Sleep and Neurobehavioral Functioning in Boys with Attention-Deficit/Hyperactivity Disorder and No Reported Breathing Problems

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Study Objective: To investigate by objective measures the neurobehavioral correlates of sleep patterns in boys with attention-deficit/hyperactivity disorder (ADHD) and no reported breathing problems and in control children.
Design: Sleep assessment was conducted for 5 consecutive days and neurobehavioral assessment was conducted in the morning of the third day of measurement in children with ADHD and no breathing problems and control children.
Setting: The neurobehavioral assessment was conducted in the school; sleep was assessed in the home.
Participants: 25 controls and 24 boys diagnosed with ADHD between 7 and 11 years of age.
Measurements: Sleep was monitored using actigraphy for 5 consecutive nights. A computerized neurobehavioral evaluation system was used to assess children's neurobehavioral functioning.
Results: Canonical correlation analyses revealed different patterns of associations between sleep and neurobehavioral functioning for the 2 groups. Significant relationships were found between measures of sleep and performance on complicated neurobehavioral tasks in the control group but not in the ADHD group. In addition, children with ADHD had increased instability of sleep parameters compared to the controls.
Conclusions: The findings highlighted the distinct nature of associations between sleep and neurobehavioral functioning in boys with ADHD children and no reported breathing problems compared to controls. Despite the similarity between symptoms caused by sleep fragmentation and symptoms of ADHD, these appear to be different clinical conditions. The source of inattentiveness in children should be identified for best planning of clinical intervention.
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INTRODUCTION

ATTENTION-DEFICIT/HYPERACTIVITY DISORDER (ADHD) IS THE MOST COMMON PSYCHIATRIC DISORDER IN CHILDREN AND OCCURS 3 TO 6 TIMES MORE FREQUENTLY IN BOYS THAN IN GIRLS.[1] It is characterized by impaired attention, impulsivity, and excessive motor activity.[2] Parents have reported high prevalence of sleep problems in children diagnosed with ADHD. Recently, it has been suggested that sleep problems associated with breathing problems might underlie symptoms of inattention and hyperactivity[3] and that treatment of sleep problems might result in improving behavior and decreasing the need for stimulant medication.[4,5] Studies focusing on the relationships between sleep and its association with daytime functioning of children diagnosed with ADHD symptoms that are not related to breathing problem are lacking. The purpose of the present study was to investigate the neurobehavioral correlates of sleep patterns in boys diagnosed with ADHD and no reported breathing problems.

The study extended previous research in several ways, first, by using validated objective instruments to assess sleep and neurobehavioral functioning (NBF). For the assessment of sleep, we utilized objective methodology rather than parental report, and we assessed natural sleep schedules for 5 consecutive nights in the natural home environment of the children rather than in the laboratory. For the assessment of daytime functioning, we used objective, age-appropriate, validated instruments. Second, we also extended previously published research findings by relying on a sample that comprised nonmedicated children who met the diagnosis for ADHD and had no reported breathing problem.

Disclosure Statement
No significant financial interest/other relationship to disclose.

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Sleep and ADHD

A high prevalence of sleep problems, including difficulties in falling asleep and frequent night awakening, has been subjectively reported by parents of children diagnosed with ADHD and by clinicians.[6,7] Studies that have used objective measures of sleep have documented increased nocturnal movement,[8] periodic limb movement disorder (PLMD),[9] and higher levels of day-to-day instability of sleep onset, sleep duration, and true sleep[10] in children with ADHD compared to unreferred controls. Despite the interest in the subject, the implications of the abnormalities of the sleep-wake system of children with ADHD on their daytime functioning remain unclear.

Sleep, NBF, and ADHD

Clinical and research data have suggested that inadequate sleep results in tiredness and daytime difficulties with focused attention, learning, and modulation of impulses.[11-14] These difficulties are very similar to the core symptoms of ADHD—inattention and impulsivity or hyperactivity.[14] Empirical data that support the subjective observations regarding the relationships between sleep and ADHD-like symptoms derive from studies that investigated the effects of sleep restriction or sleep deprivation on cognitive functioning.[15,16,17] These studies documented deterioration in vigilance, memory, and learning following sleep deprivation. However, most of these studies involved normal adult subjects. There are few empirical data that pertain directly to the effects of sleep loss on children's NBF. In an earlier study, we found that, in a nonclinical sample of school-aged children, fragmented sleep was associated with poorer performance on NBF measures and with higher rates of behavior problems.[18] However, the implication of the findings regarding children with ADHD are not clear.

Data obtained from children who suffer from medical conditions associated with breathing difficulties during the night have provided evidence for associations between symptoms of inattention and hyperactivity during the day and fragmented or insufficient sleep.[3,4,19] These conditions were found to be particularly strong among young boys.[3] However, there is a lack in parallel studies with boys diagnosed with

ADHD not associated with breathing problems. Given the dearth of empirical data regarding these issues, one goal of the current study was to examine the relationships between sleep and NBF in boys with ADHD and no reported breathing problems and normal controls.

Another body of literature that connects sleep abnormalities and cognitive functioning has focused on studying infants' sleep patterns and neurocognitive status. In these studies, the variability or stability of sleep-wake patterns was found to be correlated with infants' neurocognitive deficits.[20,21] Sleep stability and variability refer to the consolidation of behavioral and physiologic states into distinct periods of sleeping and waking and their organization into stable cycles.[22] The more consistent the temporal patterning of sleep, the more stable and less variable is the system. Because the association between sleep-wake variability and NBF has only been examined in young infants,[20,21] and in light of our earlier findings documenting increased sleep variability in children with ADHD,[10] another goal of the present study was to examine the relationships between sleep variability and NBF in boys with ADHD and no reported breathing problems and normal controls.

The Current Study

In the present study, we used actigraphy to obtain children's sleep patterns over several nights. It has been suggested that an intraindividual analysis requires at least 4 observations.[23] We measured sleep on 5 consecutive nights. Our measures of group differences across the nights of the study were the group means on each of the sleep parameters. Our measure of sleep variability was the variability of the sleep parameters as reflected in the size of their SDs for each individual during 5 days of measurement. The more varied, that is, unstable, the sleep-wake parameters, the greater the SDs of these measures. The NBF of the children was assessed by the Neurobehavioral Evaluation System (NES), a battery that has been adapted for use with children.[24, 25] The purpose of the study was to examine the relationships between sleep patterns and their intraindividual variability and NBF in boys with ADHD and no breathing problems and in normal controls. Whether the nature of associations between the sleep and NBF in the ADHD and nonclinical groups would be similar was an open empirical question that was examined for the first time in the present study.

SUBJECTS AND METHOD

Subjects

The sample consisted of 24 boys diagnosed with ADHD (mean age = 8.94 years, SD = 1.25, range = 7-11 years) and 25 nonreferred boys (mean age = 8.83 years, SD = 1.01, range = 7.67-10.4 years). Of the 24 children who met the *Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (*DSM-IV*)*[2] criteria for ADHD, 2 met the criteria for the Inattentive subtype, 4 met the criteria for the Hyperactive/Impulsive subtype, and 18 fulfilled the criteria for both Inattentive and Hyperactive/Impulsive**.** In order to eliminate confounding between symptoms that are associated with the effects of stimulant medication on sleep and sleep issues that are associated with ADHD, we excluded from the study children who were on medication. The boys with ADHD who met the DSM-IV criteria for ADHD had no comorbid diagnoses, had no reported breathing problems, and were not taking medication.

The full-module section of the Schedule for Affective Disorders and Schizophrenia Epidemiological version for School-Age Children (K-SADS)[24] on ADHD was completed by children's primary teachers and parents. The children were mainly from families with middle to upper socioeconomic status. Most of the parents were employed full time (fathers, 89.4%; mothers, 45.1%) and were well educated (mean years of formal education, 14.7). Most of the children (92.5%) lived with both parents in relatively small households (mean number of family members, 4.7). Children with any acute physical illness or children receiving medication were excluded from the study.

The study was approved and supported by the Tel Aviv University Institute Review Board, the National Ministry of Education, and the school authorities. It was part of a larger study that aimed at assessing sleep in school-aged children. The study was defined by the school authorities as a school project, and informed consent was obtained from the children and their parents. Recruitment was focused on a target school in a district whose residents belong to middle and upper-middle socioeconomic classes. Each child was rewarded with a $15 voucher (for an office and school supply store) for participating in the study. The recruitment efforts led to a consent rate of above 95% in all classes involved.

Procedure

Within 2 to 4 weeks following the completion of the questionnaires, each child's NBF was assessed with the NES[24,25] in school. His sleep was assessed at home using actigraphs attached to his nondominant wrist for 5 consecutive nights from bedtime until morning rise time. Parents were instructed to maintain the child's regular sleep schedule and routines. All children were free of medication during the evaluation. They were monitored during regular school days (excluding weekends and holidays) to eliminate variability related to sleep-schedule disruptions associated with weekends and holidays. As a result, no gross abnormalities were reported during the nights of the study. In order to reflect the natural sleep patterns of the children, no attempts were made to control sleep quality in the nights preceding the neurobehavioral testing of the participants.

Measures

We used the full-module section of the K-SADS[26] on ADHD, in which emphasis was placed on interviews with the children's primary teachers and parents. The module is composed of the 18 items from the DSM-IV (9 for attention, 6 for hyperactivity, and 3 for impulsivity), each ranked 0—not at all, 1—sometimes, or 2—often. A diagnosis of ADHD is based on a score of 2 in at least 6 symptoms of inattention or at least 6 symptoms of hyperactivity or impulsivity. Children were considered to have ADHD only when all raters made an independent diagnosis of ADHD.

Sleep Measures

Activity monitoring was used to assess sleep-wake patterns. The children were instructed to attach miniature actigraphs (Ambulatory Monitoring Inc. Ardsley, NY, USA) to their nondominant wrist in the evening for 5 continuous nights before school days when preparing for sleep and remove them in the morning. The actigraphs collected data in 1-minute epochs (activity level was sampled at 10-second intervals and summed across 1-minute intervals) and stored in amplifier setting 18 (ie, manufacturer's technical code for frequency bandpass 2-3 Hz, high gain and high threshold). This working mode is the standard mode for sleep-wake scoring. Actigraphic raw data were translated to sleep measures using the Actigraphic Scoring Analysis program (ASA, Tel-Aviv, Israel) for an IBM-compatible personal computer. These sleep measures have been validated against polysomnography with agreement rates for minute-by-minute sleep-wake identification higher than 90%.[27-29]

Actigraphic sleep measures included parameters of *Sleep Schedule:* (*a*) sleep-onset time (SOT) and (*b*) morning wake-up time (WT); *Sleep Quantity*: (*c*) sleep duration (DUR)—total sleep period (from SOT to WT)—and (*d*) true sleep time (TSLP)—sleep time excluding all periods of wakefulness; and *Sleep Quality:* (*e*) sleep efficiency (SE)—percentage of TSLP from total sleep period, (*f*) motionless sleep (ZERO)—percentage of sleep without any detected motion, and (*g*) number of night awakenings (NWK). The reliability of the sleep measures has been previously tested using reliability estimates for aggregate values over 5 successive nights of recording.[30] For all the sleep-wake measures included in the present study, reliability estimates ranged between .71 and .89, which is to be considered adequate or better.[30,31]

Breathing Problems

The assessment of breathing problems was based on subjective report on a questionnaire. The following questions were used: "Does your child snore or have difficulties breathing during sleep?" "Does your child suffer from asthma?" "Does your child suffer in the present or has your child suffered in the past from breathing problems? If *yes*, please indicate when, for how long, and the treatment that was or is provided" These questions were included in the Sleep Habits Questionnaire, a 25-item scale with good internal consistency and external validity.[32] For each item, the parent responded using a 4-point Likert-scale (0, *never*; 1, *sometimes*; 2, *often*; 3, *almost always*). Children with scores above 0 on any of the items pertaining to breathing problems were excluded from the study.

Neurobehavioral Evaluation

The NES was developed to provide a sensitive test to detect variations in neuropsychological functioning as a result of disease or environmental toxic effects.[24] It has been successfully used with school-aged children[33,34] and validated as a good predictor of attention difficulties associated with school performance and classroom behaviors. Performance on the NES has also been associated with sleep patterns in children.[18,34] For the present study, the NES was installed on a Compaq notebook computer (Contura model, Hewlett-Packard , CA, USA), and the tests administered to the children included 6 age-appropriate tests.

Finger Tapping

The child was requested to tap as fast as possible with 1 finger on a single button. This test examined motor speed. The measure used was the maximum number of taps.

Digit Span Forward

A sequence of digits was presented 1 at a time to the children, and after the whole sequence was presented, the child was required to enter the sequence on the computer keyboard. Increasingly longer spans of digits were presented until the child made 2 errors in 1 span length. The length of the longest span the child answered correctly was recorded.

Digit Span Backward

A sequence of digits was presented 1 at a time to the children. After the whole sequence was presented, the child was required to enter the sequence on the computer keyboard. In this task, the child had to respond with the order of the digits reversed (backward). The length of the longest span the child answered correctly was recorded.

Reaction Time

The child was requested to press a button as quickly as possible when a large square appeared on the screen. The intertrial interval was varied randomly to reduce effects of stimulus anticipation. Individual reaction-time latencies were recorded. Mean reaction-time latencies were calculated while omitting the first block of trials.

Symbol-Digit Substitution Task

Nine symbols and 9 digits were paired at the top of the screen, and the child was asked to press the digits on the keyboard corresponding to a test set of the 9 symbols presented in a mixed order. Six sets of 9 symbol-digit pairs were presented in succession. The measures used were average response latency (in seconds) for completing each set.

Continuous Performance Test

Different graphic images of animals were presented on the screen at varying time intervals in the Continuous Performance Test (CPT), and the child was required to respond as quickly as possible when a cat was presented and to not respond to any other animal. The measures included response time, omission errors (not responding to the cat), and commission errors (responding to other animals).

The reliability of the NES measures has been tested before using test-retest Pearson correlations.[18] For all NES measures, the reliability estimates ranged between .42 to .93, and were significant at $P < .0001$.

Statistical Analyses

Data Analysis

For analyses of group differences on sleep measures, scores on each of the actigraphic measures of sleep schedule, sleep quantity, and sleep quality were averaged across the groups across the 5 nights of monitoring. Thus, scores on the measures represent the calculated means and are labeled *Group Means of Sleep Measures*. For analyses of the level of night-to-night changes of sleep measures, the SD of sleep measures within each individual subject was used. These measures are labeled *Intraindividual Variability of Sleep Measures*. For analyses of NBF, scores that exceeded 2 SDs of the mean scores of each task were excluded from the analyses.

Analytic Plan

Age, Sleep and NBF

Pearson correlation analyses were conducted to assess the relationships between age and sleep and between age and NBF.

Assessing Group Differences in NBF

In order to assess group differences in NBF, multivariate analysis of covariance (MANCOVA) was conducted with diagnosis as the independent variable and the NBF factors as the dependent measures and age as a covariate.

Creating Subsets of NBF Variables

A principal factor analysis was conducted on the NBF tasks in order to create subsets of NBF tasks.

Testing the Association Between Sleep and NBF Functioning

Separate canonical correlation analyses (CCAs) were conducted to test the relationships between sleep measures and subsets of NBF tasks in the control and the ADHD groups. A CCA is the correlation of 2 canonical (latent) variables, 1 representing a set of independent variables and the other representing a set of dependent variables. The purpose of this canonical analysis is to explain the relation of the 2 sets of variables. A canonical variable, also called a *variate*, is a form of latent variable that is a linear combination of a set of original variables in which the within-set correlation has been controlled.

The *canonical coefficients* are the weights in the linear equation of variables that creates the canonical variables. As such, they are analogous to β weights in regression analysis. The degree to which the original variables load on the canonical variates indicates the degree to which the variables are related to the latent variable represented by the canonical variate. In this study, a minimum loading of .40 was used to assign a variable to a canonical variate. Canonical correlation squared is the percentage of variance in the dependent set explained by the independent set of variables along a given dimension. Canonical correlations can be tested for statistical significance, and only canonical variate pairs with statistically significant or marginally significant canonical correlations were interpreted for this study (see Tabachnick and Fidell, 2001 for a more detailed explanation of CCA).

Comparing Sleep Measures Between the ADHD and the Normative Groups

In order to assess group differences in scores on actigraphic sleep measures while controlling for the multiple comparisons, we conducted parallel MANCOVAs with diagnosis (ADHD / Control) as the independent variable, the standard or stability sleep measures as dependent measures, and age as covariate.

RESULTS

Means, SD, and F and *P* values of sleep parameters and of NBF measures are presented in Table 1.

Association Between Age and Sleep

Significant negative correlations between group means of sleep measures and age were found, indicating shorter DUR and smaller amount of TSLP in older children (r = -.45, P < .01; r = -.30, P < .05, respectively). Positive association was found between age and ZERO (r = .42, P < .01), indicating increased amount of motionless sleep in older children.

Association Between Age and NBF

Significant negative correlation was found between age and performance on the Symbol Digit Task (r = -.51, P < .01), and significant positive association was found between age and performance on the Digit Forward Memory task (r = .34, P < .05), both indicating better NBF in older children. Marginal age differences were found on the Finger Tapping task and on the Digit Backward Memory task (r = -.26, P < .06; r = .28, P < .06, respectively), indicating trends toward better performance on these tasks in older children.

Assessing Group Differences in NBF

MANCOVA revealed significant main effect for diagnosis, Wilks λ $F_{10,32}$ = 2.24, P < .04. Analyses of variance (ANOVAs) that were used to assess the distinct effects for each dependent measure revealed that children in the ADHD group had longer latencies on the Simple Reaction Time task, the CPT, and the Symbol Digit task; more omission errors on the CPT; and marginal differences on the Digit Forward Memory task.

Principal Component Analysis on NBF tasks

All of the NBF measures grouped on 2 factors in a principal component factor analysis with a varimax rotation (loading from .42 to .91). The first factor (eigenvalue 2.4) comprised measures of performance on the Reaction Time task, Symbol-Digit task, and CPT (reaction time, commission errors, omission errors). These scores represent performance on tasks in which subjects are required to sustain attention for prolonged periods of time, to inhibit responses, and to use working memory (ie, relatively complicated tasks) and thus were included in the subset of tasks that was labeled *NBF Complicated*. The amount of variance explained by this factor was 2.97, which was 37.12% of the total variance. The second factor (eigenvalue 1.5) comprised performance on the Finger-Tapping task and the Memory tasks (Digit Forward, Digit Backward). These scores represent performance that requires motor skills and short-term memory, relatively simple tasks, and thus were included in the subset of tasks that was labeled *NBF Simple*. The amount of variance explained by this factor was 1.52, which was 19% of the total variance.

Canonical Correlation Analyses

Separate CCAs were performed between 3 sets of standard sleep variables (ie, sleep schedule, sleep quantity, and sleep quality) and the NBF subsets of complicated and simple tasks. These analyses were followed by analyses of parallel measures of sleep stability. Results from the control and ADHD samples are shown in Table 2.

The canonical correlations between-group means of Sleep Schedule and NBF were not significant in the control and the ADHD groups. The canonical correlation between a set of intraindividual variability measures of Sleep Schedule and the Complicated NBF tasks was significant in the control group. The canonical variate for the predictor set primarily represented intraindividual variability of SOT. The canonical variate for the NBF set represented Reaction Time on Symbol-Digit task and CPT.

The canonical correlations between-group means of Sleep Quantity and the subset of the Complicated NBF tasks was significant in the control group. The canonical variate for the predictor set primarily represented TSLP. The canonical variate for the NBF set represented Reaction Time on the Symbol-Digit and CPT tasks and Omission errors on the CPT. The canonical correlation between intraindividual variability of Sleep Quantity and performance on the subset of the Complicated NBF tasks was also significant in the control group. The canonical variate represented variability of DUR and TSLP. The canonical variate for the Complicated NBF set represented Reaction Time on Symbol-Digit task and number of omission and commission errors on the CPT.

The canonical correlations between-group means and intraindividual variability measures of Sleep Quality and subset of the Complicated NBF tasks were significant in the control group. The canonical variate for the predictor set primarily represented group means of SE and NWK. The canonical variate for the predictor set comprised measures of intraindividual variability of sleep, primarily representing SE. The canonical variate for the NBF set represented the Reaction Time on the Symbol-Digit tasks and on the CPT, as well as commission and omission errors on the CPT.

The canonical correlations between intraindividual variability measures of Sleep Quality and the set of the Simple NBF tasks was also significant in the control group. The canonical variate for the predictor set comprised measures of intraindividual variability of sleep, primarily represented SE. The canonical variate for the NBF subset represented performance on all 3 tasks, ie, Finger Tapping, Digit Forward and Digit Backward.

Table 1a—Sleep Measures Recorded over 5 nights in Boys—25 Controls and 24 with Attention-Deficit/Hyperactivity Disorder

	Group Means				Intraindividual Variability			
	Control Mean ± SD	ADHD Mean ± SD	F	P	Control Mean ± SD	ADHD Mean ± SD	F	P
SOT	22 ± 0.65	21.9 ± 0.9	.00	NS	0.44 ± 0.33	0.73 ± 0.4	8.27	***
WT	6.84 ± 0.33	6.86 ± 0.37	.28	NS	0.28 ± 0.21	0.36 ± 0.2	1.39	NS
DUR	532 ± 36.8	537.7 ± 27.4	.1	NS	14.95 ± 14.2	45.54 ± 17	13.8	***
TSLP	497 ± 43.4	490.9 ± 40.45	.39	NS	29.45 ± 14.4	47.83 ± 14	17.9	***
SE	93.3 ± 9.34	62.3 ± 10.75	1.98	NS	3.02 ± 2.01	4.07 ± 2.5	1.22	NS
ZERO	64.3 ± 36.8	63.68 ± 9.59	.1	NS	5.27 ± 2.26	5.36 ± 2.4	0.05	NS
NWK	1.8 ± 1.3	2.2 ± 1.3	.1	NS	1.2 ± 0.64	1.2 ± 0.6	0.005	NS

ADHD refers to attention-deficit/hyperactivity disorder; SOT, sleep-onset time; WT, morning wake-up time; DUR, sleep duration; TSLP, true sleep time; SE, sleep efficiency; ZERO, percentage of motionless sleep; NWK, number of night awakenings.

Assessing Group Differences on Sleep Parameters

No significant differences were found between the ADHD and the control groups on the group means of sleep parameters. The MANCOVA that was conducted to compare the groups on intraindividual variability of sleep measures revealed a significant main effect for diagnosis, $F_{7,38}$ = 2.65, P < .03. ANOVAs that were conducted to assess the distinct effects for each dependent measure revealed that children with ADHD had increased intraindividual variability of DUR, TSLP, and SOT compared to children in the control group.

DISCUSSION

The major finding of this study was the lack of significant associations between sleep and NBF in the ADHD group.

Previous studies in adults and children have suggested that disrupted sleep might be associated with disturbances in the cognitive and behavioral functioning characterizing children diagnosed with ADHD.[14] The findings of the present study do not support this hypothesis.

In the control group, increased amount of sleep and increased quality of sleep, as well as smaller variability of parameters of sleep quantity and quality, were related to better performance on complicated NBF tasks. These findings are consistent with recent studies that establish a connection between sleep and performance on tasks that require complicated attention processes in a normative population of school-aged children.[18,35,38]

In the control group, intraindividual variability of sleep quality was associated with complicated and simple tasks. These findings are consistent with the findings in the infancy literature indicating that increased sleep variability in infants is associated with poorer NBF.[21,22,37] The findings of the current study further suggest that in a normal population of school-aged boys, intraindividual sleep variability of duration and sleep schedule may be linked more closely to complicated NBF tasks that require sustained attention and working memory than on simple NBF tasks that require motor functioning and short-term memory. Children in the ADHD group had more difficulties performing on the neurobehavioral tasks that required sustained attention, coordination of visual-motor abilities, and the of use working memory.

Finally, the results replicate the finding regarding increased sleep variability as a characteristic of children with ADHD. A direct relationship between the arousal and the attention systems is critical for maintaining self-regulation. Arousal regulation has important implications for ongoing information processing, learning, and memory because it serves as a gating mechanism to optimize orientation and attention. Shifts in arousal are manifested by changes in behavioral state and levels of alertness and attention.[39] We suggest a regulation-deficit explanation associated with the modulation of components of arousal, ie, sleep and attention. According to this explanation, a deficit in the system that is responsible

Table 1b—Neurobehavioral Functioning

	Control (n = 25) Mean ± SD	ADHD (n = 24) Mean ± SD	F	P
Tapping	130.33 ± 30.8	133.79 ± 14	.63	NS
SRT	421.04 ± 59.2	507.78 ± 97	11.86	***
Digit Span FW	4.63 ± 0.82	5 ± 0.9	3.73	+
Digit Span BW	3.75 ± 1.07	3.52 ± 0.9	.36	NS
SD-RT	3448.5 ± 1094	3932.1 ± 674	4	*
CPT-RT	685.29 ± 64.73	732.17 ± 60	4.65	*
CPT-Om Err	2.5 ± 2.19	3.5 ± 2.5	4.65	*
CPT-Com Err	1.38 ± 2.87	3.33 ± 2.8	2.2	NS

ADHD refers to attention-deficit/hyperactivity disorder; Tapping, number of finger tappings; SRT, Simple Reaction Time; FW, forward; BW, backward; SD, Symbol Digit; RT, Reaction Time; CPT, Continuous Performance Test; Om Err, omission errors; Com Err, commission errors.
+ marginal; *P < .05; **P <.01; ***P < .005.

Table 2a—Canonical Correlations and Canonical Variate Loadings for Sleep and NBF Measures

Sleep Schedule and Simple NBF Measures

	Control Sample				ADHD Sample			
	Group Mean		Sleep Variability		Group Mean		Sleep Variability	
	Canonical	Variates	Canonical	Variates	Canonical	Variates	Canonical	Variates
	1	2	1	2	1	2	1	2
Canonical Correlation	0.5	0.46	0.4	0.1	0.61	0.25	0.54	0.22
SOT	0.92	-0.4	-0.51	0.86	-0.98	0.19	-0.64	0.77
WT	-0.69	0.72	0.69	0.72	-0.57	0.82	-0.86	-0.51
Neurobehavioral Measures								
FT	-0.67	0.32	0.15	-0.04	-0.9	-0.28	-0.07	0.26
Digit Span FW	0.11	-0.67	-0.07	-0.98	-0.51	-0.62	0.25	0.95
Digit Span BW	-0.66	-0.75	0.87	-0.49	-0.32	0.55	-0.75	0.57

Sleep Quantity and and Simple NBF Measures

	Group Mean		Sleep Variability		Group Mean		Sleep Variability	
	Canonical	Variates	Canonical	Variates	Canonical	Variates	Canonical	Variates
	1	2	1	2	1	2	1	2
Canonical Correlation	0.5	0.28	0.38	0.19	0.6	0.3	0.54	0.26
DUR	-0.92	-0.38	-0.39	0.92	-0.99	-0.17	0.47	-0.88
TSLP	-0.59	-0.81	-0.89	0.42	-0.9	0.44	0.88	-0.48
Neurobehavioral Measures								
FT	0.08	0.39	-0.69	-0.67	0.94	-0.18	-0.47	-0.72
Digit Span FW	0.62	-0.64	0.7	0.75	0.49	0.79	-0.43	0.29
Digit Span BW	0.96	0.28	0.35	0.42	0.22	0.59	0.75	0.14

Sleep Quality and and Simple NBF Measures

	Group Mean			Sleep Variability			Group Mean		Sleep Variability	
	Canonical	Variates		Canonical	Variates		Canonical	Variates	Canonical	Variates
	1	2	3	1	2	3	1	2	1	2
Canonical Correlation	0.48	0.35	0.02	.74*	0.39	0.14	0.65	0.25	0.44	0.23
ZERO	-0.78	0.49	-0.39	-0.44	-0.6	-0.67	-0.16	0.44	0.32	-0.92
SEF	-0.3	0.83	0.48	0.72	-0.33	-0.61	-0.43	-0.18	-0.04	-0.7
NWK	0.09	-0.99	0.007	0.37	-0.9	0.23	0.68	0.05	0.7	-0.18
Neurobehavioral Measures										
FT	0.4	-0.14	-0.91	0.48	-0.21	0.85	-0.21	0.97	0.002	-0.27
Digit Span FW	-0.27	0.84	-0.47	-0.61	0.4	0.68	-0.88	0.29	-0.81	0.27
Digit Span BW	-0.82	-0.07	-0.57	-0.64	-0.64	0.44	0.7	-0.33	-0.74	-0.6

Note:SOT= sleep onset time;WT = Sleep waking time; DUR=sleep duration;TSLP=true sleep time;
ZERO=percent of motionless sleep;WL=Numbers of night wakings;SD=Symbol Digit;
RT=Reaction Time; CPT=Continuous Performance Test; Om Err=omission errors; Com Err=commission errors
*p<.05. **p<.001

for the mediation of the effects of sleep and arousal on attention regulation might underlie the lack of significant associations between measure of group means and intraindividual variability of sleep parameters and NBF in the ADHD group. This regulation problem might be associated with other regulatory problems that characterize children with ADHD. Alternatively, the higher intraindividual variability of sleep parameters in children with ADHD could account for the absence of correlation between NBF and sleep.

Clinical Implications

The lack of associations between objective measures of sleep and NBF in children with ADHD and no reported breathing problems suggests that despite the similarity between the symptoms caused by sleep fragmentation and symptoms of ADHD, these might be *different* medical conditions (as has been proposed by Mick et al[40]).

In view of these findings, it is suggested that the source of inattentiveness (eg, inattentiveness associated with breathing disorder during the night *or* with neurologic issues) and of sleep disturbances (eg, whether they are associated with medical conditions that interfere with sleep or with discipline issues) in children with ADHD symptoms should be determined in order to facilitate optimal planning of clinical interventions. Potential different clinical interventions could include increasing structure or external control over sleep bedtime as a part of parent training or the behavioral treatment plan with the child, in the case of sleeping issues that are associated with discipline problems, as opposed to treating breathing disorders that affect sleep quality and improve daytime functioning in children with a medical sleep problem.

Limitations and Future Research

The questions used to assess breathing problems are based on parental reports of problems and cannot replace full polysomnography. A replication of the study with samples assessed by polysomnography and a more elaborate measure of breathing problems is warranted.

In the present study, we assessed the relationships between sleep and NBF using objective and well-established measures of both sleep and NBF. However, the correlative design of the study limits our ability to explain the findings in causal terms. Additional research in which sleep is experimentally manipulated and environmental factors are controlled is warranted.

In the current study, participants were not receiving any psychiatric medication, as opposed to studies in which the majority of the children with ADHD are medicated. Given that many children with ADHD

Table 2b—Canonical Correlations and Canonical Variate Loadings for Sleep and Complicated NBF Measures

Sleep Schedule and and Complicated NBF Measures

	Control Sample				**ADHD Sample**			
	Group Mean		Sleep Variability		Group Mean		Sleep Variability	
	Canonical	Variates	Canonical	Variates	Canonical	Variates	Canonical	Variates
	1	2	1	2	1	2	1	2
Canonical correlation	0.67	0.36	.76*	0.38	0.54	0.34	0.56	0.38
SOT	-0.99	0.1	-0.83	0.53	-0.85	-0.52	0.79	0.62
WT	-0.44	-0.89	0.29	-0.99	-0.99	0.15	0.65	-0.76
Neurobehavioral Measures								
SD-RT	-0.05	-0.19	-0.79	0.06	0.67	0.11	-0.35	-0.34
RR	0.82	-0.12	-0.37	-0.29	0.26	0.24	-0.09	-0.95
CPT-RT	-0.1	-0.18	-0.85	-0.13	-0.07	-0.22	0.05	-0.33
CPT-Om Err	-0.3	0.07	-0.33	0.69	0.56	-0.22	-0.17	-0.23
CPT-Com Err	-0.29	-0.2	-0.51	-0.08	0.18	-0.8	0.6	-0.36

Sleep Quantity and Complicated NBF Measures

	Group Mean		Sleep Variability		Group Mean		Sleep Variability	
	Canonical	Variates	Canonical	Variates	Canonical	Variates	Canonical	Variates
	1	2	1	2	1	2	1	2
Canonical correlation	.87**	.58+	.81*	0.27	0.69	0.38	0.65	0.38
DUR	0.13	0.99	-0.53	-0.85	0.37	-0.93	0.98	-0.21
TSLP	0.65	0.76	-0.95	-0.3	0.85	-0.53	0.92	0.38
Neurobehavioral Measures								
SD-RT	-0.81	0.33	-0.89	-0.42	-0.02	-0.75	-0.14	0.73
RR	-0.05	0.92	-0.02	-0.32	-0.27	-0.62	-0.69	0.44
CPT-RT	-0.42	0.19	-0.36	-0.34	-0.83	-0.36	0.25	0.77
CPT-Om Err	-0.73	-0.2	-0.78	0.54	-0.1	-0.47	-0.05	0.01
CPT-Com Err	-0.29	0.13	-0.69	-0.02	-0.74	-0.14	0.4	0.22

Sleep Quality and Complicated NBF Measures

	Group Mean			Sleep Variability			Group Mean		Sleep Variability	
	Canonical	Variates		Canonical	Variates		Canonical	Variates	Canonical	Variates
	1	2	3	1	2	3	1	2	1	2
Canonical correlation	.85*	0.42	0.27	.83*	0.34	0.25	0.62	0.45	0.75	0.54
ZERO	-0.4	0.55	-0.68	-0.3	0.94	-0.18	0.58	0.29	-0.61	-0.38
SEF	-0.99	-0.09	-3	-0.98	-0.05	-0.21	0.95	0.2	-0.95	0.3
NWK	0.81	0.32	0.5	-0.23	-0.02	-0.97	-0.94	0.14	0.81	-0.33
Neurobehavioral Measures										
SD-RT	0.85	-0.42	0.06	-0.93	0.03	0.13	-0.3	-0.3	-0.06	0.33
RR	0.12	-0.04	0.51	-0.11	-0.83	0.41	-0.52	-0.52	-0.32	-0.82
CPT-RT	0.43	0.11	0.05	-0.43	-0.005	0.33	-0.95	-0.95	-0.81	0.17
CPT-Om Err	0.73	-0.12	0.74	0.71	-0.05	0.37	-0.28	-0.28	-0.21	0.02
CPT-Com Err	0.85	0.4	0.25	-0.75	-0.34	-0.08	-0.66	-0.66	-0.83	-0.05

Note:SOT= sleep onset time;WT = Sleep waking time; DUR=sleep duration;TSLP=true sleep time;
ZERO=percent of motionless sleep;WL=Numbers of night wakings;SD=Symbol Digit;
RT=Reaction Time; CPT=Continuous Performance Test; Om Err=omission errors; Com Err=commission errors
*p<.05. **p<.001

receive psychopharmacologic treatment, a replication of the study with treated samples is relevant to the concerns of many clinicians and educators.

Several studies have indicated that restless legs syndrome (RLS) and PLMD are more prevalent among children with ADHD.[41,42,43] The sleep questionnaire used in the present study included 1 question regarding the degree to which the child's sleep was restless and 1 question regarding excessive movement during sleep but no specific questionnaires for the assessment of RLS or PLMD. As a result, whether the increased variability of sleep found in the ADHD group was related to RLS and PLMD is not known. Future studies that include measures of RLS and PLMD are needed in order to determine the relationship between increased variability of sleep and these disorders in children with ADHD.

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