BEHAVIORAL EFFECT OF SLEEP DISORDERED BREATHING IN CHILDHOOD

The Association Between Sleep Disordered Breathing, Academic Grades, and Cognitive and Behavioral Functioning Among Overweight Subjects During Middle to Late Childhood

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Study Objectives: (1) to determine the associations of sleep disordered breathing (SDB) with behavioral functioning, cognitive test scores, and school grades during middle- to late-childhood, an under-researched developmental period in the SDB literature, and (2) to clarify whether associations between SDB and school grades are mediated by deficits in cognitive or behavioral functioning.

Design: Cross-sectional correlational study.

Setting: Office/hospital, plus reported functioning at home and at school.

Participants: 163 overweight subjects aged 10-16.9 years were divided into 4 groups based upon their obstructive apnea+hypopnea index (AHI) during overnight polysomnography and parent report of snoring: Moderate-Severe OSA (AHI > 5, n = 42), Mild OSA (AHI = 1-5, n = 58), Snorers (AHI < 1 + snoring, n = 26), and No SDB (AHI < 1 and nonsnoring, n = 37).


Results: The 4 groups significantly differed in academic grades and parent- and teacher-reported behaviors, particularly inattention and learning problems. These findings remained significant after adjusting for subject sex, race, socioeconomic status, and school night sleep duration. Associations with SDB were confined to reports of behavioral difficulties in real-world situations, and did not extend to office-based neuropsychological tests. Findings from secondary analyses were consistent with, but could not definitively confirm, a causal model in which SDB affects school grades via its impact on behavioral functioning.

Conclusions: SDB during middle- to late-childhood is related to important aspects of behavioral functioning, especially inattention and learning difficulties, that may result in significant functional impairment at school.

Keywords: Pediatrics, sleep apnea, neuropsychology, cognitive, behavioral

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SLEEP DISORDERED BREATHING (SDB) IN YOUNG CHILDREN HAS BEEN ASSOCIATED WITH POOR ACADEMIC PERFORMANCE AND BEHAVIORAL abnormalities, especially inattention, hyperactivity, and other “externalizing” behaviors (e.g., oppositionality, conduct problems).1 Cognitive test findings have been less consistent, but young children with SDB have generally shown diminished scores on tests of intelligence (IQ), attention, and executive functioning.2 Adults with SDB also display inattention, but they rarely show IQ deficits, hyperactivity, or externalizing behaviors.2,3 SDB in middle to late childhood has received much less research attention. Of the 60 published papers reviewed in 2006 by Beebe,1 most enrolled only children aged ≤ 11 years. This emphasis on younger populations has remained true in more recent publications.4 Studies that have examined a broader age range have enrolled primarily young children due to their recruitment strategies (e.g., recruiting from otolaryngology clinics) or have relied solely upon parent report of both clinical symptoms of SDB and behavioral disturbances, which can artifically inflate correlations.1 To our knowledge, only one published study has independently measured SDB and cognitive, behavioral, or scholastic functioning exclusively during middle to late childhood. Rhodes and colleagues5 reported cognitive deficits in 5 children with OSA with a mean age of 13 years. Despite the fact that SDB has been associated with cognitive, behavioral, and functional deficits in studies of thousands of young children and adults, clinicians working with older children and adolescents have extremely limited data to inform evidence-based care.

To some degree, findings from younger children and adults might be extrapolated to middle or late childhood. However, the nature of the cognitive and behavioral dysfunction that has been associated with SDB appears to differ in young children versus adults, and it is not clear when or how this developmental shift occurs.2 The risk factors for SDB also differ with age and may confound or moderate the impact of SDB. Further, the adaptive challenges faced by older children and adolescents differ substantially from those faced by young children and adults,2 so the functional impact of sleep pathology in this understudied population may be unique. Finally, older children and adolescents tend to show greater sleep restriction on school nights than do their younger counterparts, and data suggest that, even among...
children with suspected SDB, typical sleep duration is a reliable correlate of behavioral pathology.\textsuperscript{7}

SDB is unlikely to be benign during middle to late childhood, when problem-solving, social judgment, emotion regulation, and abstract reasoning rapidly mature in a manner that parallels maturation of their underlying neural substrates.\textsuperscript{6,8} By altering neurochemistry and activation patterns, SDB may disrupt these neurodevelopmental processes.\textsuperscript{9,10} Moreover, the cognitive and behavioral effects of SDB during middle to late childhood might substantially impact a key adaptive outcome—school performance—at the very time when that outcome is of greatest importance. In the US, middle school grades often determine class placement in high school, and high school performance predicts later outcomes, including school drop-out, failure to enroll in or complete college, adult mental illness, and adult vocational status.\textsuperscript{11-13} Even if the effect of high school performance predicts later outcomes, including grades often determine class placement in high school, and outcome is of greatest importance. In the US, middle school to late childhood might substantially impact a key adaptive outcome—school performance—at the very time when that outcome is of greatest importance. In the US, middle school grades often determine class placement in high school, and high school performance predicts later outcomes, including school drop-out, failure to enroll in or complete college, adult mental illness, and adult vocational status.\textsuperscript{11-13} Even if the effect of high school performance predicts later outcomes, including grades often determine class placement in high school, and outcome is of greatest importance. Thus, despite the likelihood that SDB during middle to late childhood has a significant impact upon cognitive and behavioral functioning and school performance, there is a paucity of relevant data. Moreover, the mechanism by which SDB might result in poor school performance remains unclear. It is generally assumed that the cognitive and behavioral deficits that have been associated with SDB (e.g., inattention) result in poor school performance, but this assumption has rarely been tested. The general approach to most studies in this area has been to consider cognition, behavior, and school performance on the same level, rather than testing a presumed causal sequence. However, they are conceptually distinct, with school performance representing the cumulative result of a number of contributors, such as socioeconomic circumstances and aspects of each student’s cognitive skills (e.g., IQ, memory) and behavioral functioning (e.g., classroom behaviors, study habits).

The current study had two broad goals. The primary goal was to fill a key gap in the research literature by determining the associations of SDB with cognitive and behavioral functioning and with school performance in a relatively large sample of 10- to 16-year-old overweight children and adolescents. Overweight subjects were studied exclusively to ensure adequate representation of SDB in otherwise typically developing individuals in this age range (e.g., those without genetic syndromes or craniofacial pathology). Groups of subjects showing differing levels of SDB were compared on behavioral functioning and scholastic performance, as reported by multiple sources, and cognitive functioning, as measured via neuropsychological tests. Our hypothesis was that groups with greater SDB would display poorer behavioral functioning, cognitive functioning, and school grades in a manner that could not be explained by methodological artifacts such as reporter biases or demographic confounds. The secondary goal of the study was to clarify whether associations between SDB and school grades are statistically mediated by deficits in cognitive or behavioral functioning, a finding that would support a causal sequence in which SDB leads to cognitive or behavioral deficits that result in poor school performance.

**METHODS**

**Subjects**

A total of 163 overweight subjects were recruited from a hospital-based multidisciplinary pediatric weight-management clinic (n = 126) and sleep clinic (n = 37). The results reported below did not differ based upon recruitment source. This sample expands upon that from a paper in which we demonstrated that a smaller sample of overweight adolescents’ sleep was shorter, of poorer quality, and marked by more SDB than that of demographically matched lean controls.\textsuperscript{14} For the current study, subjects were considered eligible if they were 10-16.9 years old at the time of participation, had a body mass index (BMI) > 95th percentile for age and sex, and did not meet any of the following exclusion criteria: a history of neurological illness or injury, diagnosed or overt craniofacial abnormalities, diagnosed neurodevelopmental disorder (e.g., Down Syndrome), condition involving daytime hypoxia, adenotonsillectomy or other treatment for SDB within the past 2 years, reported history of mental retardation or discovery of an IQ < 70 during the course of the study, and the use of a psychiatric medication other than stimulants commonly used to treat attention deficit hyperactivity disorder (ADHD). We elected to enroll subjects who took stimulants to avoid eliminating the very subjects at greatest risk for behavioral deficits,\textsuperscript{1} but required that the 9 relevant subjects be off medication for ≥ 36 h prior to participation (most had been off medication ≥ 48 h).

**Procedures**

All procedures were approved and overseen by the Institutional Review Board at Cincinnati Children’s Hospital Medical Center. Prior to participation, the study was explained to each subject and the parent or guardian who completed questionnaires (92% were the subject’s mother, 2% the father, and 6% a custodial grandparent or other guardian). Verbal assent was provided by the subject and written consent by the parent. Families received $50 and feedback on each subject’s assessment results. All subjects underwent a comprehensive evaluation of their sleep, cognitive and behavioral functioning that included subject-, parent- and teacher-report questionnaires, neuropsychological testing, and overnight polysomnography (PSG). The neuropsychological testing, which started between 15:30 and 16:30 and lasted around 2.5 h, occurred the afternoon immediately prior to the PSG for the vast majority of subjects; the few who had prohibitive scheduling limitations underwent testing on a day other than that immediately after the PSG to avoid any atypical sleep which might occur in the PSG lab.

**Measures**

**SDB measures and group definitions**

**Polysomnography (PSG):** Each subject underwent inpatient full-night PSG at a dedicated pediatric facility with a parent or guardian present in a separate bed. Subjects were not deprived of sleep prior to the PSG and were not given a sedative. Subject preparation and monitoring was conducted by cer-
tified polysomnographic technicians under the supervision of the fifth author (RSA), a board-certified Sleep Medicine physician, who scored the studies blind to cognitive and behavioral findings. The following were monitored: electroencephalogram (C3-A2, C4-A1, O1-A2, O2-A1), electrooculogram, submental and tibial electromyogram, nasal/oral airflow (nasal pressure transducer or a 3-pronged thermistor), nasal end-tidal CO2, oxygen saturation (pulse oximetry), infrared video monitoring, and respiratory inductance plethysmograph. Sleep staging and arousals were scored according to standardized criteria.16,17 Obstructive apneas were defined as > 80% decline in airflow over 2 breaths despite continued chest/abdominal wall movement. Obstructive hypopneas were defined as a decrease of 50% to 80% in airflow over ≥ 2 breaths associated with (a) paradoxical respiration and (b) oxyhemoglobin desaturation (> 4%) or a subsequent arousal. The obstructive apnea+hypopnea index and arousal index were each computed as the sum of relevant events divided by hours slept.

**SDB Symptoms:** Children who have normal PSG results but who show clinical symptoms of SDB (“primary snorers”) may display cognitive and behavioral morbidity.18-21 To examine this possibility, parents completed the breathing items from Chervin’s Pediatric Sleep Questionnaire (PSQ).22 Only the breathing items were used because the full PSQ includes items describing behavioral symptoms (e.g., inattention, hyperactivity) which might result in inflated associations with our other behavioral measures.

**SDB Grouping:** Subjects who had a PSG-defined obstructive index ≥ 5 comprised the Moderate or Greater OSA group (MOD+ OSA, n = 42), while those with an index of 1-4.99 comprised the Mild OSA group (n = 58). Subjects who had PSG obstructive indexes < 1 but who received a mean score > 0.33 on the PSQ breathing items were classified as non-apneic Snorers (n = 26), while the No SDB group (n = 37) was limited to those who had a score < 0.33 on these items and a PSG obstructive index < 1. The 0.33 cutoff matches that recommended by Chervin and colleagues for the full sleep disordered breathing scale of the PSQ;23 on a practical level, this cutoff requires the endorsement of ≥ 3 breathing-related symptoms (e.g., snoring loudly, snoring more than half of the night) from this questionnaire.

**Scholastic Performance**

Scholastic performance was operationalized by an 8-point rating scale from Wolfson and Carskadon’s School Sleep Habits Survey,23 on which parents and subjects indicated whether the subject’s grades were primarily As, As and Bs, Bs, Bs and Cs, Cs, Cs and Ds, Ds, or Ds and Fs. For the present study, these were coded according to the American 4-point convention, assigning 4 points for the first response (As), 3.5 for the second (As and Bs), and so on. Parent and self-reported grades correlated well, r = 0.77, P < 0.001, suggesting good reliability. Academic grades were measured, rather than achievement test scores, because academic grades better reflect functional, real-world adaptive outcomes and appear sensitive to SDB.1

**Cognitive Functioning**

Trained examiners administered neuropsychological tests one-on-one in a quiet room under the supervision of the first author (DWB), a board-certified clinical neuropsychologist. Scoring was conducted according to each test’s manual and blind to SDB group. The 5 domains assessed were based upon prior research and theory that suggest a potential impact of SDB on intelligence, memory, attention, executive functioning, and motor coordination.1,3 Tests within each domain were selected for their psychometric strengths and strong acceptance within the field of pediatric neuropsychology.24 Further supporting our test choices and domain definitions, test scores within each domain correlated well (median r = 0.51) and the correlations between tests assigned to different cognitive domains were weak (median r = 0.20).

**Intelligence** was screened with the Vocabulary and Block Design subtests of the Wechsler Intelligence Scale for Children (WISC-IV).25 *Memory* was assessed with the California Verbal Learning Test for Children (CVLT-C)26 and the story memory subtest from the Child’s Memory Scale (CMS).27 Specifically, from the CVLT-C we used the trial 1-5 total T-score and normed scores from the short-delay free recall trial, long-delay free-recall trial, and the long-delay recognition discriminability index; from the CMS we used the scores from the immediate, delayed, and delayed recognition trials. *Attention* was measured via the total correct and commission scores from the Gordon Diagnostic System vigilance task28 and the Letter-Number Sequencing subtest score from the WISC-IV. *Problem-Solving and Planning* were measured by the total correct and total move scores from the Tower of London.29 Finally, Motor Coordination was defined as the normed score for each hand on the Grooved Pegboard task.24

**Parent- and Teacher-Reported Behavioral Functioning**

While subjects underwent neuropsychological testing, parents completed the Behavior Assessment System for Children (BASC), a multidimensional behavior rating questionnaire.30 Each parent also identified a teacher whom they felt knew the subject well. That individual was asked to complete the teacher version of the BASC via mail. For subjects assessed during the summer or first month of the school year, report was solicited from a teacher from the previous year. BASC responses cluster into 11-14 subscales related to negative behaviors (e.g., poor attention, hyperactivity) and positive attributes (e.g., social skills). It has extensive psychometric support in both non-referred and clinical populations.30 All BASC scores were normed for age.30 The BASC yields several composites, but some (e.g., the Internalizing Composite) can be problematic to interpret for medically involved children.1,31 We focused on subscales that comprise the Behavioral Symptom and Adaptive Behavior Indexes, which exclude problematic subscales. The following subscales were included: Hyperactivity, Aggression, Anxiety, Depression, Attention, Atypicality, Leadership, Social Skills, and, from the teacher-report form (not available on the parent form), Learning Problems and Study Skills. In designing the study, the initial plan was to examine parent- and teacher-report results together in a domain-by-domain fashion (e.g., grouping the Attention subscales from both reporters). However, identically labeled subscales tended to correlate poorly across reporters (median r = 0.25), yet completely different subscales tended to correlate well *within* each reporter (median r = 0.49 across the parent BASC subscales, median r = 0.42 for the teacher BASC). Because of this “reporter effect,” which is common
when conducting multiple-informant research, for primary analyses we grouped behavioral subscales by reporter, rather than subscale content.

Descriptive Information and Potential Covariates

Anthropometrics
Just prior to the PSG, a trained research nurse measured subject height and weight. Body mass index (BMI; kg/m²) was compared against tables published in 2000 by the US Centers for Disease Control to obtain an age- and sex-adjusted BMI z-score.

Demographics
Demographic data including subject race, sex, and socioeconomic status (SES) were collected via parent report. For analyses, race was dichotomized into White/Non-White; consistent with the local population, the vast majority (96%) of Non-White subjects self-identified as African American, and the balance self-identified as biracial. A composite SES index was computed as the mean z-score within the sample across four variables: maternal and paternal education, annual family income, and median local income based upon the 2000 US Census for the subject’s postal code of residence. When ≥ 1 of these elements was missing (e.g., father’s education), the index was prorated from the others.

School night sleep duration
Each parent and subject independently completed a questionnaire that asked the subject’s typical sleep duration on school nights, as well as his or her typical sleep onset and offset times on school nights. Such questions have been found to correlate well with actigraphy estimates of sleep duration. To streamline analyses, for each reporter, we averaged (a) sleep duration calculated from the reported times of sleep offset minus onset with (b) the response to the direct sleep duration question. Finally, we averaged the 2 reporters’ responses into a composite school night sleep duration index for each subject, the result of which correlated 0.87-0.89 (P < 0.001) with the parent- and self-report values.

Analytic Strategy

Preprocessing of data and preliminary analyses
Statistical transformations normalized skewed indexes: the PSG obstructive index was log-transformed, the PSQ breathing subscale was dichotomized, and the distributions of the Gordon Diagnostic System indexes were truncated at 2 standard deviations from the normative means. We minimized missing questionnaire data by prorating scores when less than half of a scale’s items were missing. Nevertheless, some data remained missing due to teachers not returning forms, a BASC validity index suggesting “extreme caution” in interpreting results or examiner suspicion that cognitive test results were invalid due to poor examinee effort. The most frequently missing data were from teachers; 56% of subjects had valid teacher BASC data. Data for the other outcomes were more complete; 99% of subjects had at least one report of academic grades, and 88% had both parent and self-report of grades; 98% had valid parent BASC data; and 98% had valid cognitive test data. Chi-square, Fisher’s exact, and t-tests did not suggest systematic biases in missing data: there were no differences in age, SES, race, sex, BMI, BMI z-score, or SDB group between subjects who had teacher BASC, parent BASC, grades, or cognitive test data, and those without such data (P > 0.05).

Primary analyses
Multivariate analysis of variance (MANOVA) and analysis of covariance (MANCOVA) tested whether the following 8 outcome domains significantly differed across the SDB groups: school grades, parent-reported BASC, teacher-reported BASC, intelligence, memory, attention, problem-solving/planning and motor coordination. To control for type I false positive error due to multiple comparisons, Holm’s procedure was used within each “family” of analyses (cognitive tests vs. questionnaires). Under this procedure, the most stringent Bonferroni correction is applied only to the most statistically significant finding in a family of analyses. If this threshold is crossed, then the significant finding is deemed reliable and the next most significant finding is compared against a cutoff based upon the remaining number of analyses in an iterative fashion.

Each outcome domain was comprised of multiple variables, so while a statistically significant finding on a primary analysis would suggest important SDB group differences in a broad sense, it cannot address which aspects of the tested domain (e.g., which teacher-reported behaviors) are most closely linked to SDB, and which SDB groups showed evidence of pathology. To provide further clarity, we conducted follow-up ANOVA/ANCOVA tests on individual outcome measures, as well as planned contrasts to probe whether the Snoring, Mild OSA, or MOD+ OSA groups significantly differed from the No-SDB group. Because these follow-up tests were conducted on a post hoc basis, results should be interpreted in the context of findings from the primary analyses and not in isolation.

Analyses were initially performed unadjusted to allow for unadulterated presentation of descriptive findings across groups, then adjusted for covariates to minimize the influence of putative confounds on significance test results. Potential covariates were initially selected on theoretical grounds and prior research: age, SES, race, sex, BMI z-score, and school night sleep duration. Following the recommendations of Tabachnick and Fidell, we dropped BMI z-score as a covariate because it did not correlate with any of our dependent variables and consequently threatened to reduce statistical power. Age was similarly dropped from all analyses except those examining academic grades; the other dependent measures had been age-normed and were, not surprisingly, uncorrelated with age.

Secondary analyses
Causal sequences cannot be fully inferred from correlational data. However, because psychological, neuropsychological, and epidemiological research rarely allow for ethical experimental control of exposure to noxious stimuli, it is common to test whether a causal model fits with an observed pattern of correlations. Following procedures outlined by Holmbeck and colleagues, evidence of statistical mediation would require: (1) that SDB group is associated with cognitive or behavioral functioning; (2) that SDB group is associated with school
grades; (3) that cognitive or behavioral functioning is associated with school grades; and, most importantly, (4) that the relationship between SDB and school grades is substantially attenuated by covarying for SDB-related cognitive or behavioral measures.

The first 2 of these 4 criteria were addressed by the primary analyses. To address criterion (3), we examined partial correlations between school grades and each of the BASC subscales and the 5 neuropsychological test domains after adjusting for covariates. BASC subscales and cognitive domains that were associated both with school grades and with SDB were considered to be potential mediators of the relationship between SDB and grades. Finally, 3 MANOVA/MANCOVA models addressed criterion (4). Models 1 and 2 were simply a replication of the primary analysis findings on grades in the subsample of subjects for whom complete and valid data were available across all outcome measures. It was necessary to obtain an effect size (partial eta squared or $\eta^2_p$) and significance level in this subset of subjects to avoid artificial changes in effect size related to missing data. Model 3 repeated Model 2, but added as covariates those BASC subscales and cognitive domains that were found to be potential mediators of the relationship between SDB group and grades. Criterion (4) would be satisfied if the $\eta^2_p$ linking SDB group to grades was initially substantial and significant, but was attenuated and non-significant after consideration of cognitive and behavioral functioning.

RESULTS

Sample Description

Table 1 summarizes the demographic and sleep features of the 4 SDB subgroups. Less than one-fifth of the sample showed no evidence of SDB, while just over one-fourth had at least moderate OSA, consistent with prior findings of high rates of SDB in overweight children and adolescents. $^{14}$ BMI values clustered around 2.4 to 2.6 standard deviations above CDC benchmarks for age and sex, representing adiposity beyond the 99th percentile. The MOD+ group was slightly older and had a disproportionate number of boys compared to the other groups. There were no significant differences across groups in SES or racial composition.

More severe levels of SDB were associated with less sleep on school nights. The Snoring group had the greatest PSQ Breathing Problems symptoms, which is expected given that this group was defined in part by those symptoms. The 2 PSG-defined OSA groups also had elevated SDB symptoms. PSG results confirmed the presence of breathing obstruction, arousals from sleep, and dips in oxygen saturation with increasing SDB severity across groups, though the groups did not significantly differ across other sleep architecture variables.

Primary Analyses

Table 2 summarizes the findings of the primary MANOVA/MANCOVA analyses. The most robust finding was the association between SDB group and the school functioning domain.
though both parent- and teacher-reported behaviors also showed group effects. In contrast, there were no group effects on the cognitive test domains. Applying Holm’s method, the strongest effect for questionnaire-based measures was for grades, and this exceeded the most stringent α cutoff of 0.017 (0.05/3). The next strongest effect, that for parent-reported behaviors, remained significant beyond the next cutoff of 0.025 (0.05/2), and the final effect, that for teacher-reported behaviors, remained significant at α = 0.05. In contrast, within the neuropsychological test “family” of findings, no effects even approached an uncorrected α of 0.05.

Table 3 summarizes the results of follow-up tests on the individual measures within the domains of academic functioning and parent- and teacher-report behaviors. As can be seen, increasing SDB severity was accompanied by worsening parent and self-reported grades, though only the effect for self-reported grades remained strongly significant after entry of the covariates. On the parent-report BASC, group effects were evident across all subscales except Atypicality, Leadership, and Social Skills. Attention problems and Anxiety symptoms increased monotonically with SDB severity. The PSG-defined OSA groups also tended to fare worse than the No-SDB group on the Hyperactivity, Aggression, and Depression subscales, but the Snorer group was reported to have the greatest difficulties in each of these areas.

On the teacher-report BASC, the SDB groups significantly differed on Attention and Learning Problems, with the Mild OSA and MOD+ OSA groups faring worse than the No-SDB group. Table 4 summarizes the results of follow-up tests on each cognitive test score. Consistent with findings from the primary analyses, no cognitive test scores significantly differed across SDB groups.

**Secondary Analyses**

Secondary analyses focused on a conceptual model in which the impact of SDB on school grades is mediated by its effect on cognitive and academic functioning, and parent- and teacher-report behaviors. As can be seen, increasing SDB severity was accompanied by worsening parent and self-reported grades, though only the effect for self-reported grades remained strongly significant after entry of the covariates. On the parent-report BASC, group effects were evident across all subscales except Atypicality, Leadership, and Social Skills. Attention problems and Anxiety symptoms increased monotonically with SDB severity. The PSG-defined OSA groups also tended to fare worse than the No-SDB group on the Hyperactivity, Aggression, and Depression subscales, but the Snorer group was reported to have the greatest difficulties in each of these areas.

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On the teacher-report BASC, the SDB groups significantly differed on Attention and Learning Problems, with the Mild OSA and MOD+ OSA groups faring worse than the No-SDB group. Table 4 summarizes the results of follow-up tests on each cognitive test score. Consistent with findings from the primary analyses, no cognitive test scores significantly differed across SDB groups.
behavioral functioning. Mediation is conceptually possible only if the same variables that are linked to SDB are also associated with school grades. After adjusting for covariates, parent- and self-reported grades were associated with parent and teacher-reported attention problems ($r_p = -0.47$ to $-0.57$, $P < 0.001$), teacher-reported learning problems ($r_p = -0.51$ to $-0.53$, $P < 0.001$), and, to a lesser extent, parent-reported anxiety and hyperactivity ($r_p = -0.17$ to $-0.29$, $P < 0.05$), all of which were found above to be associated with SDB. Although parent-reported aggression and depression also associated with SDB, they did not have consistent partial correlations with academic grades, and therefore were not considered potential mediators of the association between SDB and grades. Conversely, study skills, leadership, social skills, and the cognitive domains of intelligence, attention, and memory were significantly associated with grades ($r_p = 0.25$ to $0.59$, $P < 0.05$), but were not considered potential mediators because they did not significantly differ across SDB groups.

Having culled the potential mediator pool, three MANOVA/MANCOVA models tested whether behavioral functioning mediated the relationship between SDB and school grades. Model 1 found significant differences in grades across SDB groups before entry of covariates. Wilks lambda ($\Lambda$) (6, 268) = 3.14, $\eta_p^2 = 0.066$, $P = 0.005$, an effect that was minimally attenuated after entry of demographic and sleep duration covariates in Model 2, $\Lambda$ (6, 258) = 2.64, $\eta_p^2 = 0.058$, $P = 0.017$. In contrast, the SDB group effect was markedly attenuated in Model 3, which covaried the following potential mediators: parent-reported hyperactivity, anxiety, and attention problems, and teacher-reported attention and learning problems. The cross-group difference on academic grades in Model 3 was cut by more than half and was no longer statistically significant, $\Lambda$ (6, 136) = 0.58, $\eta_p^2 = 0.025$, $P = 0.740$. These data are consistent with a model in which the impact of SDB on school performance is mediated by its impact on specific behaviors, including attention and learning problems.

**DISCUSSION**

This study had three main findings. First, SDB in overweight 10- to 16-year-olds was associated with lower academic grades and certain aspects of behavioral functioning. Second, these associations were confined to reports of behavioral difficulties in real-world situations, and did not extend to office-based cognitive tests. Finally, the data were consistent with, but cannot definitively confirm, a causal model in which SDB affects school grades via its impact on important aspects of behavioral functioning, such as attention regulation.

**Methodological Considerations**

The pediatric SDB literature has been criticized as capitalizing upon confounding factors and reporter and sample biases. Our analyses took into account multiple potential confounding factors, including race, sex, socioeconomic status, and typical sleep duration. Body mass was also considered as a potential confounder but was trimmed from analyses because it did not correlate with any of our outcome domains. The association between SDB group and the overall domains of academic function-
ing and parent- and teacher-reported behaviors extended beyond these potential confounds (Table 2), and follow-up tests indicated key areas of behavioral weakness that persisted after entry of covariates (Table 3). Parent report of breathing problems partially defined the Snoring group, so reporter biases would be most obvious if effects occurred only on parent-report scales, primarily due to pathology in the Snoring group. Indeed, the Snoring group was reported by parents to show the worst hyperactivity, aggression, depression, and leadership skills. However, the two PSG-defined OSA groups also tended to fare worse than the no-OSD group in these areas. Moreover, parents and teachers alike reported more attention problems in children who had OSD, in a clear dose-response fashion. Finally, although parent- and self-reported grades were well correlated, SDB had the most robust association with self-reported grades, and teachers reported greater learning problems in subjects with OSA than those without.

With respect to sampling biases, our sample was not randomly selected. We chose to focus on clinically referred patients to provide access to a key target population: those who were overweight and consequently at greatest risk for OSD. Importantly, all of our subjects—from those eventually found to have no signs of SDB to those with severe OSA—were recruited in the same manner. Although clinically referred patients may show a higher base rate of pathology than the general population, there is no reason to suspect that our recruitment strategy would affect the relationships between SDB and behavioral functioning.

Behavioral Functioning

Prior studies have repeatedly shown associations between attention problems and OSD among young children and sustained attention is impacted by OSD in adults, so it is not surprising to find a similar effect in 10- to 16-year-old subjects. Obtaining this effect on teacher-report questionnaires is relatively unique, however, as few publications have reported findings from teachers. Two studies have reported associations between SDB and teacher-reported attention or the related construct of work-related symptoms. The reasoning was that ADHD was a confounding factor that caused problems with both sleep and school functioning.

School Functioning

Our findings of deficits in scholastic functioning are consistent with prior reports of links between SDB in young children and poorer school grades. But contrast with reports of minimal or no association between SDB and scores on academic achievement tests. This apparent inconsistency might be reconciled by careful consideration of what is being measured. Academic achievement tests, especially those administered one-on-one, measure accumulated knowledge in a manner that minimizes the impact of other behaviors, such as inattention. They are not designed to measure examinees’ ability to independently complete work or maintain motivation or attention for extended periods. However, these and many other behaviors contribute to school grades, with accumulated knowledge having an important but partial role. If OSD impacts attention or study skills, there may be little short-term effect on academic achievement tests, yet the functional impact in the classroom may be large.

Cognitive Functioning

We did not find associations between OSD and formal cognitive test results. These findings are at odds with the large effects reported by Rhodes and colleagues, though the fact that they assessed only 5 patients with OSD raises the possibility of an idiosyncratic effect or disproportionate impact of an outlier. Our findings are partially consistent with the rest of the published literature. Reliable differences on intelligence tests have been found primarily in children aged 6 and younger, with inconsistent findings in older children and no appreciable effects in adults with OSD. Memory test results have been inconsistent across both pediatric and adult OSD studies, with multiple failures to replicate effects on declarative memory tests. Although tests of attention and executive functioning have more often shown deficits in children with OSD, there have been numerous failures to replicate in this domain as well.

It is not entirely clear why the behavioral deficits that have been repeatedly shown to occur in the daily lives of children with SDB at varying ages have proven more difficult to quantify in the office. Although some have been tempted to dismiss parent report of difficulties in daily functioning as artifacts of methodological biases, such biases cannot account for the present findings, nor those of other carefully conducted studies. We posit that it is important to think carefully about how a child’s functioning is assessed, and encourage future researchers to use multimodal assessments with measures that are relevant to attention and scholastic functioning in daily life (i.e., outside of the testing office).

How the data are conceptualized and analyzed may also be important. Because neuropsychological tests often yield many scales, we chose a broad multivariate approach that clustered scores into well-accepted neuropsychological domains. It may be more fruitful in the future to examine targeted domains of functioning using theoretically driven models of disease mechanisms and vulnerability. Indeed, while our broad approach seemed necessary in light of discrepant findings across studies of young children as compared to adults, future work should capitalize on our findings to pursue more conceptually refined models. Such refined models might suggest specific tests that are more sensitive to OSD than those used here.

Taking a careful theoretical perspective can also guard against the misuse of covariates. Covarying a variable that has a mediating (not confounding) role may result in misinterpretation. Mayes and colleagues recently dismissed associations between parent-reported sleep problems and measures of school performance because these associations disappeared after covarying for ADHD symptoms. The reasoning was that ADHD was a confounding factor that caused problems with both sleep and school functioning.
That is one possibility, but we propose an alternative. Although sometimes reified in the literature, ADHD in fact represents a cluster of behavioral symptoms.60 If SDB causes inattention, impulsivity, or hyperactivity, then these behavioral symptoms may not be confounders, but rather an intermediate step in a causal sequence that ultimately leads to poor scholastic performance.

Clinical Implications

Effect sizes in the current study were modest, but these findings nevertheless have clinical implications because modest shifts in a distribution of scores can result in markedly more children showing clinical pathology. On the BASC, for example, scores beyond one standard deviation from the normative mean are classified as “at risk” or “clinically significant.”30 Our subjects without SDB rarely exceeded this cutoff on the attention problems scale (11% per parent-report, 0% per teachers), whereas such problems were common among those with moderate or worse OSA (44% per parents, 38% per teachers). Similarly, although the SDB groups averaged no more than half a letter grade apart, many more individuals with SDB obtained poor marks; 30% of subjects with moderate or worse OSA reported typical grades below a “C,” whereas only 15% of those without SDB earned such poor marks. None of the subjects with moderate or worse OSA reported that they typically earn “A” grades, but 15% of those without SDB reported such high marks.

Poor school performance may be particularly important during middle- to late-childhood. Whereas high school students with A averages are competitive for college enrollment, for example, those with grade point averages below a C are unlikely to attend college,23 highlighting the potential real-world, long-term consequences of unaddressed SDB. These findings support the routine clinical screening for SDB during this developmental period, especially among those who are overweight and are struggling academically.

Limitations and Concluding Statements

As with all studies, this project had limitations. Perhaps the greatest of these related to our measurement of school performance. While measuring academic grades allowed for a better summary estimate of “real world” school performance than would have been provided by standardized achievement testing, there is inherent variability in grading standards both across and within schools. Additional variability may have been introduced by our reliance on parent- and self-report of academic grades, though the strong correlation between parent- and self-reported grades was reassuring. While we were unable to control for variability in grading standards, unreliability in measurement artificially weakens statistical associations, suggesting that our finding of links between SDB and school performance may, if anything, be conservative.

With respect to other study limitations, our focus upon a clinically involved sample of overweight subjects may impact its generalizability to other populations. In addition, although we have attempted to account for potential confounding variables, the cross-sectional nature of the study tempers the conclusions that can be drawn, especially regarding the presence and nature of causality. We elected to focus on an understudied age range in this study, but this research was not truly developmental in nature. We did not find age to be a significant moderator of effects, but did not thoroughly assess other factors, such as pubertal stage, that may moderate the associations between SDB and cognitive or behavioral functioning. For this study, we also did not have consistent information on subjects’ sleep the night prior to the neuropsychological testing; although we had attempted to collect actigraphy on all subjects during the week prior to testing, too many subjects were missing data from the night before the testing (due to instrument failure or subject nonadherence) to consider actigraphy data as a potential covariate. Instead, we co-varied based on parent- and self-report of typical sleep duration on school nights, which better fits the measurement timeframe used for academic grades and the behavior questionnaires, but which may not be as strongly predictive of neuropsychological test performance. Finally, the study does not speak directly to the physiological mechanisms that may underlie the impact of SDB.

We look forward to findings from ongoing and future work that takes a longitudinal perspective, uses multimodal assessments, examines markers for putative physiological mechanisms and, when possible, involves experimental methods (e.g., a randomized clinical trial such as the NIH-funded multi-site Children’s Adenotonsillectomy Trial or CHAT). Present findings suggest that researchers and clinicians alike should take time to focus on middle and late childhood, during which SDB may have significant functional deficits that have long-term consequences. The importance of SDB does not appear to decline across childhood, even as other challenges (e.g., short sleep duration) emerge to complicate the clinical picture.

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