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Child Executive Control as a Moderator of the Longitudinal Association Between Sleep Problems and Subsequent Attention-Deficit/Hyperactivity Disorder Symptoms

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Abstract

Objective To examine the longitudinal associations among sleep, executive control (EC), and attention-deficit/hyperactivity disorder (ADHD) symptoms in childhood. **Methods** In this longitudinal study ($N = 271$), parents answered questions about sleep problems when children were 3 years old, children completed a comprehensive EC task battery at 4.5 years, and teachers completed standardized measures of child ADHD symptoms in 4th grade. **Results** Latent moderated structural equation models demonstrated that sleep problems at 3 years and EC deficits at 4.5 years were associated with ADHD symptoms in 4th grade. EC moderated the relationship between sleep problems and hyperactivity/impulsivity, such that children with both sleep problems and poor EC were particularly at risk for hyperactivity/impulsivity. **Conclusions** Sleep problems and EC deficits early in development were associated with increased risk for ADHD symptoms in elementary school. Early assessment and intervention to promote healthy sleep and EC development may be helpful in ADHD prevention.

Key words: ADHD; child; executive control; sleep.

Attention-deficit/hyperactivity disorder (ADHD) is a common neurodevelopmental condition affecting about 7% of children in the United States (Thomas, Sanders, Doust, Beller, & Glasziou, 2015). Among the many factors associated with this disorder, problems with executive control (EC)—a set of cognitive abilities for directing attention and behavior (also known as executive functioning)—have received the most attention as a contributor to the daily symptoms and impairments of ADHD (Barkley, 1997; Carlson, 2005; Garon, Bryson, & Smith, 2008). Research and theory also suggest that early sleep problems could result in later ADHD symptoms through deleterious effects of sleep loss on skills subserved, at least partially, by the prefrontal cortex (PFC; Beebe, 2011). Moreover, sleep problems may be worse for children with poor EC because they have more limited cognitive resources for overcoming deficits associated with suboptimal sleep. However, despite the conceptual links between sleep and EC and ADHD symptoms, research examining the interplay between these constructs within longitudinal studies is lacking.

Early Sleep Problems and Development of ADHD Symptoms

Preschool is a critical period for the development of the PFC (Durston & Casey, 2006; Giedd & Rapoport, 2010; Huttenlocher, 1990), and research suggests that early sleep problems may compromise PFC maturation (Beebe, 2011). For instance, research has demonstrated specific deleterious effects of sleep loss on the PFC, particularly in terms of daytime inattention symptoms (Gruber et al., 2012; Lundahl, Kidwell, Van Dyk, & Nelson, 2015). Early sleep problems may increase the risk for ADHD symptoms by interfering with the PFC at an important developmental time point.

As measured through experimental, correlational, and longitudinal designs, findings suggest that insufficient sleep interferes with higher-level cognitive abilities such as attention, working memory, and inhibition, which are strongly influenced by PFC functioning (Beebe, 2011, Chervin, Ruzicka, Archbold, & Dillon, 2005; Gregory, Eley, O'Connor, & Plomin, 2004; Lundahl et al., 2015; Sadeh, Gruber, & Raviv, 2003). For example, Chervin and colleagues (2005) found that snoring predicted hyperactivity 4 years later in children, and Gregory et al. (2004) found that sleep problems at ages 3 and 4 predicted hyperactivity at age 7. In a meta-analysis of studies examining experimental sleep restriction/extension and inattention/hyperactivity symptoms, Lundahl and colleagues (2015) found that youth experienced increased symptoms of inattention following experimental sleep restriction. Poor sleep also predicted poor judgment, poor decision-making, and low motivation (Owens et al., 2014), each of which requires core PFC abilities for optimal functioning. Taken together, the current literature base indicates that sleep problems are associated with ADHD symptomatology.

Even when examined in healthy samples, sleep problems have been associated with increases in ADHD-like symptoms (Gruber et al., 2012). For instance, Gruber and colleagues (2012) examined objectively measured sleep across three nights in healthy children aged 7–11 years and found that worse sleep was associated with teacher ratings of inattention on the Conners' Teacher Rating Scale. Research demonstrating that sleep problems predict ADHD symptoms provides support for the theory that sleep problems have deleterious effects on attention and behavior (Cassoff, Wiebe, & Gruber 2012; Gregory et al., 2004); however, more research is needed to replicate and extend current findings, including exploration of factors that may moderate the association between sleep and ADHD symptoms (see Gregory & Sadeh, 2012 for review).

Early EC Deficits and Development of ADHD Symptoms

In addition to the likely co-occurrence of sleep problems and ADHD, EC is a construct strongly linked to ADHD. EC includes working memory, inhibitory control, and flexible shifting, and strong EC allows for problem-solving, self-regulation, and planning, precisely the areas that are often difficult for children with ADHD. Thus, researchers have theorized that difficulties with EC contribute to the self-regulation difficulties inherent to ADHD (Barkley, 1997; Barkley, 2012). Preschool is a critical period in EC development, as EC abilities develop rapidly during preschool, paralleling maturation in the PFC (Durston & Casey, 2006; Giedd & Rapoport, 2010; Huttenlocher, 1990). Furthermore, EC begins to differentiate from more foundational cognitive abilities like Intelligence Quotient (IQ) during preschool (Espy, 2016). Thus, preschool is an important period to study emerging EC abilities. As EC deficits are implicated in the etiology of ADHD (Barkley, 1997; Willcutt et al., 2005), those with poor EC in preschool may be especially likely to show subsequent ADHD symptoms.

Researchers have found support for the theory that EC deficits contribute to ADHD symptoms (Brocki, Eninger, Thorell, Bohlin, 2010; Espy, Sheffield, Wiebe, Clark, & Moehr, 2011; Rabinovitz, O'neill, Rajendran, Halperin, 2016). For example, a meta-analysis conducted by Willcutt and colleagues (2005) found that youth with ADHD had impairments on all examined EC tasks. They argued that the moderate effect sizes indicated that EC deficits were not a sufficient explanation for all cases of ADHD, but rather EC deficits were one contributing factor in a complex constellation of causes (Willcutt et al., 2005). Halperin and Schulz (2006) have proposed a slightly different theory of the role of EC in ADHD. They argue that ADHD is caused, at least in part, by subcortical dysfunction. As EC develops, it exerts top-down influence on subcortical regions, which allows for improvement in ADHD symptoms. Fitting with Halperin and Schulz's (2006) theory, children experiencing EC deficits would experience increased ADHD symptoms owing to the weaker top-down influence of EC on subcortical regions. However, there have been few studies examining EC and ADHD symptoms in typically developing samples, and longitudinal studies of the association between behaviorally measured EC and ADHD are rare. Research with a community sample would allow for questions of generalizability to be addressed.

Sleep–EC Interaction

Poor EC in preschool may interact with early sleep problems to worsen the risk for ADHD because children with poor EC have fewer cognitive resources to draw on to overcome sleep deficits. Essentially, the PFC experiences "double adversity" (sleep impairment and EC impairment), further compromising daily cognitive and behavioral functioning. Moreover, it is possible that the deleterious effects of poor sleep and poor EC on daily functioning are not merely additive, but rather multiplicative, with poor sleep *interacting* with poor EC to result in particular vulnerability to ADHD symptoms. Despite this possibility, longitudinal research examining the interaction between early EC and sleep in predicting later ADHD symptoms is lacking. Further, it may be important to study the effects of early sleep and EC on functioning in elementary school in particular for several reasons. First, during elementary school, academic demands increase and ADHD rates tend to increase. Second, with increased classroom structure, symptoms of ADHD become increasingly apparent. Overall, sleep problems may have greater consequences for children with poor EC because they already have more limited cognitive resources, and these consequences may be more apparent in the increasingly demanding environment of the elementary school classroom.

Building on research demonstrating that sleep and EC are independently associated with ADHD, some studies have investigated the associations among sleep, EC, and ADHD. For instance, Schneider, Lam, and Mahone (2016) examined the associations among sleep, EC, and ADHD in a sample of children with and without ADHD aged 4–7 at a single time point. They found that sleep problems were associated with ratings of ADHD symptoms, but sleep problems were not associated with performance on EC tasks. Further, children with ADHD demonstrated worse performance on EC tasks. Additionally, Sadeh, Gruber, and Raviv (2003) examined objectively measured sleep, EC (neurobehavioral functioning using computerized measures), and behavior problems in a community sample of school-aged children. Children with more fragmented sleep experienced problems with both EC and daytime behavior. Despite these studies linking both sleep problems and poor EC to ADHD, the interaction between the two constructs in predicting later ADHD symptoms has not yet been examined (to our knowledge).

Study Rationale

Sleep problems during preschool could have deleterious effects on brain development, particularly in the PFC, during a critical time for PFC development, thus potentially changing the individual's trajectory of PFC development in childhood. The consequences of these sleep problems (and any associated detrimental effects on brain development) may be most evident later in elementary school because that is when ADHD symptoms tend to become particularly apparent as the academic and behavioral demands on children increase relative to preschool (DuPaul & Stoner, 2014). Although poor sleep is known to have short-term negative cognitive and behavioral effects (Beebe, 2011), some of these effects may not be immediately observable on a day-to-day basis in preschool because of relatively limited demands on preschool children to direct and sustain attention and inhibit their behavior. Such demands increase substantially in elementary school, though, so underlying deficits in cognitive and behavioral control may begin to manifest as observable daytime ADHD symptoms at this time. Along these lines, previous studies have found that preschool sleep problems significantly predicted ADHD symptoms years later in elementary school (Gregory et al., 2004). If sleep problems were to persist, sleep problems in preschool would be especially detrimental for children with poor EC because they would have more limited cognitive resources to draw on in overcoming the daytime effects of suboptimal sleep. In contrast, children with strong EC may be better able to compensate for the effects of poor sleep by drawing on existing resources. The current study is uniquely positioned to examine this interaction between sleep problems and EC abilities in predicting the emergence of later ADHD symptoms given the timing of measurement across preschool and elementary school.

The current study addresses several important limitations in the literature. First, this study uses a longitudinal design at theoretically important points in development to examine the moderating role of EC on the sleep–ADHD relationship. Specifically, we examine the longitudinal associations among sleep problems at age 3, EC deficits at 4.5 years, and ADHD symptoms in 4th grade. Second, this study included developmentally appropriate performance-based measurement of EC using a comprehensive behavioral task battery. By using performance-based behavioral tasks, this study improves on previous research relying on parent report of child EC by obtaining objective measures of child abilities. Third, this study integrates teacher-report of ADHD symptoms, which incorporates the critical school context. Finally, this study offers a novel examination of the moderating role of EC in the sleep–ADHD association, which has the potential to identify how known risk factors for ADHD interact to affect risk.

Hypotheses

The current study had three hypotheses. The first hypothesis was that preschool sleep problems would be associated with later ADHD symptoms in 4th grade. This hypothesis was based on previous findings of significant associations between early sleep problems and ADHD symptoms, but extends previous research into later elementary school using a longitudinal design. Second, it was expected that preschool EC deficits would be related to symptoms of ADHD later in development. This hypothesis was based on research and theory demonstrating that EC deficits often underlie ADHD symptoms. The third hypothesis—and the main focus of this study—was that EC would moderate the association between sleep and ADHD symptoms, such that those with both sleep problems and EC deficits would be at greatest risk for later ADHD symptoms.

Table I. *Descriptive Statistics on Sample Demographics and Observed Variables*

Variable			Mean	*SD*	Min	Max	% Over clinical cutoff
CBCL Sleep Problems Scale—Baseline			54.6	5.9	50	88	5.9
CBCL ADHD Subscale—Baseline			52.5	3.5	50	67	1.8
Conners 3-T Inattention—4th grade			50.7	11.5	41	89	13.3
Conners 3-T Hyperactivity—4th grade			52.7	13.8	41	90	18.5
Age in 4th Grade			10.1	0.36	9.3	11.3	–
Gender	*N*	%					
Male	137	50.6					
Female	134	49.4					
Ethnicity							
European American	199	73.4					
African American	14	5.2					
Hispanic	20	7.4					
Multiracial	38	14.0					
SES—at-risk							
Yes	126	46.5					
No	145	53.5					

Method

Participants

Participants were 271 children initially recruited at age 3 years through flyer distribution at two Midwestern study sites for a longitudinal study spanning preschool to elementary school. The two study sites were comparable in terms of ethnicity, gender, and household income. Recruitment involved stratification by these key demographic variables to ensure comparable recruitment numbers. There were no significant recruitment-site differences in gender, ethnicity, or socioeconomic status (SES; p's > .05). As the larger project focused on examining typical cognitive development, children with diagnosed developmental, behavioral (including ADHD), or language disorders *at study entry* were excluded; however, children who were diagnosed after initial recruitment for the longitudinal study were not excluded. Children were not screened for sleep disorders at study entry. To be eligible for the study, the primary language spoken at home had to be English. In terms of race and ethnicity, the sample was regionally representative with 73.43% of children reported as European American, 7.38% as Hispanic/Latino, 5.17% as African American, and 14.02% as multiracial. Participant recruitment was stratified by both gender (49.4% female) and sociodemographic risk, with 46.5% of the sample considered at-risk based on qualification for Medicaid/Children's Health Insurance Program (CHIP) or by falling below the federal poverty guidelines. Descriptive statistics for sample demographics are presented in Table I.

Procedures

The larger longitudinal study consisted of a cohort sequential design spanning multiple time points beginning in preschool. For the current study, parents completed sleep questions at study entry when children were 3 years old. Behavioral EC tasks were completed in the laboratory at age 4.5 years for all participants. Both parent and child visited the university laboratory to participate, with a technician administering the battery of EC tasks to the child. In the spring of 4th grade, teachers completed measures of ADHD symptoms. Teachers were mailed questionnaire packets along with a prepaid return envelope. To maintain interest in participating in the project, there was interim contact with the families via seasonal newsletters and birthday cards. The parent provided contact information of two close friends or relatives whom the researchers could contact if the family's phone number or address changed to maintain contact with the family. All study procedures were approved by the institutional review board at the University of Nebraska-Lincoln.

At study entry, 271 children participated at age 3 years, and all had complete data on the initial sleep measure and baseline ADHD symptoms (100%). At age 4.5 years, 258 children participated (95.2%), and 234 children participated in 4th grade (86.3%). Of the 234 who participated in 4th grade, 211 children had teacher-reported data on ADHD symptoms (90.2%). Children who had complete data did not differ from children with missing data on gender, ethnicity/race, SES at-risk status, the initial score on the sleep problems scale, or baseline ADHD symptoms (ps > .05). Full information maximum likelihood (FIML) estimation was used for moderation analyses, and thus, the full sample of 271 participants was included in the analyses. FIML estimation is a preferred way to handle missing data to avoid introducing bias (Enders, 2010; Little, Jorgensen, Lang, & Moore, 2014).

Measures

Child Sleep Problems

Sleep problems were assessed at age 3 years using the sleep problem questions from the Child Behavior

Checklist for ages 1½–5 (CBCL/1½-5), a widely used caregiver-completed measure of children's emotional and behavioral functioning (Achenbach & Rescorla, 2000; Ebesutani et al., 2010). The sleep problems subscale is a commonly used measure of sleep issues in childhood (Gregory et al., 2011; Gregory & O'Connor, 2002), consisting of seven items measured on a 3-point Likert scale (*Never/Not True*, *Sometimes/Somewhat True*, and *Often/Very True*) gauging common sleep problems (e.g., difficulty sleeping, short/long typical sleep duration). Recent research has demonstrated that the CBCL sleep problems composite score is highly correlated with well-validated measures of sleep (e.g., Children's Sleep Habits Questionnaire; Owens, Spirito, & McGuinn, 2000) and clinical diagnosis of sleep problems (Becker, Ramsey, & Byars, 2015). Internal consistency for the sleep problems questions in the current sample was acceptable ($\alpha = .70$). Refer to Table I for mean, *SD*, range, and percentage of cases above clinical cutoffs for the CBCL sleep problems scale.

Executive Control

Children completed EC tasks at age 4.5 years. The EC battery consisted of nine tasks reflecting the three major aspects of EC (i.e., inhibitory control, working memory, and flexible shifting). Three tasks in the battery measured working memory: *Delayed Alternation*, *Nine Boxes*, and *Nebraska Barnyard*. Four tasks gauged inhibitory control by requiring the children to inhibit a prepotent response: *Big-Little Stroop*, *Go/No-Go*, *Shape School* (*Inhibit condition*), and *modified Snack Delay*. Two tasks measured flexible shifting: *Shape School* (*Switching Condition*) and *Trails* (*Switching Condition*). The tasks have demonstrated excellent psychometric properties with excellent discriminant validity, construct validity, and reliability (refer to Espy, 2016 for a more detailed description of psychometric performance of the tasks). The tasks were used to make a latent EC factor to best represent underlying EC abilities (Nelson, James, Chevalier, Clark, & Espy, 2016). See Table II for a brief description of each EC task.

Child ADHD Symptoms

In 4th grade, child ADHD symptoms were assessed using the Conners' 3rd Edition Teacher Ratings Scale (Conners 3-T; Conners, Pitkanen, & Rzepa, 2011), a teacher-report measure of hyperactive-impulsive and inattentive symptoms in the classroom. Teacher-report of ADHD symptoms is critical because symptoms are typically more apparent in structured settings such as school classrooms (DuPaul & Stoner, 2014). The Conners 3-T is a validated measure that includes updated *T*-scores based on a geographically representative normalization sample (Kollins, Epstein, & Conners, 2014). Each subscale is composed of 4-point Likert scale items, with high scores corresponding to diagnostic criteria for ADHD subtypes. The internal consistency for both the hyperactivity and inattention scales were excellent (hyperactivity $\alpha = .94$; inattention $\alpha = .95$). Refer to Table I for mean, *SD*, range, and percentage of cases above clinical cutoffs of the Conners 3-T hyperactivity and inattention scales.

To control for baseline ADHD symptoms, the ADHD subscale of the CBCL/1½-5 was included in the analyses from when children were 3 years old (Achenbach & Rescorla, 2000). Because teacher-report data were not applicable for the 3-year-olds in this study, parent-report of baseline ADHD symptoms was used as a control variable. Parents responded to the items using a 3-point response scale (*Not True [as far as you know]*, *Somewhat or Sometimes True*, and *Very True or Often True*). The preschool-aged version of the CBCL has only one subscale for ADHD symptoms. Refer to Table I for descriptive statistics of the CBCL/1½-5 ADHD subscale.

Analysis Plan

A latent moderated structural equation (LMS) model was used to determine whether EC was a moderator of the relationship between 3-year-old sleep problems and ADHD symptoms in 4th grade. LMS has advantages over conventional moderator analyses because the estimates of interactions are unaffected by measurement error, which reduces the likelihood of biased estimates (Maslowsky, Jager, Hemken, 2016). Because the LMS model does not provide standardized results, all variables were standardized into *Z*-scores before being entered into the model, so that the relative magnitude of the path coefficients could be compared (Maslowsky et al., 2016). However, the model does not provide true standardized coefficients. The seven sleep items were standardized before making the latent sleep factor, and the nine EC task scores were standardized before making the single latent EC variable. Previous research using the nine EC tasks found that preschool EC was best modeled using a single factor based on fit and parsimony (Nelson et al., 2016). The fit of the single factor structure was confirmed with the current sample.

In this model, predictor variables were latent and outcome variables were observed for several reasons. Because past research (Espy, 2016) has demonstrated that EC is best represented with a latent construct, latent moderator analyses were chosen to estimate EC as the moderator variable. LMS models perform best when the interaction term is composed of two latent variables (Maslowsky et al., 2016). Thus, the predictor, sleep problems, was also estimated as a latent factor. However, because latent variable interactions require numeric integration (repeated rectangling of

Table II. *Description of Executive Control Tasks*

EC task	Brief description	Source	*M* (*SD*)
Working memory			
Delayed Alternation	Child chooses one of two locations on a board to find a reward. After a delay, the location of the reward alternates, and the child must remember the last location to make the correct choice.	Espy et al. (1999); Goldman et al. (1971)	5.85 (5.50)
Nine Boxes	Child searches among nine differently colored and shaped boxes for a reward. The child must remember which boxes he/she has already searched to find the reward in the fewest number of trials.	Adapted from Diamond et al. (1997)	5.20 (1.75)
Nebraska Barnyard	Child is shown nine animals in colored boxes arranged in a 3 × 3 grid. The animal pictures are then removed from the boxes. Child must remember which animal went on which box to correctly point out sequences of animals.	Adapted from Hughes, Dunn, & White. Noisy Book task (1998)	6.84 (2.60)
Inhibitory control			
Big-Little Stroop	Child is presented with images of smaller objects within larger objects. Child must name the smaller object, which requires suppressing the larger object name.	Adapted from Kochanska et al. (2000)	0.84 (0.23)
Go/No-Go	Child views a series of fish or shark images. Child is asked to press a button when a fish is shown to catch the fish. The child must inhibit pressing the button when a shark is shown because the shark will break the net.	Adapted from Simpson & Riggs (2006)	2.27 (0.80)
Shape School—Inhibit	Child is presented with happy or sad cartoon faces and is asked to name the color of the stimulus when the face is happy and to inhibit naming the color when the face is sad.	Espy (1997); Espy et al. (2006)	0.91 (0.21)
Modified Snack Delay	Child is seated next to a piece of candy and is asked to remain still until a bell rings.	Adapted from Kochanska et al. (1996); Korkman et al. (1998)	22.13 (9.67)
Flexible shifting			
Shape School—Switching	The child is presented with cartoon figures that are different colors and shapes. Some of the figures are wearing a hat and some are not. Child is asked to say the color of the stimulus when the figure is not wearing a hat and to say the shape when it is wearing a hat.	Espy (1997); Espy et al. (2006)	0.72 (0.25)
Trails—Switching	Child is asked to alternate between placing a stamp mark on either the dog or bone stimuli.	Adapted from Espy & Cwik (2004)	0.86 (0.12)

the latent trait distributions), it is generally recommended to limit the number of latent factors included in a single LMS model (Hoffman, 2015). Thus, the outcome and control variables were the observed scores rather than latent factors. Both inattention and hyperactivity were included as observed outcomes in the same model. Gender and the CBCL ADHD subscale at baseline were included as observed control variables.

The two-step procedure for latent moderator analyses recommended by Maslowsky and colleagues (2016) was implemented in Mplus version 6.12 (Muthén & Muthén, 2013) using maximum likelihood. First, the measurement model that estimated the relationships between the latent predictors and observed variables was evaluated to ensure acceptable fit statistics. Second, the latent moderator (latent sleep problems X latent EC) was added to the structural equation model. Because LMS model does not provide fit statistics, a likelihood ratio test was used to compare the LMS model with the measurement model (Maslowsky et al., 2016). Maximum likelihood estimation handles missing data well and allows all cases to be included in the analyses regardless of missing data.

Results

Preliminary Analyses

Correlations were calculated to determine whether there were any gender, ethnicity/race, or SES differences on the outcome variables. Gender significantly correlated with inattention and hyperactivity symptoms, but neither ethnicity/race nor SES was significantly correlated with ADHD scale ($ps > .05$). Thus, gender was included in the subsequent models as a control variable, along with baseline ADHD symptoms.

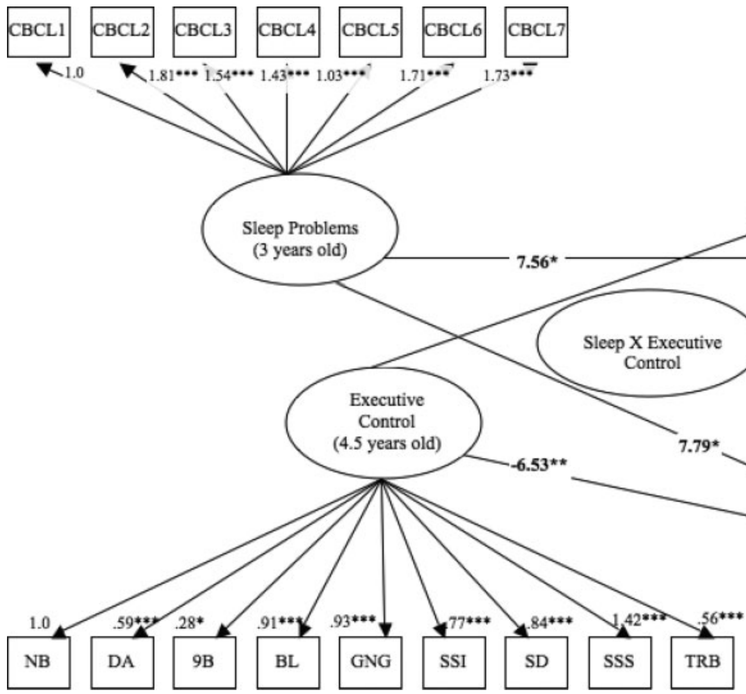

Figure 1. Results of latent moderated structural equation model (LMS).

Notes: Because standardized results have not been developed for LMS models, variables were standardized (*Z*-scores) before being entered into the model.

† = .058, **p* < .05, ***p* < .01, ****p* < .001.

NB = Noisy Book; DA = Delayed Alternation; 9B = 9 Boxes; BL = Big-Little Stroop; GNG = Go/No-Go; SSI = Shape School Inhibit; SD = Snack Delay; SSS = Shape School Switch; TRB = Trail Making Test.

Structural Equation Model

The measurement model that estimated the associations among the latent predictors and observed variables demonstrated excellent fit, Root Mean Square Error of Approximation (RMSEA) = 0.03, Comparative Fit Index (CFI) = 0.96, Tucker-Lewis Index (TLI) = 0.95, Standardized Root Mean Square Residual (SRMR) = 0.05. All item loadings contributing to the latent sleep problems and EC constructs were significant. The likelihood ratio test comparing the latent moderator model with the original measurement model indicated that the model with the latent moderator was the better model, χ^2 (1) = 234.46, $p < .001$. See Figure 1 for a depiction of the latent moderator model results. (Note that although the sleep × EC interaction is depicted in one circle in the figure, the interaction was not a main effect in the latent moderator model, but rather, EC was estimated as a true moderator).

Inattention

In the latent moderator model controlling for gender and baseline ADHD symptoms, sleep problems significantly predicted more inattention symptoms, $b = 7.56$, $SE = 3.25$, $t = 2.33$, $p = .020$. EC also significantly predicted inattention symptoms, such that children with worse EC had more inattention symptoms, $b = -8.54$, $SE = 2.27$, $t = -3.76$, $p < .001$. The latent sleep problems × EC moderator variable did not significantly predict greater inattention, but rather, trended toward significance, such that those with both sleep problems and EC deficits experienced a trend toward more inattention symptoms than those with high EC, $b = -16.88$, $SE = 8.89$, $t = -1.90$, $p = .058$.

Hyperactivity

In the latent moderator model controlling for gender and baseline ADHD symptoms, sleep problems significantly predicted more hyperactivity symptoms, $b = 7.79$, $SE = 3.53$, $t = 2.21$, $p = .027$. EC also significantly predicted hyperactivity symptoms, such that children with worse EC had more hyperactivity symptoms, $b = -6.53$, $SE = 2.45$, $t = -2.67$, $p = .008$. The latent sleep problems × EC moderator variable significantly predicted greater hyperactivity, such that those with both sleep problems and EC deficits experience more hyperactivity symptoms than those with high EC, $b = -18.59$, $SE = 9.11$, $t = -2.04$, $p = .041$.

Visually comparing the relative coefficient terms demonstrates that sleep problems were equally predictive of inattention and hyperactivity symptoms, EC was associated with a slightly larger increase in inattention than hyperactivity symptoms, and the interaction term was related to a larger increase in hyperactivity symptoms than inattention symptoms.

Discussion

The current study examined early sleep and EC problems as predictors of ADHD symptoms in 4th grade. Consistent with the first hypothesis that preschool sleep problems would predict later ADHD symptoms, results demonstrated that sleep problems at age 3 were significantly associated with greater ADHD symptomatology in 4th grade. In support of the second hypothesis that early EC deficits would predict elementary ADHD symptoms, EC deficits at age 4.5 years were associated with ADHD symptoms in 4th grade. Finally, the results indicated that EC deficits moderated the relationship between sleep problems and hyperactivity.

The finding that sleep problems at age 3 were significantly associated with higher levels of inattention and hyperactivity in 4th grade builds on previous research on sleep problems and symptoms of ADHD (Chervin et al., 2005; Gregory et al., 2004). This study shows that early sleep problems predicted the subsequent emergence of ADHD symptoms in a sample without clinical ADHD symptoms in preschool. By using an extended longitudinal design with children who had not yet been diagnosed with ADHD at study entry and by controlling for baseline symptoms of ADHD, this study provides support for the theory that sleep problems are associated with increased risk for the development of ADHD symptoms.

Results also indicated that EC deficits predicted greater ADHD symptoms, an outcome that maps onto findings in the literature of associations between EC and ADHD (Espy et al., 2011; Sadeh et al., 2003; Willcutt et al., 2005) and provides support for Barkley's (1997) theory of EC deficits underlying ADHD. This study also builds on previous studies by examining the constructs in a longitudinal design starting early in development. Moreover, the results support the theory that over time, EC becomes increasingly important in processes related to self-regulation and behavior management (Halperin & Schulz, 2006). Thus, children with poor EC may have worse behavioral control, which exacerbates ADHD symptomatology in elementary school (Rabinovitz et al., 2016).

This study also found that EC was a moderator of the relationship between sleep problems and ADHD symptoms, with findings showing that children with both sleep problems and EC deficits experienced more hyperactivity than those with high EC. The sleep × EC interaction did not significantly predict inattention symptoms, but instead trended toward significance. The moderator findings in the current study are in line with results from Schneider et al. (2016), who found associations between sleep and ADHD symptoms, and that children with ADHD demonstrated worse performance on EC tasks. However, Schneider and colleagues' (2016) study was limited by a focus on associations at a single developmental time point and by a lack of mediation or moderation analyses. The current study extends the work of Schneider et al. (2016) by examining associations among sleep, EC, and ADHD at three time points in a longitudinal design and by examining EC as a moderator of the sleep–ADHD relationship.

Implications

The findings that early sleep and EC deficits were associated with inattention and hyperactivity symptoms later in childhood have important clinical implications. Health-care providers are encouraged to provide sleep and EC interventions in preschool. First, for young children presenting with sleep problems, practitioners can provide behavioral sleep treatments such as techniques for managing bedtime resistance and education on sleep hygiene. Research has begun to demonstrate that treating sleep problems as part of routine clinical care reduces ADHD symptoms and associated problems (Hiscock et al., 2015; Keshavarzi et al., 2014; Nelson, Van Dyk, McGinnis, Nguyen, & Long, 2016). Second, health-care providers are encouraged to assess for EC difficulties starting in preschool. For children who demonstrate poor EC, practitioners are encouraged to recommend interventions that may improve EC. Research has demonstrated that EC is modifiable (Halperin et al., 2013; Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005), and studies have found support for computerized interventions (Mackey, Hill, Stone, & Bunge, 2011), school-based curricula (Diamond, Barnett, Thomas, & Munro, 2007; Raver et al., 2011), tae kwon do (Lakes & Hoyt, 2004), and yoga/mindfulness programs (Razza, Bergen-Cico, & Raymond, 2015).

In the context of future research, these findings lay the groundwork for research on the efficacy of sleep treatments for children with ADHD by demonstrating that early sleep problems are associated with ADHD symptoms. Because a typically developing sample was recruited (children with diagnosed emotional and behavioral disorders at the initial time point were excluded), this study demonstrates that the associations among sleep, EC, and ADHD symptoms are generalizable to a community sample. Sleep and EC appear to contribute to the complex constellation of predictive factors of ADHD.

Limitations and Future Directions

The current findings should be considered in the context of the study's limitations. First, the parent-report sleep measure at age 3 was limited by the parent-report format. This study used the parent-report CBCL sleep questions to make a latent sleep scale.

Although not an ideal measure of sleep duration and quality, items from the CBCL are useful predictors of objectively assessed child sleep problems (Gregory et al., 2011). Recent research has demonstrated that the CBCL sleep problems composite score is highly correlated with well-validated measures of sleep (e.g., Children's Sleep Habits Questionnaire; Owens, Spirito, & McGuinn, 2000) and clinical diagnosis of sleep problems (Becker, Ramsey, & Byars, 2015). Although actigraphy would provide a more accurate measurement of sleep duration, the CBCL is able to identify sleep problems and symptoms that may not be fully captured by actigraphy (Lewandowski, Toliver-Sokol, & Palermo, 2011; Nelson, Nelson, Kidwell, James, & Espy, 2015). Future research is needed to replicate the current findings using a combination of subjective and objective measurement of sleep. Future research would also benefit from specifically assessing sleep duration and how sleep duration is associated with inattention and hyperactivity. Second, ADHD symptoms may not be as well-measured in 3-year-olds as in older children, and thus, the baseline covariate may not be as effective in controlling for early ADHD symptoms. Third, ADHD symptoms were assessed in a community sample with a teacher-report rating scale rather than conducting a thorough assessment of whether children had diagnosable, clinical ADHD. Toplak and colleagues (2009) demonstrated convergent validity of teacher-reported questionnaire data of ADHD symptoms with clinicians' structured diagnostic interviews with similar factor loadings across the assessment measures. However, future researchers may choose to examine the interaction of sleep and EC in subsamples of youth diagnosed with ADHD to build on the current study that examined the constructs in a community sample. Fourth, this sample was primarily European American, which is regionally representative of the Midwest of the United States. Although the children were primarily European American, other ethnicities were represented (26.6% were an ethnic minority), and the sample was oversampled on socioeconomic risk status to provide variability in SES.

Moreover, there are multiple conceptual explanations for how sleep, EC, and ADHD may be related. In practice, it is difficult to distinguish between inattentiveness that derives from sleepiness and inattentiveness that is symptomatic of ADHD (Owens, 2005). The results of the current study indicate that when examined longitudinally, sleep problems at 3 years old predicted greater teacher-rated inattention and hyperactivity symptoms in 4th grade when controlling for baseline ADHD symptoms. It could be that sleep problems are a risk factor for inattention and hyperactivity years later, or that concurrent sleep problems result in ADHD-like symptoms, or that early sleep problems are a prodromal sign of ADHD, or that sleep loss results in impaired functioning in the PFC leading to ADHD symptoms. Because measures of key variables included in this study were limited to single time points, the associations among sleep, EC, and ADHD may not be causally related but simply reflect covarying traits. Future researchers may want to examine the interaction between sleep and EC measured at multiple time points and predicting ADHD symptoms earlier in development. Furthermore, it is possible that other variables may be associated with sleep problems, poor EC, and ADHD symptoms. For example, ineffective parenting practices could lead to sleep problems and also exacerbate problems with attention and hyperactivity. More research is needed on sleep, EC, and ADHD to elucidate the complex relationships at work.

Despite the limitations of the current study, there are many strengths of the research design. First, the extended longitudinal design allows for more confidence in the findings that sleep problems at 3 years and EC problems at 4.5 years precede symptoms of ADHD. To examine the temporal sequence of the developmental trajectory, sleep, EC, and ADHD symptoms were assessed at different time points. Second, because sleep and EC change across development, children were assessed within 2 weeks of turning 3 and 4.5 years old to control for age. Third, teachers reported on symptoms of ADHD because inattention and hyperactivity are typically more apparent in structured settings such as school classrooms (DuPaul & Stoner, 2014). Finally, rather than using parent-rated EC, nine developmentally appropriate behavioral tasks were used to assess the various components of EC.

Conclusions

In conclusion, this study found that early sleep problems at 3 years old and EC deficits in preschool predicted ADHD symptoms in elementary school. This study provided a novel examination of EC as a moderator, finding that EC moderated the relationship between early sleep problems and hyperactivity, such that children with both sleep problems and poor EC were particularly susceptible to exhibiting hyperactivity. It is recommended that health-care providers assess and treat early sleep problems and EC problems to mitigate risk of inattention and hyperactivity symptoms.

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