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The effect of stimulants on sleep characteristics in children with attention deficit/hyperactivity disorder

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Abstract

Objective: To investigate the effects of stimulant medications on subjective and objective sleep characteristics of children with attention deficit/hyperactivity disorder (ADHD) compared with control children.

Methods: An observational study in the sleep clinic and the community. Children with characteristics of ADHD, both stimulant-medicated ($n = 53$), and non-medicated ($n = 34$), together with control children ($n = 53$) completed a sleep habits questionnaire prior to undergoing full overnight polysomnographic assessment.

Results: Medicated and non-medicated ADHD subjects were reported to have more sleep disturbances compared with controls. Both groups of ADHD children also demonstrated decreased REM sleep percentage compared with controls ($P = 0.006$ for ADHDmed; $P = 0.02$ for ADHDnon). However, the use of stimulant medication ($n = 53$) was not associated with differences in subjective sleep quality or objective sleep measures, compared to ADHD children not taking any medication ($n = 34$; $P =$ n.s.).

Conclusions: Despite the high prevalence of reported sleep disturbance in children with ADHD, stimulant medication appears to have minimal effects on subjective and objective sleep characteristics in children with reported ADHD.

Keywords: Child; Sleep; Attention deficit/hyperactivity disorder; Stimulant medication; Polysomnography; Rapid eye movement sleep

1. Introduction

A growing number of studies have addressed the prevalence of sleep problems among children with attention deficit/hyperactivity disorder (ADHD). The majority of these studies is based on subjective parental reports and indicates a high prevalence of sleep complaints among children with ADHD compared to controls [1–3(p. 76–77), 4–7]. In contrast, the few studies that have objectively assessed sleep characteristics in the ADHD population have been unable to confirm that such striking differences exist. A review of the published literature by Corkum et al. [8] yielded inconsistent findings regarding objective measures of sleep in ADHD. Indeed, there was either an absence of any discernible differences in sleep variables among ADHD subjects and controls [9,10], or significant changes emerged in sleep onset latency [11–14], in sleep efficiency [13,14], or in the characteristics of rapid eye movement sleep (cyclical movements of closed eyes during sleep; rapid eye movement (REM)) and non-rapid eye movement sleep (NREM) sleep in children with ADHD [12,13,15,16]. Furthermore, an increased frequency of periodic leg movement during sleep (PLMS) has been reported in children with ADHD [17,18], raising speculation into possible shared neurobiological mechanisms underlying both ADHD and periodic limb movement disorder (PLMD) [18,19].

Many of the putative sleep problems in ADHD have been

Abbreviations: ADHD, attention-deficit hyperactivity disorder; ADHDmed, children with ADHD and medicated with stimulants; ADHDnon, children with ADHD and not medicated; AHI, apnea/hypopnea index; AI, apnea index; DSM-IV, diagnostic and statistical manual version IV; ECG, electrocardiogram; EEG, electroencephalogram; EMG, electromyogram; EOG, electro-oculogram; OSA, obstructive sleep apnea; PLMS, periodic leg movements during sleep; PSG, polysomnography; REM, rapid eye movements; SpO_2, arterial oxygen saturation measured by pulse oximetry; SWS, slow wave sleep; TIB, time in bed; TST, total sleep time.

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attributed to the use of stimulants, the most widely prescribed treatment for this behavioral disorder. The impact of stimulants on sleep in ADHD has been previously examined using objective measures such as polysomnography [9,11,12,16,20–22] or actigraphy [10,23]. While in some studies, there were no differences between medicated and non-medicated children with ADHD [12,20], other researchers reported increased number of REM episodes with increased REM activity [16] or prolonged REM sleep latency [9,11] with decreased percentage of REM sleep [21] among those receiving medication for ADHD. However, small sample sizes, lack of control subjects, and skewed clinical populations drawn from tertiary referral centers potentially detract from the validity of such findings and make it very difficult to compare across studies. As a result, the question of whether psychostimulant use is associated with sleep disturbance remains unanswered, despite their widespread use for the treatment of ADHD behavioral symptoms.

The purpose of this study was therefore to investigate the potential effects of stimulants on the subjective and objective sleep characteristics by comparing parental sleep complaints and polysomnographic variables in stimulant-medicated and non-medicated children with ADHD and in controls.

2. Methods

2.1. Subjects

Participants were selected from two sources, namely a chart review of all children with reported ADHD (obtained from parental interviews, having confirmation by either the referring physician or psychologist) referred to Kosair Children's Hospital Sleep Medicine and Apnea Center during the years 2000–2002, and a community survey of 5–7-year-old children in Jefferson County, Louisville during the same period. All children referred to Kosair Children's Hospital Sleep Medicine and Apnea Center completed a detailed questionnaire about sleeping habits (Appendix A). Only those children who were referred to the Sleep Center and who underwent overnight polysomnography (PSG) as part of their clinical assessment were included in the chart review sample. For the community survey, parents of all 5–7-year-old children attending Jefferson County Public Schools system were invited to complete a detailed questionnaire about their child's sleeping habits. This questionnaire was less detailed regarding bedtime routines than that used in the clinical assessment, but contained the same questions regarding quality of sleep and parasomnias (Appendix A). Questions also included: "Does your child have ADHD?" and "Is your child hyperactive?" Parents were also asked to list any medications for ADHD/hyperactivity that their child was taking. Children were selected on the basis of parental reports indicating the presence of ADHD and no other associated medical conditions. No formal diagnostic assessments were performed to confirm the presence of ADHD; however, the Conners Parent Rating Scale [24] was used to confirm the presence of hyperactive behaviors. Although not a diagnostic tool for ADHD, the ADHD index of this rating scale is well validated and a score of two SD above the mean (i.e. a score ≥ 70) provides a recognized measure of children at high risk for a diagnosis of ADHD [25,26].

All ADHD subjects were required to be medicated with stimulants only (ADHDmed) or no medications (ADHDnon). All children in the ADHDmed group had taken their usual stimulants on the day preceding the PSG. Subjects were excluded if they had neurodevelopmental disabilities, were taking any other medications, or had any genetic or craniofacial syndromes. In addition, subjects were excluded from the community sample if they did not score ≥ 2 SD above the mean on the ADHD index of the Conners Rating Scale. Controls were randomly selected from those children with no medical conditions and no hyperactivity. Both ADHD children and controls were invited for an overnight polysomnographic assessment in the sleep laboratory.

This study was approved by the University of Louisville Institutional Review Board, and parental informed consent and child assent, in the presence of a parent, were obtained.

2.2. Parental reports of sleep disturbance

Subjective information regarding sleep habits was routinely obtained during the initial clinic appointment for those children referred to the Sleep Medicine Center and documented using a structured problem-based survey instrument. Many of the questions pertained to the bedtime routine, such as "Will your child fall asleep alone in bed? In order to fall asleep does your child need a special toy or object? Do you get annoyed/angry when your child cannot sleep? What do you think prevents your child from falling asleep?" while other questions focused on the presence of sleep disturbances, e.g. daytime sleepiness, restless sleep, sleepwalking, nightmares, enuresis, apnea, and snoring. For more details on the questions, see Appendix A.

Parents of children from the community survey completed a detailed sleep questionnaire that focused almost entirely on the presence of sleep disturbances (as above). Since these questions were the same as those from the clinical questionnaire, it was possible to accurately compare their responses. Parents answered one question for each item, and the responses were graded 'never', 'rarely' (once per week), 'occasionally' (twice per week), 'frequently' (three to four times per week) and 'almost always' (more than four times per week). For analysis, these responses were dichotomously classified as 'never'/'rarely' and 'occasionally'/'frequently'/'almost always'.

Information about bedtime routine was not obtained from the community sample of children and therefore is not

reported. In addition to demographic information and significant medical history of the child, questions were included on whether the child had difficulty initiating sleep, restless sleep, enuresis, nightmares, sleepwalking, apnea, sleepy during the day, snoring and, if so, the severity of the snoring.

2.3. Polysomnographic assessment

A standard overnight multichannel polysomnographic evaluation was performed at the Sleep Medicine Center of Kosair Children's Hospital. Children were studied for up to 12 h in a quiet, darkened room with an ambient temperature of 24°C in the company of one of their parents. All studies were terminated when the children woke up spontaneously or at approximately 7 A.M. if they were still sleeping, whether or not the studies were performed on a school night or during the weekend. This was similar to the time that children awoke for school, and thus was not considered to affect the variables measured. No studies were terminated while the children were in REM sleep. No drugs were used to induce sleep. The following parameters were measured: chest and abdominal wall movement by respiratory impedance or inductance plethysmography, heart rate by electrocardiogram (ECG), air flow with a sidestream end-tidal capnograph which also provided breath-by-breath assessment of end-tidal carbon dioxide levels ($PETCO_2$; Pryon SC-300, Menomonee Falls, WI), and/or a thermistor. Arterial oxygen saturation (SpO_2) was assessed by pulse oximetry (Nellcor N 100; Nellcor Inc., Hayward, CA), with simultaneous recording of the pulse waveform. The bilateral electro-oculogram (EOG), eight channels of electroencephalogram (EEG), chin and anterior tibial electromyograms (EMG), and analog output from a body position sensor (Braebon Medical Corporation, NY) were also monitored. All measures were digitized using a commercially available polysomnography system (Stellate Systems, Montreal, Canada). Tracheal sound was monitored with a microphone sensor (Sleepmate, VA) and a digital time-synchronized video recording was performed.

2.4. Sleep variables

Sleep architecture was assessed by standard techniques [27] and PSGs were scored blind to the subject's diagnosis and medication status. The apnea index (AI) was defined as the number of apneas per hour of total sleep time (TST). Hypopneas were defined as a decrease in nasal flow of $\geq 50\%$ with a corresponding decrease in SpO_2 of $\geq 4\%$ and/or arousal. The apnea/hypopnea index (AHI) was defined as the number of apneas and hypopneas per hour of TST. Obstructive sleep apnea (OSA) in this study was defined as an AHI of ≥ 5. Despite the absence of normative data in the literature [28], we have previously shown that the threshold for disease (i.e. >2SD beyond the mean) would represent an apnea index >0.5 and/or an AHI >3.4 [29]. Thus, AHI >5 was selected to represent clinically significant disease. The mean oxygen saturation, as measured by pulse oximetry (SpO_2), together with SpO_2 nadir, was determined. Arousals were defined as recommended by the American Sleep Disorders Association Task Force report [30] and included respiratory-related (occurring immediately following an apnea, hypopnea or snore), technician-induced and spontaneous arousals. Arousals were expressed as the total number of arousals per hour of sleep time (arousal index). Central, obstructive and mixed apneic events were counted. Obstructive apnea was defined as the absence of airflow with continued chest wall and abdominal movement for a duration of at least two breaths [28,31]. Periodic leg movements during sleep (PLMS) were scored if there were at least four movements of 0.5–5 s duration, and between 4 and 90 s apart. A PLM index of ≥ 5 per hour of sleep is generally considered to be rare in normal children [32].

2.5. Data analysis

Data are presented as means ± SD unless otherwise indicated. For questionnaire-derived responses, comparisons were made with chi-square analyses (dichotomous outcomes). Analysis of variance was employed for comparisons of polysomnographic measures between the study groups with P values adjusted for unequal variances when appropriate. All P-values reported are two-sided with statistical significance set at <0.05.

3. Results

3.1. Parental surveys

A total of 87 children with reported ADHD were included in the population sample ($n = 41$ from the chart review sample; $n = 46$ from the community sample). A total of 53 children were medicated with stimulants (methylphenidate = 20, methylphenidate slow release = 13, and amphetamine/dextroamphetamine = 21). Sixty eight percent of the children recruited from the clinical sample were medicated compared with 54% of the community sample, P = n.s.). Demographic information is given in Table 1. There were no differences in mean age between the study groups although there were significantly more males in the ADHDmed group compared with controls.

Table 2 summarizes the differences in subjective parental sleep reports between the groups. There were significantly more subjective sleep complaints in both the ADHDmed and ADHDnon groups compared with controls. The parents of ADHDmed children were more likely to report restless sleep ($P < 0.02$), enuresis ($P = 0.03$), and nightmares ($P < 0.0005$) than controls. Non-medicated subjects were more likely to report enuresis ($P = 0.005$) and nightmares

Table 1
Demographic characteristics of medicated (ADHDmed), unmedicated (ADHDnon), and control children

	ADHDmed ($n = 53$)	ADHDnon ($n = 34$)	Control ($n = 53$)
Mean age (years)	6.9 ± 1.4	6.5 ± 1.5	6.6 ± 0.6
Age range (years)	3.5–10.9	4.6–11.6	5.6–8.3
Male gender	40 (75%)*	18 (53%)	23 (43%)
Medication status:			
Methylphenidate	32 (60%)	n/a	n/a
Amphetamines	21 (40%)	n/a	n/a

*$P < 0.01$ versus controls.

($P = 0.0002$) than controls. However, there were no significant differences in the subjective parental sleep complaints between the two ADHD groups (ADHDmed and ADHDnon). Regardless of whether the ADHD samples were obtained from the clinical chart review or the community survey, children with reported ADHD had significantly more subjective sleep complaints than controls (Table 3). However, the clinical ADHD sample was more likely to complain of nightmares ($P = 0.0007$), enuresis ($P = 0.0008$), and witnessed apnea ($P = 0.0009$) than the ADHD children in the community survey.

3.2. Polysomnographic findings

Results of the PSG for the three study groups are shown in Table 4. Analysis of variance revealed that ADHDmed had shorter mean total recording time than controls ($P = 0.02$). None of the groups differed with respect to sleep latency, sleep efficiency or proportion of slow wave sleep (SWS%, stages 3 and 4). However, the ADHDmed group had a tendency to longer REM sleep latencies than controls although this did not reach statistical significance ($P = 0.073$). Both the ADHDmed and the ADHDnon groups had a decreased percentage of REM sleep compared to controls (REM%; $P = 0.006$ and $P = 0.02$, respectively).

No significant differences were found between the medicated and non-medicated groups of ADHD children for any of the sleep measures.

Table 2
Subjective sleep problems in 53 medicated, 34 non-medicated ADHD children and 53 controls

Variable	ADHDmed ($n = 53$) (%)	ADHDnon ($n = 34$) (%)	Control ($n = 53$) (%)
Restless sleep	88*	84	65
Nightmares	31**	45**	8
Sleepwalks	15	22	12
Enuresis	35*	42**	13
Snores	74	76	72
Stops breathing	22	23	12
Excessive daytime sleepiness	44	52	40

*$P < 0.05$ versus controls; **$P < 0.005$ versus controls.

Table 5 demonstrates that there were no differences in the demographics or PSG values between the clinical medicated and non-medicated groups, nor were there any differences between the community medicated and non-medicated groups. The only differences between the clinical medicated and community medicated groups, and the clinical non-medicated and community non-medicated groups were more frequent spontaneous arousals in the community groups ($P = 0.009$ and $P = 0.045$, respectively). The clinical medicated group also had a lower mean SpO_2 than the community medicated group ($P = 0.031$) whereas the community non-medicated group had a lower mean SpO_2 than the clinical non-medicated group ($P < 0.0001$). These differences are, however, unlikely to be clinically relevant.

Six children (7%) with ADHD fulfilled criteria for obstructive sleep apnea, four children in the ADHDmed group, and two children in the ADHDnon group. Five of these children were recruited from the community survey. Eight children (15%) in the control group had OSA ($P =$ n.s.).

A PLM index ≥ 5 was present in 15% of ADHDmed subjects, 12% of ADHDnon and 11% of controls ($P =$ n.s.). However, the three children with the highest PLM indices (35.0, 21.4, and 19.5/h TST) were all among the ADHD children, with two of the three in the ADHDmed group.

4. Discussion

In this study, we have shown that psychostimulant medications used for the behavioral management of ADHD do not appear to be associated with detrimental effects on either subjective or objective measures of sleep. Approximately half of our ADHD group was recruited from the local community, and therefore we were not restricted to clinical samples alone. Since parents of the children from the community sample reported significantly more sleep disturbances than the controls, we are confident that the increased reports of sleep disturbances do not reflect a bias towards the clinical sample (recruited from a sleep clinic). However, we were unable to perform rigorous assessments for ADHD and this is clearly a limitation of the present study. To the best of our knowledge, the cohort constitutes the largest sample of reported ADHD and healthy control children to be evaluated for sleep disturbances, using both subjective parental reports and polysomnographic measures of sleep. As such, our findings lend further credence to previous reports on the lack of a sleep effect induced by stimulant therapy in ADHD children [12,20].

Based on subjective measures of sleep, parents of ADHD children in our study reported significantly more sleep difficulties, such as restless sleep, nightmares, and enuresis when compared to parental reports for control children.

Table 3
Comparison of subjective information for the clinical and community populations

Variable	Clinical chart review ($n = 41$) (%)	Community survey ($n = 46$) (%)	Control ($n = 53$) (%)
Restless sleep	86*	86*	65
Nightmares	58**¶	20**	8
Sleepwalks	26	11	12
Enuresis	58**¶	20	13
Snores	83	67	72
Stops breathing	41**¶	7	12
Excessive daytime sleepiness	56	39	40

*$P < 0.05$ versus controls; **$P < 0.01$ versus controls; ¶$P < 0.01$ versus community.

These results are similar to those previously reported in the literature [1,2,7,8,33], and underscore the possibility that children with ADHD may not only have intrinsic sleep problems but also exhibit increased frequency of parasomnias and sleep-related involuntary movements. In contrast to Chervin et al. [34], we did not find a difference in snoring or sleep disordered breathing between the ADHD and control group. Indeed, we have recently demonstrated that children with mild hyperactivity but not ADHD per se show increased prevalence of OSA [35]. The mechanism(s) by which OSA may contribute to hyperactivity remain undefined. It is possible that both the sleep fragmentation and episodic hypoxia that characterize OSA will lead to alterations in the neurochemical substrate of the pre-frontal cortex and resultant executive dysfunction [36].

In contrast with recently published studies that found no differences in subjective sleep reports for ADHD children after controlling for pharmacotherapy with stimulants and other psychopathology [33,37], our data indicate that parents of ADHD children, regardless of their medication status, are more likely to report sleep problems when compared to parents of controls. However, our findings need to be interpreted with caution since children included in this study were not specifically evaluated for the presence of comorbid disruptive behaviors and other psychiatric disorders that may impact on some of the subjective reports of sleep disturbances. Further studies including a psychiatric or neurologic control group may provide additional information on the sleep characteristics of these groups and determine whether the differences observed in the present study are unique to ADHD or affect neuropsychiatric disease in general.

Table 4
Overnight polysomnographic findings in medicated, non-medicated ADHD children and controls

	ADHDmed ($n = 53$)	ADHDnon ($n = 34$)	Control ($n = 53$)
Total recording time	8.6 ± 0.5*	8.7 ± 0.7	8.8 ± 0.4
Range (h)	(7.6–9.8)	(6.9–10.2)	(7.9–9.9)
Total sleep time (h)	7.5 ± 0.9	7.6 ± 0.8	7.8 ± 0.8
Sleep efficiency (%TIB)	88.1 ± 9.2	87.6 ± 8.3	88.6 ± 8.4
Sleep latency (min)	29.5 ± 26.2	32.6 ± 37.5	27.3 ± 36.8
REM latency (min)	155.7 ± 71.9	143.7 ± 51.9	132.1 ± 70.7
SWS (%TST)	22.3 ± 7.0	23.5 ± 6.9	22.3 ± 4.9
REM (%TST)	20.3 ± 6.5**	20.5 ± 8.1*	24.1 ± 6.5
Spontaneous arousal index	7.1 ± 4.0	7.0 ± 4.0	7.7 ± 3.3
Respiratory arousal index	0.5 ± 1.1	0.4 ± 0.6	1.7 ± 4.0
PLM index (/h TST)	2.4 ± 5.0	2.6 ± 6.3	1.8 ± 3.5
AHI (/h TST)	1.6 ± 2.2	1.1 ± 1.6	3.3 ± 6.2
Mean SpO_2 (%)	97.8 ± 0.9	97.8 ± 1.1	97.4 ± 1.1
SpO_2 nadir (%)	92.4 ± 5.0*	93.1 ± 5.1*	88.9 ± 8.6

*$P < 0.05$ versus controls; **$P < 0.01$ versus controls. TIB, time in bed; SWS%, percentage of slow wave sleep (stages 3 and 4); REM%, percentage of rapid eye movement sleep; PLM index, periodic leg movement index; AHI, apnea/hypopnea index; SpO2, arterial oxygen saturation measured by pulse oximetry.

Similar to earlier studies [7,16], the differences in the majority of sleep parameters reported by parents of ADHD children in our study were not verified by objective sleep assessment. We found that sleep architecture in ADHD children and controls was different only with regard to the percentage of REM sleep and that the ADHDmed group showed a tendency towards increased REM sleep latency, although not significant. Both ADHD groups had a lower REM sleep percentage than controls; however, when the two groups of ADHD children were compared in relation to stimulant pharmacotherapy, no significant differences emerged in their polysomnographic measures.

Our polysomnographic findings are in close agreement with those studies reporting no differences between the unmedicated and medicated children with ADHD treated with methylphenidate [12,20] or dextroamphetamine [9]. We did, however, find differences in mean SpO_2 values between the children recruited from the clinical and community samples. These differences however, are unlikely to be of any clinically applicable relevance due to the narrow range of SpO_2 values.

There is some evidence indicating that the medication schedule can influence sleep outcome measures [21,23,38]. Delay in the first REM sleep period and decreased REM sleep percentage were reported by Chatoor et al. [21] after nocturnal administration of stimulant medication in children with ADHD. It also appears from the literature that not only the schedule but also the type and dosage of stimulant can affect sleep characteristics in children. Efron et al. [39], after conducting a double-blind, crossover trial of methylphenidate and dexamphetamine in children with ADHD, reported

Table 5
Comparison of demographics and sleep variables for the clinical and community populations

	Clinic		Community	
	Medicated ($n = 28$)	Non-medicated ($n = 13$)	Medicated ($n = 25$)	Non-medicated ($n = 21$)
Mean age (years)	8.1 ± 1.8	8.0 ± 2.0	6.6 ± 0.5	6.4 ± 0.6
Age range (years)	3.5–10.9	4.6–11.6	5.6–7.6	5.3–7.7
Male gender	20 (71%)	9 (69%)	19 (76%)	10 (48%)
PSG variables:				
Total recording time	8.5 ± 0.5	8.5 ± 0.9	8.6 ± 0.5	8.9 ± 0.5
(range) (h)	(7.8–9.8)	(6.9–10.2)	(7.6–9.6)	(7.7–10.0)
Total sleep time (h)	7.3 ± 0.9	7.6 ± 0.9	7.8 ± 0.7	7.7 ± 0.8
Sleep efficiency (%TIB)	85.5 ± 10.6	89.5 ± 5.2	90.9 ± 6.3	86.5 ± 9.7
Sleep latency (min)	26.9 ± 23.5	18.3 ± 15.9	32.5 ± 29.2	41.5 ± 44.2
REM latency (min)	158.9 ± 84.1	162.0 ± 42.5	152.1 ± 56.7	132.3 ± 54.8
SWS (%TST)	24.0 ± 7.5	25.1 ± 5.7	20.4 ± 5.8	22.5 ± 7.5
REM (%TST)	18.1 ± 6.0	17.1 ± 6.1	22.8 ± 6.1	22.7 ± 8.5
Spontaneous arousal index	5.4 ± 1.9[§]	4.9 ± 2.6*	9.1 ± 4.8	8.4 ± 4.2
Respiratory arousal index	0.5 ± 1.3	0.2 ± 0.4	0.4 ± 0.9	0.4 ± 0.7
PLM index (/h TST)	2.4 ± 4.8	5.1 ± 9.5	2.3 ± 5.2	1.0 ± 2.3
AHI (/h TST)	1.3 ± 2.2	0.7 ± 0.4	1.8 ± 2.1	1.4 ± 2.0
Mean SpO2 (%)	98.1 ± 0.9[§]	98.5 ± 0.8*	98.6 ± 0.9	97.3 ± 1.0
SpO2 nadir (%)	92.4 ± 6.0	94.8 ± 2.7	92.3 ± 3.5	92.1 ± 5.6

[§]$P < 0.05$ versus community medicated; *$P < 0.05$ versus community non-medicated.

dexamphetamine causing more severe insomnia than methylphenidate. In another study [10], the only altered sleep parameter in ADHD children receiving either methylphenidate hydrochloride (0.3–0.4 mg/kg) or placebo was total sleep duration. In our study, children receiving either methylphenidate (60%) or dexamphetamine (40%) did not show any differences in sleep characteristics compared with non-medicated children with ADHD. Of interest, the ADHD sample also included children receiving extended release formulations of stimulants, whose influence on sleep architecture is yet to be conclusively determined.

A potential limitation of this study is that we have no definitive information on whether the non-medicated ADHD children were drug-naïve, and if not, what time interval had elapsed since the medication was discontinued. One could postulate that if stimulant therapy was recently discontinued, the recorded sleep characteristics may have been influenced by the residual tail effect of the medication. Since sleep characteristics were assessed only at one point in time, this study was not designed to establish causal relationships between initiation of stimulant medication and the potential development of sleep disturbances. A second limitation was the absence of an adaptation period in the sleep laboratory prior to testing. Thus, first night effect could differentially affect ADHD children from controls, and such differences may be reflected in our objective sleep measures. However, it is unlikely that this consideration may have affected ADHDmed and ADHDnon differently.

We were unable to confirm the presence of significantly elevated PLM indices in children with ADHD when compared to controls [17,18]. Since we did not perform formal DSM-IV assessments, the possibility exists that some of the children, particularly those in the ADHDnon group, may not have met DSM-IV ADHD diagnostic criteria. Nevertheless, the relatively high proportion of control children with a PLM index ≥ 5 suggests that even if some diagnostic adjustments among the ADHD children had been necessary, such adjustments would have been unlikely to significantly alter our figures. Of note, we did find that those subjects with the most elevated PLM indices were in the ADHD groups.

In summary, we provide initial evidence that treatment with stimulant medications appears to impose little, if any, effect on either subjective or objective sleep characteristics in children reported to have ADHD. However, further work is required to confirm these observations, particularly in children who have undergone rigorous assessment for ADHD. More definitive prospective double-blind, placebo controlled studies will also be needed to ascertain the effects of the recently developed slow-release stimulant formulations on sleep structure in children with ADHD.

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Appendix A. The sleep questionnaire

Child's demographic information:
Name
Address
Telephone Number
Date of Birth
Gender
Ethnicity

Child:
Medical problems:
Medications:
Allergies:
Birth Weight
Adenoids or Tonsils removed: YES NO
Does child sleep alone, share with 1, share with 2, share with 3, share with >3
Do any of his/her siblings snore? YES NO
Does your child have ADHD (also called hyperkinetic/attention deficit)? YES NO
Is your child hyperactive? YES NO
Is your child on any ADHD Medication? YES NO; Which one:
How long does your child sleep at night?
At what time does your child go to bed?
At what time does your child wake up?

*The following questions can be answered with a "*yes" or "no". "Yes" means "occasionally", "frequently", or "almost always":
Does your child have nightmares?
Has he/she expressed fear of sleeping in the dark?
Is your child easy to wake up in the morning?
Does your child go to bed willingly?
Is he/she a restless sleeper?
Does he/she wake up at night?
Have you observed him/her sleepwalking?
Does he/she grind his/her teeth during sleep?
Have you observed repetitive actions such as rocking or head banging during sleep?
Does he/she have problems with bed wetting?
Does your child complain about difficulties going to sleep?
Does your child get up to go to the bathroom during the night?
Does your child stop breathing during sleep?
Does your child struggle to breathe while asleep?
Does your child fall asleep easily?
Are you ever concerned about your child's breathing during sleep?
How often does your child snore?
How often does your child have a sore throat?
Does your child complain of morning headaches?
Is your child a daytime mouth breather?
Is your child sleepy during the daytime?
Does your child fall asleep at school?
Does your child fall asleep while watching television?

References

[1] Kaplan BJ, McNichol J, Conte RA, Moghadam HK. Sleep disturbance in preschool-aged and hyperactive and nonhyperactive children. Pediatrics 1987;80:839–44.
[2] Trommer BL, Hoeppner JB, Rosenberg RS, Armstrong KJ, et al. Sleep disturbance in children with attention deficit disorder (abstract). Ann Neurol 1988;24:322.
[3] Barkley RA. Attention deficit hyperactivity disorder: a handbook for diagnosis and treatment. New York, NY: Guilford; 1990.
[4] Ball JD, Tiernan M, Janusz J, Furr A. Sleep patterns among children with attention-deficit hyperactivity disorder: a re-examination of parental perceptions. J Pediatr Psychol 1997;22:389–98.
[5] Ring A, Stein D, Barak Y, Teicher A, et al. Sleep disturbances in children with attention-deficit/hyperactivity disorder: a comparative study with healthy siblings. J Learn Disabil 1998;31:572–8.
[6] Owens J, Maxim R, Nobile C, McGuinn M, et al. Parental and self-report of sleep in children with attention deficit/hyperactivity disorder. Arch Pediatr Adolesc Med 2000;154:549–55.
[7] Corkum P, Tannock R, Moldofsky H, Hogg-Johnson S, et al. Actigraphy and parental ratings of sleep in children with attention deficit/hyperactivity disorder (ADHD). Sleep 2001;24:303–12.
[8] Corkum P, Tannock R, Moldofsky H. Sleep disturbance in children with attention-deficit hyperactivity disorder. J Am Acad Child Adolesc Psychiatry 1998;37:637–46.
[9] Feinberg I, Hibi S, Braun M, Cavness C, et al. Sleep amphetamine effects in MBDS and normal subjects. Arch Gen Psychiatry 1974;31:723–31.
[10] Tirosh E, Sadeh A, Munvez R, Lavie P. Effects of methylphenidate on sleep in children with attention-deficit hyperactivity disorder. Am J Dis Child 1993;147:1313–5.
[11] Small A, Hibi S, Feinberg I. Effects of dextroamphetamine sulphate on EEG sleep patterns of hyperactive children. Arch Gen Psychiatry 1971;25:369–80.
[12] Haig JR, Schroeder CS, Schroeder SR. Effects of methylphenidate on hyperactive children's sleep. Psychopharmacologia 1974;37:185–8.
[13] Ramos Platon MJ, Vela Bueno A, Espinar Sierra J, Kales S. Hypnopolygraphic alterations in attention deficit disorder (ADD) children. Int J Neurosci 1990;53:87–101.
[14] Palm L, Persson E, Bjerre I, Elmqvist D, et al. Sleep and wakefulness in preadolescent children with deficits in attention, motor control and perception. Acta Paediatr 1992;81:618–24.
[15] Busby K, Firestone P, Pivik RT. Sleep patterns in hyperkinetic and normal children. Sleep 1981;4:366–83.
[16] Greenhill L, Puig-Antich J, Goetz R, Hanlon C, et al. Sleep architecture and REM sleep measures in prepubertal children with attention deficit disorder with hyperactivity. Sleep 1983;6:91–101.
[17] Picchietti D, England S, Walters A, Willis K, et al. Periodic limb movement disorder and restless legs syndrome in children with attention-deficit hyperactivity disorder. J Child Neurol 1998;13:588–94.
[18] Picchietti DL, Underwood DJ, Farris WA, Walters AS, et al. Further studies on periodic limb movement disorder and restless legs syndrome in children with attention-deficit-hyperactivity disorder. Mov Disord 1999;14:1000–7.
[19] The Dopaminergic Therapy Study Group, Walters AS, Mandelbaum DE, Lewin DS, Kugler S. Dopaminergic therapy in children with restless legs/periodic limb movements in sleep and ADHD. Pediatr Neurol 2000;22:182–6.
[20] Nahas AD, Krynicki V. Effect of methylphenidate on sleep stages and ultradian rhythms in hyperactive children. J Nerv Ment Dis 1977;164:66–9.

[21] Chatoor I, Wells KC, Conners CK, Seidel WT, et al. The effects of nocturnally administered stimulant medication on EEG sleep and behavior in hyperactive children. J Am Acad Child Psychiatr 1983;22: 337–42.
[22] Busby K, Pivik RT. Auditory arousal thresholds during sleep in hyperkinetic children. Sleep 1985;8:332–41.
[23] Stein MA, Blondis TA, Schnitzler ER, O'Brien T, et al. Methylphenidate dosing: twice daily versus three times daily. Pediatrics 1996; 98:748–56.
[24] Conners CK. Conners' rating scales – revised. North Tonawanda, NY: Multi-Health Systems Publishing; 1997.
[25] Brown RT, Freeman WS, Perrin JM, Stein MT, et al. Prevalence and assessment of attention-deficit/hyperactivity disorder in primary care settings. Pediatrics 2001;107:E43.
[26] American Academy of Pediatrics, Clinical practice guideline: diagnosis and evaluation of the child with attention-deficit/hyperactivity disorder. Pediatrics 2000;105:1158–70.
[27] Rechtschaffen A, Kales A. A manual of standardized terminology, techniques and scoring systems for sleep stages of human subject (Publication No. 204). Washington, DC: National Institutes of Health; 1968.
[28] Marcus CL, Omlin KJ, Basinski DJ, Bailey SL, et al. Normal polysomnographic values for children and adolescents. Am Rev Respir Dis 1992;156:1235–9.
[29] Gozal D, Wang M, Pope DW. Objective sleepiness measures in pediatric obstructive sleep apnea. Pediatrics 2001;108:693–7.
[30] Sleep Disorders Atlas Task Force, EEG arousals: scoring and rules and examples. Guilleminault C, editor. Sleep 1992;15:173–84.
[31] American Thoracic Society, Standards and indications for cardiopulmonary sleep studies in children. Am J Respir Crit Care Med 1996; 153:866–78.
[32] Diagnostic Classification Steering Committee (Thorpy MJ, chair), Periodic limb movement disorder. International classification of sleep disorders: diagnostic and coding manual. Rochester, MN: American Sleep Disorders Association; 1990. p. 69–71.
[33] Corkum P, Moldofsky H, Hogg-Johnson S, Humphries T, et al. Sleep problems in children with attention-deficit/hyperactivity disorder: impact of subtype, comorbidity, and stimulant medication. J Am Acad Child Adolesc Psychiatry 1999;38:1285–93.
[34] Chervin RD, Archbold KH, Dillon JE, Panahi P, et al. Inattention, hyperactivity, and symptoms of sleep-disordered breathing. Pediatrics 2002;109:449–56.
[35] O'Brien LM, Holbrook CR, Mervis CB, Klaus CJ, et al. Sleep and neurobehavioral characteristics of 5–7 year-old children with parentally reported symptoms of ADHD. Pediatrics 2003;111: 554–63.
[36] Beebe DW, Gozal D. Obstructive sleep apnea and the prefrontal cortex: towards a comprehensive model linking nocturnal upper airway dysfunction to daytime cognitive and behavioral deficits. J Sleep Res 2002;11:1–16.
[37] Mick E, Biederman J, Jetton J, Faraone S. Sleep disturbances associated with attention deficit hyperactivity disorder: the impact of psychiatric comorbidity and pharmacotherapy. J Child Adolesc Psychopharmacol 2000;9:157–68.
[38] Kent JD, Blader JC, Koplewicz HS, Abikoff H, et al. Effects of a late-afternoon methylphenidate administration on behavior and sleep in attention-deficit hyperactivity disorder. Pediatrics 1995;96:320–5.
[39] Efron D, Jarman F, Barker M. Side effects of methylphenidate and dexamphetamine in children with attention deficit hyperactivity disorder: a double-blind, crossover trial. Pediatrics 1997;100:662–6.