather than sleep deprivation per se, increases behavioral changes the following morning. It is remarkable that a single night of sleep disturbance induced by sleep in a laboratory setting was associated with behavior ratings. However, it is also possible that the children with greater emotional-regulation difficulties may have been more vulnerable to having their sleep disturbed by the novel sleep-lab environment and multiple polysomnography sensors.

Before we discuss the potential implications of our findings, some technical issues deserve comment. First, it is important to note that this was strictly a research study using a community sample and that the polysomnography protocol was arranged to accommodate each subject’s normal schedule. Appointments were scheduled and polysomnography hookups organized to preserve the routine bedtimes, subjects were allowed to sleep in the morning until they awoke spontaneously, and the ambient noise in the sleep center was kept to a minimum for this purpose. Such conditions are fairly impractical and unlikely to be followed in a clinical setting, and, therefore, we anticipate that our findings are rather conservative and would likely be more pronounced if subjects were expected to follow artificial bedtimes and rise times, as dictated by standard sleep clinic schedules. Second, there has been criticism of the use of actigraphy in pediatric populations as a proxy for sleep architecture from polysomnography. For this reason, we exclusively used the actigraphic recordings to compare nights at home and in the laboratory. Furthermore, the same device and recording protocol were used, and the actigraph was placed by the parent both at home and in the laboratory. Finally, the number of participants in the study was relatively low, requiring a more stringent criterion for accepting significant differences and relationships (p > .01).

This study shows that several actigraphic sleep measures are disrupted in toddlers during a night in the sleep laboratory, when compared with measures obtained in the home setting. Furthermore, the degree of sleep disruption correlates with emotional

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**Table 3**—Mean Actigraphy Values During Home Nights, Actigraphy Values During In-Laboratory Night, and Difference Scores

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Home Nights</th>
<th>PSG Night</th>
<th>p Value</th>
<th>Cohen d</th>
<th>Difference Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleep start time</td>
<td>21:06 ± 67.8</td>
<td>21:27 ± 44</td>
<td>.192</td>
<td>.58</td>
<td>32.0 ± 48.4</td>
</tr>
<tr>
<td>Sleep end time</td>
<td>7:35 ± 57.8</td>
<td>7:03 ± 53</td>
<td>.008</td>
<td>.66</td>
<td>66.6 ± 66.9</td>
</tr>
<tr>
<td>TST, min</td>
<td>547.1 ± 59.5</td>
<td>480.3 ± 65.0</td>
<td>&lt;.001</td>
<td>1.1</td>
<td>66.6 ± 66.9</td>
</tr>
<tr>
<td>Sleep efficiency %</td>
<td>87.0 ± 5.5</td>
<td>83.7 ± 5.1</td>
<td>.004</td>
<td>.57</td>
<td>3.4 ± 4.8</td>
</tr>
<tr>
<td>Mean sleep bout time, min</td>
<td>359.9 ± 140.5</td>
<td>356.5 ± 89.4</td>
<td>.004</td>
<td>.03</td>
<td>15.2 ± 20.6</td>
</tr>
<tr>
<td>Immobile percentage, %</td>
<td>87.3 ± 5.8</td>
<td>84.0 ± 4.8</td>
<td>.003</td>
<td>.62</td>
<td>15.2 ± 4.6</td>
</tr>
<tr>
<td>Mean activity in sleep, score</td>
<td>5.4 ± 2.8</td>
<td>8.6 ± 3.7</td>
<td>&lt;.001</td>
<td>.98</td>
<td>3.2 ± 2.7</td>
</tr>
<tr>
<td>Movement &amp; Fragmentation Index</td>
<td>19.9 ± 5.3</td>
<td>22.4 ± 5.6</td>
<td>.043</td>
<td>.46</td>
<td>2.6 ± 5.4</td>
</tr>
</tbody>
</table>

Data are presented as mean ± SD. Data for bedtime and rise time are shown as mean clock time ± SD, in minutes. TST refers to total sleep time.

*Difference scores are calculated as the average of the value of the sleep parameter on home nights minus the value on the polysomnography (PSG) night.

**Table 4**—Ratings From the Bayley Scales of Infant Development-II

<table>
<thead>
<tr>
<th>Scale</th>
<th>MDI (90-122)</th>
<th>PDI (69-112)</th>
<th>BRS (21-96)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MDI</td>
<td>103.9 ± 2.0</td>
<td>96.6 ± 3.0</td>
<td>69.5 ± 4.8</td>
</tr>
<tr>
<td>PDI</td>
<td>96.6 ± 3.0</td>
<td>69.5 ± 4.8</td>
<td>69.5 ± 4.8</td>
</tr>
<tr>
<td>BRS subscale percentiles</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orientation/Engagement</td>
<td>65.6 ± 5.9</td>
<td>65.9 ± 5.9</td>
<td>72.6 ± 6.1</td>
</tr>
<tr>
<td>Emotional Regulation</td>
<td>65.9 ± 5.9</td>
<td>65.9 ± 5.9</td>
<td>72.6 ± 6.1</td>
</tr>
<tr>
<td>Motor Quality</td>
<td>72.6 ± 6.1</td>
<td>72.6 ± 6.1</td>
<td>72.6 ± 6.1</td>
</tr>
</tbody>
</table>

Data are presented as mean ± SEM (range). The Bayley Scales of Infant Development-II consists of a mental scale (MDI), a motor scale (PDI), and a behavior rating scale (BRS).
disturbance. However, although TST differed at home compared with the sleep lab, this measure was not associated with assessment scores. This was somewhat surprising considering the evidence from experimental and intentional sleep restriction in older children. Indeed, mild reductions in the opportunity to sleep in school-age children has been associated with substantial difficulties in attention and impulsivity control. Similar findings are reported in naturalistic studies in which the overall duration of sleep in the home has been linked to aggressive and delinquent behavior as well as social and attention problems. Of interest, when a 2-hour sleep restriction has been imposed on children, the most prominent manifestation of sleepiness occurs around 10:00 am, usually the time at which neurobehavioral testing will take place after the sleep study in the laboratory.

One concern of the current findings is how to interpret previous studies that have used the standard protocol of administering assessments the morning following the polysomnography. Based on our results, we would not expect a night of disturbed sleep to alter standardized testing scores when there are no time limits or pressures to perform. However, the data suggest that administration of tests that may be affected by emotional regulation the morning following polysomnography without an adjustment night should be considered a study limitation. Further, it is unknown whether a single adjustment night would eliminate the effects of sleep disturbance in the laboratory.

Based on our current findings, the effects of unintended sleep disturbance during laboratory-based polysomnography should be considered in behavioral studies of young children, particularly those using measures vulnerable to impaired emotional regulation. These data recommend that behavioral assessments, especially those vulnerable to difficulty with emotional regulation, be administered at a time when the subject is not likely to have experienced sleep disruption.

ACKNOWLEDGMENT

National Institutes of Health Grants F32 HL-074591 (HM-D) and HL65270 (DG), The Children’s Foundation Endowment for Sleep Research, and the Commonwealth of Kentucky Challenge for Excellence Trust Fund (DG). We are grateful to the parents and their children who participated in the study.

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