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Sleep, Neurobehavioral Functioning, and Behavior Problems in School-Age Children

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The aim of this study was to examine the associations between sleep and neurobehavioral functioning (NBF) in school-age children. These variables were assessed for 135 unreferred, healthy school children (69 boys and 66 girls), from second-, fourth-, and sixth-grade classes. Objective assessment methods were used on the participants in their regular home settings. Sleep was monitored using actigraphy for 5 consecutive nights; and NBF was assessed using a computerized neurobehavioral evaluation system, administered twice, at different times of the day. Significant correlations between sleep-quality measures and NBF measures were found, particularly in the younger age group. Children with fragmented sleep were characterized by lower performance on NBF measures, particularly those associated with more complex tasks such as a continuous performance test and a symbol-digit substitution test. These children also had higher rates of behavior problems as reported by their parents on the Child Behavior Checklist. These results highlight the association between sleep quality, NBF, and behavior regulation in child development; and raise important questions about the origins of these associations and their developmental and clinical significance.

INTRODUCTION

Decades of researching the function of sleep have led to a growing body of knowledge on the effects of sleep deprivation and sleep disorders on human functioning and well-being (Bonnet, 1994; Pilcher & Huffcutt, 1996). Minimal efforts were invested in exploring these issues among kindergarten and school children, however, (Sadeh, Raviv, & Gruber, 2000; Wolfson, 1996). This neglect is intriguing, considering the importance of these periods in brain maturation and cognitive development (Levin et al., 1991; Welsh & Pennington, 1988; Welsh, Pennington, & Groisser, 1991). A high prevalence of fragmented sleep in school-age children has been documented recently (Sadeh et al., 2000) by using objective sleep measures.

The existing literature, mostly based on adult studies, suggests that sleep fragmentation, characterized by multiple and/or prolonged night-wakings, has adverse effects on daytime alertness and cognitive performance. The present study focused on understanding the neurobehavioral correlates of sleep patterns in school-age children. Bearing in mind the established links between arousal level and the time of day, the role of the time of day (during which testing occurred) was assessed as a moderating factor vis-à-vis the associations between sleep and neurobehavioral functioning (NBF). Recent data suggesting that the treatment of sleep disorders may lead to an improvement in academic achievements in school-age children (Gozal, 1998) highlights the importance of understanding the relation between sleep and NBF in unreferred school-age children.

The following review focuses on five pertinent research categories: (1) the effects of sleep deprivation or sleep restriction on NBF; (2) correlative studies on sleep and NBF in normal individuals; (3) NBF and sleep in clinical populations; (4) sleep and behavior problems in nonclinical samples; and (5) sleep, time of day, and NBF. In this article the term NBF is used to refer to specific cognitive, attention, and performance skills; and the term behavior or behavior problems is used to refer to broader categories or behavioral patterns (behavior problems, psychopathology, and temperament).

Experimental Sleep Deprivation and Sleep Fragmentation Studies

Experimental sleep deprivation studies provide a unique understanding of the relations between sleep and NBF (Bonnet, 1994; Pilcher & Huffcutt, 1996). These studies have two main design dimensions: (1) the amount of sleep deprived, ranging from limited sleep restriction for a few hours to a total sleep deprivation for extended periods; and (2) the duration of sleep deprivation/restriction, ranging from 1 night to multiple consecutive days.

Extensive research efforts have been directed at studying the effects of sleep deprivation in adults. A recent meta-analysis of the adult literature has identified 56 sleep deprivation studies in a period of 8 years (Pilcher & Huffcutt, 1996). The main conclusion from

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this meta-analysis was that sleep deprivation has very profound detrimental effects on cognitive functioning. The authors claimed that sleep-deprived individuals functioned at a level that is comparable with the ninth percentile of non-sleep-deprived subjects (Pilcher & Huffcutt, 1996).

Another important conclusion that can be drawn from the adult sleep deprivation studies is that complex or difficult tasks are more sensitive to sleep deprivation than simple tasks (Harrison & Horne, 1998; Monk, 1994; Ryman, Naitoh, & Englund, 1985). Complex tasks usually entail higher levels of executive function, cognitive processing, language skills, attentional responsivity, and working memory. Prefrontal cortex involvement in these tasks appears to be a key factor in determining their sensitivity to sleep variations (Dahl, 1996; Harrison & Horne, 1998; Horne, 1993).

Only a small number of sleep deprivation studies with children have been published (Carskadon, Harvey, & Dement, 1981a, 1981b; Copes & Rosentswieg, 1972; Randazzo, Muehlbach, Schweitzer, & Walsh, 1998). Decrements in psychomotor performance were found following total sleep deprivation in children (Copes & Rosentswieg, 1972). Carskadon, Harvey, and Dement (1981a, 1981b) studied the effects of sleep restriction (1 night of 4 hours of sleep) and sleep deprivation (1 full night) and found performance decrements only after the full night of sleep deprivation. Their findings suggest that sleep restriction may not always lead to detectable decrements as does total sleep deprivation. Randazzo, Muehlbach, Schweitzer, and Walsh (1998), however, reported decrements in performance in children following a single night's restriction to 5 hours in bed in comparison with children who spent 11 hours in bed. These decrements were found on measures of verbal creativity and on the Wisconsin Card Sorting Test. Effects of sleep deprivation were not found on less complex memory tasks. The authors concluded that the higher cognitive functions that involve verbal creativity and abstract thinking are more sensitive to sleep restriction in children.

Another perspective on the relations between sleep and NBF is based on sleep fragmentation studies in which the participant is experimentally awakened multiple times for a brief duration. In many sleep disorders, sleep fragmentation is the major factor with or without reduction in sleep time (Philip, Stoohs, & Guilleminault, 1994). It has been suggested that the adverse effects of sleep fragmentation result from the increase of less restorative sleep and the relative decrease in deeper and more restorative sleep stages (Philip et al., 1994; Roehrs, Merlotti, Petrucelli, Stepanski, & Roth, 1994; Wesensten, Balkin, & Belenky, 1999). These effects were associated with increased daytime sleepiness and decrements in NBF. In view of earlier findings indicating high prevalence of fragmented sleep in a nonclinical sample of school-age children (Sadeh et al., 2000), these sleep fragmentation studies highlight the potential adverse effects of multiple night-wakings and reduced sleep quality on subsequent daytime functioning—a topic that has never been directly studied in children.

Sleep and NBF in Normal Children: Correlative Studies

Little research has been conducted on sleep and NBF in children. Most of the studies have been based on surveys of sleep–wake patterns and academic achievement or behaviors associated with daytime sleepiness and attention problems in children and adolescents (Epstein, Chillag, & Lavie, 1998; Gau & Soong, 1995; Mercer, Merritt, & Cowell, 1998; Morrison, McGee, & Stanton, 1992; Saarenpaa-Heikkila, Rintahaka, Laippala, & Koivikko, 1995; Tynjaelae, Kannas, Levaelahti, & Vaelimaa, 1999; Tynjala, Kannas, & Levalahti, 1997; Wolfson & Carskadon, 1998). For instance, Wolfson and Carskadon (1998) have reported that later bedtimes, shorter sleep duration, and weekdays–weekend sleep schedule irregularities were associated with increased daytime sleepiness and poorer academic achievements in high school students. Epstein et al. (1998) reported that early school start time was associated with shorter sleep and increased attention problems during school hours in fifth-grade Israeli students.

From a different perspective, concurrent and predictive relations between sleep and neurobehavioral functioning have been documented with younger children and infants (Freudigman & Thoman, 1993; Thoman, 1975; Thoman, Denenberg, Sievel, Zeidner, & Becker, 1981). For instance, Freudigman and Thoman (1993) have found that sleep–wake measures of newborns on their first and second postnatal days were significantly correlated with their Bayley mental scores at 6 months of age. The authors concluded that the sleep–wake system might be a sensitive predictor of early neurobehavioral organization and later development.

Sleep and NBF in Clinical Samples

The respiratory system is very vulnerable during sleep and some of the most prevalent and severe sleep disorders are associated with breathing disorders (sleep apnea and asthma). Sleep apnea is a disorder of breathing during sleep that can result in severe fragmentation of sleep and increased daytime sleepiness

(Carrol & Louglin, 1995). In children, it has been shown that sleep-disordered breathing (including "benign" snoring) is associated with increased daytime tiredness or sleepiness and with NBF deficits (Chervin & Archbold, 2001; Chervin, Dillon, Bassetti, Ganoczy, & Pituch, 1997; Gozal, 1998; Hansen & Vandenberg, 1997; Rosen, 1999; Sadeh, Horowitz, Wolach-Benodis, & Wolach, 1998; Stores, Ellis, Wiggs, Crawford, & Thomson, 1998). The NBF deficits that have been associated with sleep in these studies were related to attention, memory, concentration, and academic achievements. Of special interest is Gozal's finding that when the breathing disorder is treated, some deficits are reversible and children can improve their academic achievements following such intervention (Gozal, 1998). Another sleep disorder that has been associated with compromised NBF is the periodic limb movement disorder (Chervin et al., 1997; Picchietti & Walters, 1999). Overall, these studies suggest that sleep disorders are associated with NBF deficits and related symptoms.

Viewing the issue from a developmental psychopathology perspective, specific developmental or neurobehavioral disorders have been associated with sleep problems. For instance, one disorder that has attracted considerable attention in children is Attention-Deficit/Hyperactivity Disorder (ADHD). A higher prevalence of sleep problems has frequently been reported in children diagnosed with ADHD; however, most studies that have used objective sleep assessment methods failed to detect clinically significant differences between children with ADHD and controls (Corkum, Tannock, & Moldofsky, 1998). In a recent study, we found that the sleep schedule of children with ADHD was characterized by higher levels of day-to-day instability in comparison with that of unreferred controls (Gruber, Sadeh, & Raviv, 2000). Despite the inconsistent findings on the links between sleep and ADHD, these links have gained relatively much attention, because the attentional system and the arousal system (which is closely related to sleep) are functionally and neuroanatomically interrelated (Corkum et al., 1998; Dahl, 1996; Posner & Petersen, 1990).

Research on sleep in other clinical groups of children with neurobehavioral developmental disorders has documented increased rates of sleep problems (Hering, Epstein, Elroy, Iancu, & Zelnik, 1999; Levanon, Tarasiuk, & Tal, 1999; Marcotte et al., 1998; Okawa & Sasaki, 1987; Patzold, Richdale, & Tonge, 1998; Quine, 1992). In summary, these studies indicate that children with developmental disorders (Autism, Pervasive Developmental Disorder, and learning and other neurobehavioral disorders) exhibit a higher prevalence of disorganized or disturbed sleep in comparison with control children.

Sleep and Behavior Problems in Nonclinical Samples

Significant links between sleep problems and manifestations of poor behavior regulation, behavior problems, and psychopathology have been demonstrated in both clinical and nonclinical samples (Dahl et al., 1996; Mindell, Owens, & Carskadon, 1999; Sadeh & Gruber, 1998). Sleep problems have been associated with difficult temperament in infants and young children (Carey, 1974; Novosad, Freudigman, & Thoman, 1999; Owens-Stively et al., 1997; Sadeh, Lavie, & Scher, 1994; Schaefer, 1990; Weissbluth, 1984; Weissbluth & Liu, 1983). In older children, sleep problems or sleep disorders have been associated with behavior problems and specific psychopathological disorders such as affective disorders, anxiety disorders, and Posttraumatic Stress Disorder (Dahl, 1996; Lavigne et al., 1999; Moore, 1989; Owens, Opipari, Nobile, & Spirito, 1998; Sadeh, 1996; Seifer, Sameroff, Dickstein, & Hayden, 1996; Wolfson & Carskadon, 1998). In the present study, the associations between sleep and behavior problems in a representative sample of unreferred children was further explored.

Sleep, Time of Day, and NBF

NBF is determined by multiple factors including the level of arousal during performance (Monk, 1994; Monk et al., 1997). The level of arousal at a given moment is determined by multiple factors, including those related to sleep and circadian rhythms (Borbely, 1994; Monk, 1994). Hence, when assessing the relations between sleep and performance, it is important to also consider the time of day as a major factor that determines alertness.

Circadian rhythms (or time-of-day effects) in cognitive performance and NBF have been documented (Andrade & Menna Barreto, 1996; Folkard, Monk, Bradbury, & Rosenthall, 1977; Heuer, Spijkers, Kiesswetter, & Schmidtke, 1998; Huguet, Touitou, & Reinberg, 1995; Lawrence & Stanford, 1999; Lenne, Triggs, & Redman, 1998; Montangner, De Roquefeuil, & Djakovic, 1992; Morton & Kershner, 1993; Natale & Lorenzetti, 1997). Furthermore, it has been shown that the course of sleep inertia plays a role in performance following awakening from sleep (Jewett et al., 1999; Tassi & Muzet, 2000). Sleep inertia—the decreased performance and increased disorientation that occurs after awakening from sleep—has been documented in many studies (Tassi & Muzet, 2000). These studies have shown that this phenomenon can last up to 4 hours after awakening. Furthermore, it has been demonstrated that prior sleep deprivation enhances sleep inertia. These studies, mostly focused on adults, suggest that the time of day should be considered as a major factor in assessing NBF in general, and in testing the associations between sleep and NBF in particular. One of the goals of the present study was to investigate the significance of the time of day in assessing the correlations between sleep and NBF. Our assumption was that sleep-disturbed children would be more likely to show lower performance during the early morning hours—when sleep inertia might still play a more significant role—than the later hours of the school day.

Summary and Specific Goals of the Study

The literature reviewed above suggests that there appear to be significant links between the sleep–wake system and children's cognitive performance NBF and children's behavior regulation. The nature of these relations in normal development, however, is far from being understood. The existing literature on children relies mostly on studies based on objective methodologies in experimental or unnatural circumstances (sleep laboratory) or on studies using subjective sleep measures and rough estimates of NBF (school achievement or subjective reports). Furthermore, developmental perspective and design were lacking in many of the studies conducted on this topic.

The purpose of the present study was to explore the associations between sleep and NBF in unreferred school children using objective measures. Three distinct age groups provided a detailed developmental perspective. We were especially interested in whether the NBF of younger children would show a stronger association with sleep disruptions than that of older children. In addition, it was hypothesized that the time of day during which participants were tested would play a moderating role in determining the relations between sleep and NBF; that is, that early morning NBF would have a stronger association with sleep quality than would NBF later in the day. Based on adult sleep deprivation studies and the existing knowledge on sleep and NBF, we further hypothesized that tasks that involve more complex cognitive functions and require sustained engagement of the attention system would show higher correlations with sleep variations as opposed to the more simple motor or memory tasks.

METHOD

Participants

One hundred and thirty-five children (69 boys and 66 girls) participated in the study. The children were sampled from three distinct age groups: second grade (N = 48; age: *range* = 7.2–8.6 years, M = 7.9, SD = .34), fourth grade (N = 36; age: *range* = 9.3–10.4 years, M = 9.7, SD = .30); and sixth grade (N = 51; age: *range* = 11.2–12.7 years, M = 11.8, SD = .45). Two different classes for each grade level were included in this sample.

The study was approved and supported by the Israel Ministry of Education. It was defined by the school authorities as a school project and informed consent was obtained from the children and their parents. Each child was rewarded with a $15 voucher (for an office and school supply store) for completing the study. The recruitment efforts led to above 95% consent rate in all classes involved. Because our goal was to assess a broad picture in total class samples of healthy school children, only narrow exclusion criteria were employed: only children with acute physical illness or children receiving medication were excluded from the study.

The sample consisted mostly of children from middle- to upper-class families. Most of the parents had a full-time job (fathers: 89.4%; mothers: 45.1%) and were well educated (number of years of formal education: M = 14.7, *range* = 8–24). Most of the children (92.5%) were living with both parents in relatively small households (number of family members: M = 4.7, *range* = 2–9). Thirty-eight percent of the children were firstborn.

Procedure

Following the informed consent by children and parents, the parents were asked to complete a battery of questionnaires that included family background material and the Child Behavior Checklist (CBCL; Achenbach & Edelbrock, 1983). Within 2 to 4 weeks following the completion of the questionnaires, children's sleep and NBF were evaluated. Over the course of the same week, children were tested twice with the Neurobehavioral Evaluation System (NES; Arcia, Ornstein, & Otto, 1991; Letz, 1991) in school and their sleep was assessed at home using actigraphs. The first NBF test was administered at one of two testing times (morning, 8:00–9:00 AM, or noon, 12:00–1:00 PM), chosen randomly for each child. The second test was performed 3 to 4 days later at the complementary time (e.g., children who were first tested in the morning performed their second test at noon, and vice versa). Both morning and noon administrations were conducted during regular class hours (test duration: 30–45 min). Testing children during special class activities was avoided to prevent motivational biases.

Measures

Sleep assessment. Activity monitoring was used to assess sleep–wake patterns. Children were instructed to attach the miniature actigraphs (Mini Motionlogger, Ambulatory Monitoring, Inc., Ardsley, NY) to their nondominant wrist in the evening while preparing for sleep and to remove them in the morning. Sleep assessment was performed for 5 continuous nights during school days. Repeated actigraphic assessment was conducted in 6 children due to technical failure ($n = 4$) or report of sudden illness ($n = 2$) during the monitoring week. The actigraphs collected data in 1-min epochs (activity level was sampled at 10-sec intervals and summed across 1-minute intervals) and stored in amplifier setting 18 (i.e., manufacturer's technical code for frequency bandpass 2 to 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 for an IBM-compatible personal computer. These sleep measures have been validated against polysomnography with agreement rates for minute-by-minute sleep–wake identification of higher than 90% (Sadeh, Alster, Urbach, & Lavie, 1989; Sadeh, Hauri, Kripke, & Lavie, 1995; Sadeh, Lavie, Scher, Tirosh, & Epstein, 1991; Sadeh, Sharkey, & Carskadon, 1994).

Actigraphic sleep measures included (1) sleep onset time, (2) morning awakening time, (3) total sleep period—from sleep onset time to morning awakening time, (4) true sleep time—sleep time excluding all periods of wakefulness, (5) sleep percent—percent of true sleep time (Measure 4) from total sleep period (Measure 3), (6) number of night-wakings, (7) longest sleep period—the longest period of continuous sleep without any wakefulness, and (8) Quiet sleep—percent of sleep without any detected motion (motionless sleep).

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 (Letz, 1991). The NES was originally developed for adults, but it has been successfully used with school-age children (Arcia et al., 1991; Dahl et al., 1996; Needleman, Schell, Bellinger, Leviton, & Allred, 1990; Otto, Skalik, House, & Hudnell, 1996) and validated as a good predictor of attention difficulties associated with school performance. Arcia et al. (1991) assessed 105 children aged 7–10 years using selected tests from the NES as well as other class behavior measures and academic achievements. NES measures were found to be highly predictive of school achievements and class behaviors, such as attentional skills and independent functioning.

For the present study, the NES was installed on a Compaq notebook computer (Contura model) and the tests administered to the children included six age-appropriate tests:

1. Finger tapping: The child is requested to tap as fast as possible with one finger on a single button. This test examines motor speed. The measure used is the maximum number of taps.
2. Simple reaction time test: The child is requested to press a button as quickly as possible when a large square appears on the screen. The intertrial interval is varied randomly to reduce effects of stimulus anticipation. The measure used is reaction time.
3. Continuous performance test (CPT): The CPT measures sustained visual attention. Different graphic images of animals are presented on the screen at varying time intervals and the child is required to respond as fast as possible when a cat is presented and not respond to any other animal. The measures include response time, omission errors (not responding to the cat), and commission errors (responding to other animals). Test duration was 10 min.
4. Symbol-digit substitution (SDS): The test used in the present study was a computerized version of the SDS (similar to the paper-and-pencil version included in the Wechsler Intelligence Scale for Children–Revised). Nine symbols and nine digits are paired at the top of the screen and the child is requested to press the digits on the keyboard corresponding to a test set of the nine symbols presented in a mixed order. Six sets of nine symbol–digit pairs are presented in succession. The measure used is average response latency (in s) for completing each set.
5. Visual digit span test: The child is presented with a sequence of digits on the screen and is then required to repeat the sequence on the computer keyboard (forward). Longer spans are increasingly presented until the child makes two errors in a span length. Once the child completes this task and reaches the two-error limit, the test is repeated with new sets of digits, however, the child is required to enter the digits in reverse order (backward). Measures used are the lengths of the longest span answered correctly forward and backward.
6. Serial digit learning test: A long sequence of single digits is presented in succession and the child is requested to recall as many of the digits as possible. The same sequence of digits is presented again until either the child recalls the entire sequence correctly (two trials in a row) or the maximum of eight trials is reached. The measure used is an error score that is the sum of the errors over all trials attempted. One point is added for a "nearly correct" answer (two thirds of the digits entered correctly) and two points are added for a worse response.

Table 1 Pearson Correlations between Sleep and Measures of Neurobehavioral Functioning (NBF)

	Sleep Measure					
NBF Measure	SOT	DUR	SP	ZERO	NW	TSLP
Tapping	−.07	.14	.04	−.05	−.04	.14
Simple RT	.00	.04	.01	.15	−.03	.03
Symbol-digit RL	.04	−.09	−.32****	−.17	.21*	−.26***
CPT—RT	.05	−.07	−.12	.00	.14	−.13
CPT—Om Err	.08	−.06	−.11	−.13	.08	−.11
CPT—Com Err	.08	−.07	−.30****	−.05	.25***	−.23**
Digit span FW	.07	−.09	.18	.02	−.10	−.06
Digit span BW	−.03	.06	.07	.07	−.09	.10
Digit learning ES	.10	−.06	−.09	−.09	.14	−10

Note: SOT = sleep onset time; DUR = sleep duration; SP = sleep percent; ZERO = percent of motionless sleep; NW = number of night-wakings; TSLP = true sleep time; RT = reaction time; CPT = Tapping = number of finger tappings; RL = response latency; CPT = Continuous Performance Test; Om Err = omission errors; Com Err = commission errors; FW= forward; BW = backward; ES = error score.

* $p < .05$; ** $p < .01$; *** $p < .005$; **** $p < .001$.

Child behavior problems—parental reports. The CBCL was used to assess behavior problems as perceived by parents (Achenbach & Edelbrock, 1983). The CBCL is a widely used instrument for assessing behavior problems with well-established psychometric properties. The Hebrew version of this instrument has been translated and validated in Israel (Zilber, Auerbach, & Lerner, 1994).

RESULTS

Reliability of the Measures

Sleep measures. The reliability (or day-to-day stability) of the sleep measures was tested before using reliability estimates for aggregated values over 5 successive nights of recording (Acebo et al., 1999; Winer, 1971). The statistic used was a reliability estimate for multiple repeated measurements (Winer, 1971). For all the sleep−wake measures included in the present study, reliability estimates ranged from .71 to .89, which is considered adequate or better (Acebo et al., 1999; Sadeh et al., 2000).

NBF. The reliability of the NES measures was tested using test−retest Pearson correlations between the first and the second administration for each child. High reliabilities were found on the SDS reaction time, $r = .93$, finger tapping $r = .80$, CPT reaction time, $r = .79$, simple reaction time, $r = .72$, and CPT commission errors, $r = .71$. Lower test−retest correlations were found for digit backward, $r = .61$, SDS error score, $r = .50$, CPT omission errors, $r = .45$, and digit forward, $r = .42$. All test−retest correlations were significant, $p < .001$.

NBF

Before assessing the correlations between the sleep and NBF measures, the anticipated correlations between these measures and age were assessed. All of the NBF measures were significantly correlated with age in the direction of improved performance with age: SDS response latency, $r = -.76$, finger tapping, $r = .52$, simple reaction time, $r = -.58$, CPT reaction time, $r = -.62$, CPT commission errors, $r = -.36$, CPT omission errors, $r = -.33$, digit backward, $r = .51$, digit forward, $r = .51$, and digit learning error score, $r = -.51$; all correlations were significant at $p < .001$. Among the sleep measures, only the measures related to sleep schedule and quantity were correlated with age: sleep onset time, $r = -.64$, sleep duration, $r = -.69$, and true sleep time, $r = -.57$; all correlations were significant at $p < .001$.

To assess the associations between the sleep measures and the NBF measures, partial correlations between the two sets of variables were first calculated.

Partial Pearson correlations were calculated between the sleep measures and the NBF measures for the total sample, with age partialed out. These correlations are presented in Table 1. The results mainly reflect moderate but significant correlations between sleep quality measures and specific NBF related to the SDS and the CPT.

On the basis of the results of this global correlation matrix separate correlations were calculated for each age group for the specific measures that were correlated in the global analysis (Table 2). The correlations clearly indicate that stronger correlations existed be-

Table 2 Correlations between Sleep Percent and the Measures of the Symbol–Digit Test and Continuous Performance Test (CPT) in Each Age Group and Test for Significant Differences between the Age Groups (Z Transformation)

NES Measures	2nd Grade	4th Grade	6th Grade	Z test[a]
Symbol-digit substitution	−.56**	−.03	−.16	2nd > 4th, 6th
CPT—reaction time	−.31*	−.10	−.03	*ns*
CPT—omission errors	−.47**	.28	.11	2nd > 4th, 6th
CPT—commission errors	−.57**	−.26	.04	2nd > 4th, 6th

Note: NES = Neurobehavioral Evaluation System .
[a] Significant difference at $p < .05$.
* $p < .05$; ** $p < .001$.

tween sleep and the NBF measures in the second-grade group than in the other two groups.

Comparison between "Good" and "Poor" Sleepers

Fragmented sleep is a combined manifestation of two factors: the number of awakenings during sleep and the duration of wakefulness after sleep onset. In a recent study (Sadeh et al., 2000) "poor sleepers" were defined as those who met at least one of the following two criteria: (1) an average of at least three awakenings per night (each awakening lasting 5 min or longer), and (2) sleep percent that was 90% or lower (i.e., the child spent at least 10% of the night after sleep onset in wakefulness). In the present study, 25 children were defined as poor sleepers using these criteria. They were evenly divided between the age groups.

Neurobehavioral functioning measures. In analyzing the group differences on NBF the role of the time of day was assessed in determining the relations between sleep and NBF. Each child was tested twice (during the morning hours, 8:00–9:00 AM; and during noontime, 12:00–1:00 PM). The time of day (TOD) was used as an additional independent measure. A multivariate analysis of variance (MANOVA) with sleep group (good versus poor), and TOD as independent variables was conducted to assess the differences in NBF between good and poor sleepers and the interaction with the time of day. To control for age and order of administration (first versus second administration), these measures were included as covariates in the analysis. The MANOVA revealed a significant sleep-group effect, $F(9, 122) = 2.32$, $p < .05$, and a significant TOD effect, $F(9, 122) = 2.14$, $p < .05$. The significant results of this analysis are shown in Figure 1.

The univariate ANOVAs revealed significant sleep-group differences on the SDS test, $F(1, 129) = 4.11$,

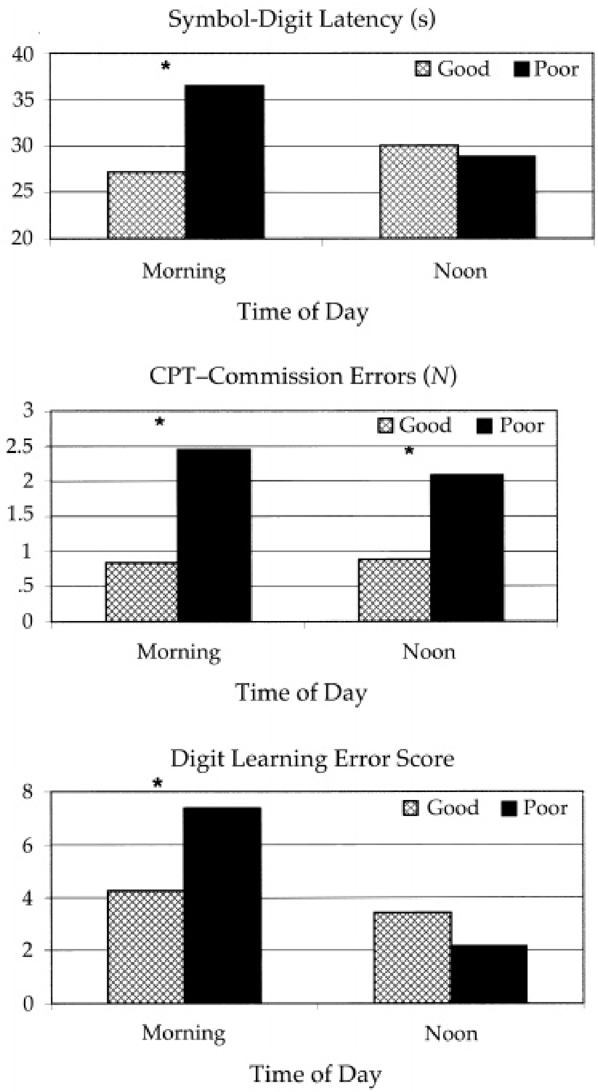

Figure 1 Comparison between "good" and "poor" sleepers on neurobehavioral functioning measures at different schedules. CPT = Continuous Performance Test. *Post hoc comparison: $p < .05$.

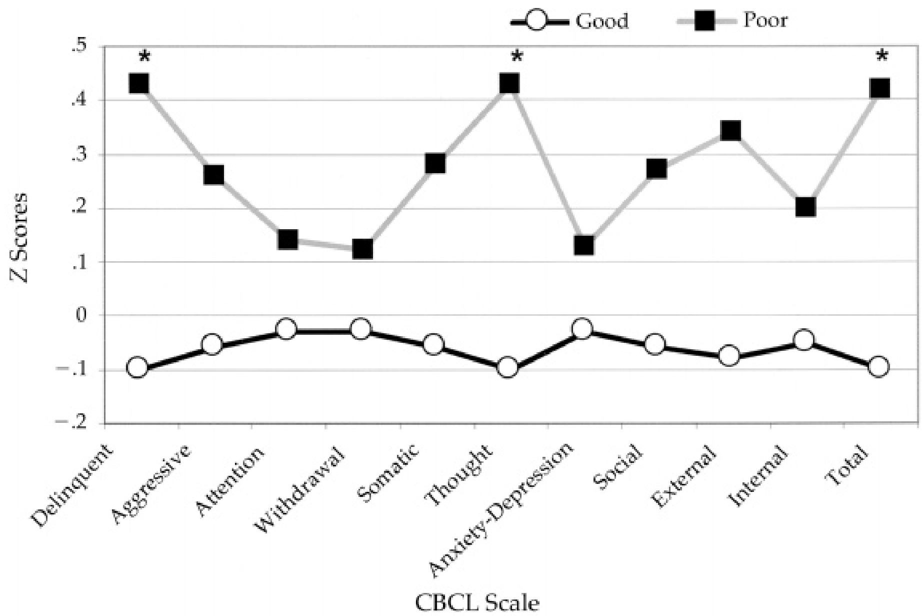

Figure 2 Comparison between good and poor sleepers on the Child Behavior Checklist (CBCL) scales. * $p < .05$.

$p < .05$, and on the CPT–commission errors, $F(1, 129) = 13.3$, $p < .001$. Significant TOD effects were found on the digit learning error score, $F(1, 129) = 16.6$; $p < .001$. Significant TOD × Sleep Group interactions were found on the SDS response latency, $F(1, 129) = 5.58$, $p < .05$, and on the digit learning error score, $F(1, 129) = 5.16$, $p < .05$.

CBCL scales. The MANOVA conducted to assess the differences between poor and good sleepers on the CBCL scales revealed significant group differences, $F(9, 130) = 4.11$; $p < .05$. Discrete ANOVAs revealed significant differences between poor and good sleepers on three CBCL scales (see Figure 2). The CBCL ratings of poor sleepers were significantly higher on the total behavior problem score, $F(1, 129) = 5.53$, $p < .05$; on the delinquent behavior scale, $F(1, 129) = 6.02$, $p < .05$; and the thought disorder scale, $F(1, 129) = 5.81$, $p < .05$.

DISCUSSION

The present study assessed the associations between sleep and NBF in school-age children. The use of objective and well-established measures of both sleep and NBF in a large sample of unreferred children provided unique insight into the NBF correlates of fragmented sleep in children. The main advantage of the study, however—its naturalistic—correlative design—was also a major limitation for interpretation of the relations found in terms of causality. There is a solid theoretical and empirical background that may lead to the interpretation that the compromised NBF is a result of reduced alertness or increased sleepiness associated with sleep fragmentation. Other competing interpretations should not be ignored, however.

The lack of more specific diagnosis of the sleep fragmentation phenomena detected in the present study (i.e. medical versus behavioral disorder) is another impediment in the interpretation of the findings. Furthermore, other potential factors or comorbid disorders (e.g., puberty, physiological reactivity, stress, ADHD) that could impact sleep and/or NBF were not fully assessed in this study. Therefore, the sources for the associations between sleep and NBF found in this study remain questionable beyond our hypothesized links between sleep and NBF.

Another methodological problem is the lack of standard criteria for defining “poor sleep” in children. For the purposes of standardization, the criteria used in this study was the same as that used in other actigraphic sleep studies in children; however, the question of where to draw the line between “poor” and “normal” is valid in this area, as in many other areas of child psychopathology (Dahl, 1996; Gruber et al., 2000; Mindell et al., 1999; Sadeh & Gruber, 1998; Sadeh et al., 2000).

The results of the present study reflected no significant correlations between sleep schedule or sleep duration and NBF. These results are incongruent with some studies that have found correlations between these measures of sleep and academic achievements (Epstein et al., 1998; Gau & Soong, 1995; Mercer et al., 1998; Wolfson & Carskadon, 1998).

The correlations between the sleep and the NBF measures found in the present study appear to be specific and in accord with previous research and the theoretical framework linking poor or insufficient sleep with attentional deficits or compromised executive control (Bonnet, 1994; Dahl, 1996; McCarthy & Waters, 1997; Pilcher & Huffcutt, 1996). The present study's results associate fragmented sleep with the more complex neurobehavioral tasks of SDS and the CPT, which involve higher executive control. Simple tasks of motor speed, memory, and reaction time were not correlated with any of the sleep measures. It is also important to note that NBF is affected by multiple factors including the length of the tests, motivation, feedback, and physiological state (of which arousal level is only one component). This may explain the relatively moderate correlations between sleep and NBF that were found in this study.

The correlations within the specific age groups suggest that stronger associations between the sleep and NBF measures existed in the younger age group (second grade). There are competing explanations for this finding. One possible explanation is that younger children are more vulnerable and sleep disruptions affect their NBF more significantly. Another explanation would be that other, unidentified factors (e.g., medical or genetic factors) interfere with these two systems in a stronger fashion in younger children. It is also possible that the nature of the sleep disruptions is different at different age groups (e.g., higher prevalence sleep-disordered breathing in younger children), but such a difference could not be detected by actigraphy. Yet another explanation is a methodological one—a possible floor effect in the NBF measures such as reaction time and CPT errors that reduce the variability on these measures in the older children and therefore suppress possible correlations between the two domains.

The specific correlations between sleep quality measures and the CPT measures suggest that fragmented sleep is associated with increased difficulty in sustained attention and difficulty in behavioral inhibition. It has been suggested that commission errors on the CPT reflect impulsivity or difficulty in behavioral inhibition (Halperin, Wolf, Greenblatt, & Young, 1991). The CPT has been used extensively to examine the issue of sustained attention in ADHD (Corkum & Siegel, 1993). These findings that link fragmented sleep with impulsivity or difficulty in behavior inhibition are particularly interesting in light of the growing interest and emphasis on these constructs in developmental psychopathology. Behavioral inhibition and impulsivity have been empirically linked to psychopathology in children (Barkley, 1997a, 1997b; Nigg, 1999, 2000; Olson, Schilling, & Bates, 1999; Oosterlaan, Logan, & Sergeant, 1998). Inhibition has been a key construct in many theories of developmental psychopathology (Barkley, 1997a, 1997b; Nigg, 2000). Barkley (1997a, 1997b), for instance, suggested that behavioral inhibition is essential for the development and expression of higher executive control. He further proposed that impulsivity, or the inability to inhibit prepotent responses, is the core problem in ADHD. Other studies have suggested that this factor is associated with a broader spectrum of externalizing disorders (Nigg, 2000; Olson et al., 1999; Oosterlaan et al., 1998).

The comparison between poor and good sleepers and its interaction with the time of day during which the child was tested further clarifies the picture. As predicted, good sleepers performed better than poor sleepers on three measures: SDS response latency, CPT commission errors, and digit learning error score. This was particularly true for these three measures during the morning testing, whereas during the noon session the only significant difference maintained was on CPT commission errors. This is the first finding on the interaction between sleep quality and time of day vis-à-vis NBF in children. This pattern of results may suggest that the NBF of poor sleepers is mainly compromised during the early morning hours—possibly due to a stronger sleep-inertia effect during these hours (Jewett et al., 1999; Tassi & Muzet, 2000)—in contrast with the later noon hours when some group differences disappeared. Previous studies in adults have suggested that time of day may interact with circadian typology (i.e., morning versus evening types) in determining cognitive functioning (Adan, 1991; Anderson, Petros, Beckwith, Mitchell, & Fritz, 1991; Natale & Lorenzetti, 1997; Petros, Beckwith, & Anderson, 1990). The present study's findings are in accord with theories of alertness that emphasize the contribution of both prior sleep (quantity and quality) and chronobiological factors (time of day) in determining alertness and performance (Borbely, 1994; Monk, 1994). Furthermore, an independent time-of-day component emerged, indicating that performance on the SDS task at noontime was significantly better than performance in the morning.

Compared with good sleepers, behavior problems were more prevalent among poor sleepers, as reported by their parents on the CBCL. The rationale for the specific association of poor sleep with thought disorders is unclear. Otherwise, these associations between poor sleep and behavior problems are in line with previous research and theory suggesting that poor sleep in childhood is associated with poor behavior regulation and increased risk for psychopathology (Dahl, 1996; Gruber et al., 2000; Mindell et al., 1999; Sadeh & Gruber, 1998; Sadeh et al., 2000). Furthermore, the findings on poor sleepers' poorer performance on tasks involving executive function and inhibitory control suggest that these deficiencies may play a role in the relation between sleep and behavior regulation and some forms of psychopathology.

Our earlier findings that close to 18% of school-age children suffer from undiagnosed fragmented sleep (Sadeh et al., 2000), in conjunction with the new finding of the present study that fragmented sleep is associated with compromised NBF, further highlight the role of sleep in child development and developmental psychopathology. It is important to re-emphasize that some prevalent medical problems during childhood, such as asthma and atopic dermatitis, have been associated with sleep fragmentation (Dahl, Bernhisel-broadbent, Scanlonholdford, Sampson, & Lupo, 1995; Reuveni, Chapnick, Tal, & Tarasiuk, 1999; Sadeh et al., 1998; Stores, Burrows, & Crawford, 1998; Stores, Ellis, et al., 1998). Our study suggests that these children may be at risk for compromised NBF that may also explain the academic underachievement reported in some of these clinical groups (Annett & Bender, 1994; Dunleavy & Baade, 1980; Fowler, Davenport, & Garg, 1992; Lindgren et al., 1992; Suess & Chai, 1981).

Considering the results of the present study and its methodological limitations, we recommend that future research address the following questions: (1) What are the causes for the identified sleep fragmentation in so many school-age children? (2) What are the effects of experimental sleep fragmentation on children's NBF, emotion, and behavior regulation? and (3) What are the effects of experimental moderate restriction or extension of sleep on the same behavioral systems in children at different ages?

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