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Novel insights from actigraphy: Anxiety is associated with sleep quantity but not quality during childhood

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Abstract

Anxiety and sleep function change dynamically across development, and sleep dysfunction has emerged as a correlate and predictor of anxiety in pediatric clinical samples. Despite this, previous research has not investigated how associations between qualitative and quantitative measures of sleep function change with anxiety across development, specifically from childhood to adolescence. The present study used actigraphy collection to examine whether associations between quantitative and qualitative sleep function and anxiety differed as a function of developmental stage in a community pediatric sample (8–17 years old; $N = 92$). Age moderated the association between anxiety and sleep quantity, but not sleep quality. Contrary to hypotheses, higher anxiety was related to increased sleep for children, but not adolescents. Results suggest age-related changes in the association between sleep function and anxiety across development, with implications for targeting sleep-related interventions for youth with anxiety.

Keywords

Sleep; actigraphy; anxiety; childhood; adolescence

Sleep-wake functions are a critical target of research on arousal and modulatory systems, highlighting the pervasiveness of sleep dysfunction in psychiatric disorders (Cuthbert & Insel, 2010). This focus on sleep suggests that tracing the roots of sleep dysfunction—and its association with psychopathology—throughout development may lead to greater optimization of treatment for mental illness across the lifespan (El-Sheikh and Buckhalt, 2015). Up to 90% of children diagnosed with anxiety disorders report sleep-related problems, and an estimated 88% of clinically anxious youth have a comorbid sleep disorder diagnosis (Alfano, Ginsburg, & Newman Kingery, 2007; Storch et al., 2008). Although specific patterns of sleep-related problems appear to be dependent on type of anxiety disorder diagnosis (Alfano, Pina, Zerr, & Villalta, 2010), numerous studies have documented that children and adolescents with anxiety disorders experience sleep-related problems including more difficulty falling asleep and maintaining sleep, going to sleep later, and getting less sleep than their non-anxious peers (Hudson, Gradisar, Gamble, Schniering, & Rebelo, 2009; Stein, Mendelsohn, Obermeyer, Amromin, & Benca, 2001).

Previous research on associations between sleep and anxiety across development has focused on the transition from childhood to adolescence, when individuals experience significant shifts in both hormonal factors and social contexts that have been hypothesized to underlie sleep disturbance (McMakin & Alfano, 2015), and when rates of psychiatric disorder onset peak for both males and females (Kessler et al., 2005). Higher rates of sleep-related problems (e.g., sleep disturbance, bedtime resistance, sleep anxiety, and parasomnia) are observed in younger children diagnosed with an anxiety disorder, as compared to adolescents (Alfano et al., 2010), which is consistent with previous reports that sleep-related problems may more commonly co-occur with anxiety disorders earlier in development (Alfano, Zakem, Costa, Taylor, & Weems, 2008; Dahl, 1996). However, both sleep function and the prevalence of anxiety symptomatology—as well as frontolimbic circuitry that underlies anxiety—undergo dynamic changes during adolescence (Casey, Heller, Gee, & Cohen, 2017), with adolescence representing a peak in anxiety disorder onset (Kessler et al., 2005), as well as a developmental period characterized by significant changes in circadian rhythms (Darchia & Cervena, 2014).

In addition to discrepant associations between anxiety and sleep during childhood versus adolescence, developmental changes in the biological processes underlying the emergence of both sleep disturbance and anxiety suggest that age may be an important moderator of associations between sleep quality and quantity and anxiety-related symptoms, particularly during the transition from childhood to adolescence (Gee et al., 2013; Gabard-Durnam et al., 2014; Hare et al., 2008; Kessler et al., 2005; Skeldon, Derks, & Dijk, 2016). Furthermore, sleep dysfunction has emerged as both a correlate and predictor of anxiety in pediatric clinical and community samples (Gregory, Van der Ende, Willis, & Verhulst, 2008; Roberts & Duong, 2017; Shanahan, Copeland, Angold, Bondy, & Costello, 2014). Such findings have provided evidence for the bidirectional nature of the relation between sleep problems and anxiety disorders and prompted further investigation of how the association between sleep and anxiety may change during development (Sadeh, Tikotzky, & Kahn, 2014). These findings have also promoted the theory that sleep problems in childhood may contribute risk for the onset of anxiety-related symptomatology in adolescence (Cowie et al., 2014; Kelly & El-Shiekh, 2015; Willis & Gregory, 2015).

Although recent advances in technology have facilitated the objective measurement of sleep, the majority of studies examining associations between sleep and anxiety disorders in pediatric samples have employed subjective (typically parent-report) measures of sleep quality and sleep-related problems (Willis & Gregory, 2015) with fewer studies examining associations between objective measures of sleep-related problems and anxiety disorders. Among studies employing objective measures of sleep function—including polysomnography and actigraphy—findings have been inconsistent and appear to vary by type of objective measurement. Polysomnography studies have identified disruptions in sleep among anxious youth. One study reported that clinically anxious children and adolescents (age 7–17) exhibited more nighttime awakenings, less slow-wave sleep, and longer sleep onset latency, as measured with polysomnography, than depressed and control groups (Forbes et al., 2008). In a separate sample of children age 7–11, children diagnosed with generalized anxiety disorder (GAD) showed increased sleep onset latency and reduced latency to REM sleep, also measured by polysomnography (Alfano, Reynolds, Scott, Dahl, & Mellman, 2012). However, prior research employing actigraphy as an objective measure of sleep quality has not identified sleep-related differences between clinically anxious youth and non-anxious controls. A comparison of youth with social anxiety disorder and controls revealed no differences on actigraphy-based measurements of sleep quality (Mesa, Beidel, &

Bunnell, 2014) and, similarly, a comparison of children with GAD and same-aged controls found no differences on actigraphy-based sleep function (Alfano, Patriquin, De Los Reyes, 2015).

Prior evidence has also highlighted discordance between subjective and objective reports of sleep quality and sleep-related problems across development. For example, previous studies have found weak and non-significant associations between subjective reports of sleep quality (parent- and child-report) and objective measures of sleep quality (e.g., actigraphy; Alfano et al., 2015; Gregory et al., 2011). Taken together, findings spanning studies employing subjective and multiple types of objective measurement of sleep imply a strong need for further investigation using objective measures of sleep quality in both clinical and community samples to determine whether associations between anxiety and subjectively-reported sleep function are consistent with associations between anxiety and objectively-measured sleep function.

In this vein, the present study builds on the extant literature in several major ways—by contributing to the limited literature examining associations between objective sleep function and anxiety-related symptomatology in community samples, and specifically, by testing associations between sleep function and anxiety-related symptomatology across the transition from childhood to adolescence, a developmental period when frontoamygdala circuitry, which is hypothesized to be influenced by circadian rhythms (Dayan et al., 2017; Pace-Schott et al., 2015), is particularly in flux (Gee et al., 2013; Gabard-Durnam et al., 2014; Hare et al., 2008). The current study aimed to examine the following questions: 1) What is the relation between anxiety and objective measures of sleep quantity and quality in a community sample of children and adolescents? and 2) How does the relation between objective sleep function and anxiety symptomatology differ by age among 8–17-year-olds? Given previous reports of discrepant findings between subjective and objective measures of sleep quality, these associations were also tested using a subjective measure of sleep for a subset of adolescents who had available data on self-reported sleep function. It was hypothesized that lower quantitative and qualitative sleep function would be associated with higher levels of anxiety and that this association would be strongest in adolescence.

Methods

Participants

Participants were a subset of subjects from the publicly available Enhanced Nathan Kline Institute Rockland Sample (NKI-RS; Nooner et al., 2012). Cross-sectional behavioral data from 1178 participants ages 6 – 80 were retrieved from the NKI-RS sample; data were collected from 2012–2016. Based on the inclusion and exclusion criteria described below, the final sample consisted of 92 participants (54.30% male) age 8–17 (M_{age} = 12.73, SD = 2.89). Participants were excluded if they exhibited low intellectual functioning (IQ < 80; measured using Wechsler Abbreviated Scales of Intelligence-II; Wechsler, 1999) or if they had missing data on the behavioral measures of interest. After assessing for all exclusionary criteria, outliers on each behavioral measure of interest (defined as three standard deviations or more from the mean) were also excluded from analyses. All subjects provided written informed consent (assent for minors) to unrestricted distribution of anonymous data through the International Neuroimaging Data-Sharing Initiative (INDI1; 1000 Functional Connectomes Project [FCP], 2009) according to the procedures set forth by the NKI Institutional Review Board. 14.1% of participants in the final sample met DSM-IV criteria for a current anxiety disorder diagnosis (*n* = 13).

Measures

Participants were administered a comprehensive battery of questionnaire, biological, and behavioral measures as part of the broader NKI-RS procedures. In the present study, we utilized assessments of anxiety symptomatology and sleep. **Anxiety symptomatology**. The Multidimensional Anxiety Scale for Children (MASC; March & Parker, 2004) was used to assess anxiety symptomatology. The MASC is a 39-item self-report questionnaire that assesses anxiety in youth and yields the following subscales: physical symptoms, harm avoidance, social anxiety, separation/panic, and total anxiety. Participants were asked to rate their own behavior on a 4-point scale ranging from 0 ("Never true about me") to 3 ("Often true about me"). The present study used the total anxiety raw score, which had good internal consistency (39 items, Cronbach α = 0.89). The MASC has been shown to have good reliability and validity (March, Parker, Sullivan, & Stallings, 1997). A higher score on the MASC indicates higher self-reported anxiety-related symptomatology.

Sleep function.

Objective sleep function.: Actigraphy data were collected using a Philips Respironics Actiwatch 2. Participants wore the waterproof unit continuously on their non-dominant wrist for 1–18 days (mean = 7.96 days) depending on the spacing of participants' first and second laboratory visits, in order to collect data on sleep function, respiration, and heart rate. Participants were instructed to press the event marker button immediately before going to sleep. The Philips Respironics Actiwatch 2 has been shown to have good interunit reliability and criterion validity (Gironda, Lloyd, Clark, & Walker, 2007). Mean hours of sleep per night was used as the primary measure of quantitative objective sleep function in the present study. The following variables were used as measures of qualitative objective sleep function: average sleep onset (minutes), average sleep efficiency percentage (percentage of time asleep), average duration of awakenings after sleep onset (minutes), and average number of awakenings.

Subjective sleep function.: The Pittsburgh Sleep Quality Index (PSQI; Buysse, Reynolds, Monk, Berman, & Kupfer, 1989), a well-validated and widely used measure that is correlated with other subjective measurements of sleep function (e.g., sleep diaries) (Buysse et al. 1989; Backhaus et al. 2002), was used to assess subjective sleep function in participants age 13–17. The overall sleep quality scale of the PSQI was used as the primary subjective qualitative sleep variable for a subset of participants who completed the questionnaire. A higher score on the PSQI indicates worse self-reported sleep quality.

Socioeconomic status.: To control for socioeconomic status, participants' parents completed the Hollingshead Four Factor Index of Socioeconomic Status (Hollingshead, 1975), which is designed to assess social status based on marital status, employment status, educational attainment, and occupation prestige. Parental education was rated on a 7-point scale ranging from 7 (graduate or professional training) to 1 (less than 7th grade). Parental occupation was rated on a 9-point scale ranging from 9 (higher executive, proprietor of large businesses, major professional) to 1 (farm laborers, menial service workers, students, housewives, dependent on welfare, no regular occupation). Scores were summed across these dimensions to yield the child SES composite score, which was used in the present study.

Data Analysis Plan

Multiple linear regression was conducted using the PROCESS Macro for SPSS (Hayes, 2015) to test the hypothesis that sleep function would be negatively correlated with anxiety symptomatology, with age examined as a potential moderator of this association. Overall anxiety symptomatology was the dependent variable in one family of regression analysis that examined age as a moderator of the association between quantitative sleep function and anxiety symptomatology (independent variables: age, average number of hours of sleep per night). In a second family of tests that examined age as a moderator of the association between qualitative sleep function and anxiety, four separate models were run to examine each qualitative sleep variable of interest (i.e., a separate model for each of the following variables: average sleep onset (minutes), average sleep efficiency percentage (percentage of time asleep) average duration of awakenings after sleep onset (minutes), and average number of awakenings). Because there were four sleep variables of interest within the family of regression analyses focusing on qualitative sleep function, Bonferroni correction for multiple comparisons was applied ($.05/4 = p < .0125$). Sleep function and age were coded continuously and were mean-centered (Aiken & West, 1991) and multiplied to yield the interaction term in the model. In order to better assess for R^2 change, the analysis was conducted as a hierarchical multiple linear regression in which the initial step included the primary independent variables, followed by the two-way interactions (sleep × age) in the second step. Standardized Beta coefficients were used as an estimate of effect size.

For a subsample of adolescent participants with subjective, self-reported sleep function data available ($n = 43$), hierarchical multiple linear regression [initial step: primary independent variables (overall sleep quality [PSQI], age), second step: two-way interaction (overall sleep quality × age) with overall anxiety symptoms as the dependent variable] was conducted to test whether age moderated the association between subjective sleep quality and anxiety symptomatology. Due to recommendations that participants wear actigraphy monitors for at least five days during collection of objective sleep function data (Sadeh & Acebo, 2002), all analyses were re-run in the subsample of participants who wore the actigraphy monitor for at least five days ($n = 73$). All findings in this subsample were consistent with the results reported in the overall sample.

Results

Preliminary Analyses

Seven outliers were excluded from the sample (remaining $n = 92$). Skew and kurtosis cutoffs (West, Finch, & Curran, 1995) indicated normal distributions across all main study variables in the final sample. Descriptive statistics for main demographic, predictor, and outcome variables of the final sample are presented in Table 1.

Correlation analyses were conducted to examine associations between the main study variables. Zero-order correlations among main study variables are presented in Table 2. Of note, anxiety was positively correlated with the quantitative index of sleep function, average hours of sleep per night, $r(90) = 0.24$, $p = .024$. There was no significant association between anxiety and any of the measures of qualitative sleep function (all p-values > .50). Age was negatively correlated with average hours of sleep per night, $r(90) = -0.34$, $p = .001$ and with anxiety, $r(90) = -0.23$, $p = .031$, respectively. In a subsample of adolescents (age 13–17) with available subjective sleep function data ($n = 43$), self-reported overall sleep quality was not associated with objective hours of sleep per night (as measured by actigraphy), $r(41) = -0.18$, $p = .25$, but was significantly positively correlated with average sleep onset latency (as measured by actigraphy), $r(41) = -0.40$, $p = .008$, suggesting that participants who took longer to fall asleep reported poorer sleep quality. Subjective sleep function was not significantly associated with any of the other qualitative indices of sleep quality, as measured by the actigraphy monitor (all p-values > .30).

Preliminary analyses were also conducted to test whether participant sex or SES were related to any predictor variables (quantitative and qualitative indices of sleep function, anxiety, age). Results showed no differences by sex (all p-values > .05), with the exception of anxiety, which was higher for females ($M = 46.95$, $SD = 18.17$) than males ($M = 36.94$, $SD = 15.45$), $t(90) = -2.86$, $p = .005$. Additionally, there were no significant associations between SES with quantitative or qualitative indices of sleep quality or age (all p-values > .10). Anxiety was significantly positively correlated with SES, $r(90) = 0.34$, $p = .001$, such that individuals with higher SES reported higher levels of anxiety symptomatology. Given these preliminary findings, all analyses were conducted with and without SES and sex included as covariates in the model (covariates were entered in the first block before the dependent variable).

Regression Analyses

In the first family of tests examining sleep quantity, a two-way interaction (quantitative indicator of sleep function × age) emerged as a significant predictor of anxiety, $B = -0.47$, $SE = 0.23$, $p = .039$. Among children (ages 8–11, based on median split), sleep was a significant predictor of anxiety, $B = 2.13$, $SE = 0.79$, $p = .010$, whereas, in contrast, there was no significant association between quantitative sleep function and anxiety among adolescents (ages 12–17), $B = -0.11$, $SE = 0.76$, $p = .883$. In the second family of tests examining sleep quality, no significant interactions between any of the qualitative indicators of sleep function and age emerged as a significant predictor of anxiety. Specifically, the two-way interactions between average onset sleep latency and age did not predict anxiety, $B = -0.04$, $SE = 0.05$, $p = .414$, nor did the interaction between average sleep efficiency and age predict anxiety, $B = -0.03$, $SE = 0.07$, $p = .685$. Similarly, the two-way interaction between average number of awakenings after sleep onset and age was not a significant predictor of anxiety, $B = -0.00$, $SE = 0.01$, $p = .920$, nor was the interaction between average number of awakenings and age, $B = 0.01$, $SE = 0.07$, $p = .853$. In the subsample of participants with self-reported qualitative sleep function data available, the age × self-reported sleep quality interaction did not predict anxiety, $B = 3.21$, $SE = 3.27$, $p = .331$. Results did not differ when analyses were conducted in the subsample of participants who wore the actigraphy monitor for at least 5 days ($n = 73$).

Discussion

In their recent review of a forum on sleep across child development sponsored by the Society for Research on Child Development, El-Sheikh and Buckhalt (2015) outline a model for integrating investigations of the role of sleep in the developmental trajectories of psychopathology and other health-related outcomes, underscoring the numerous implications of such work for clinical intervention and policy. The present study—which highlights age as a key moderator of patterns of association between sleep and anxiety—contributes to our understanding of the role of sleep in the development of anxiety during the transition from childhood to adolescence. Consistent with previous studies that have identified childhood, as compared to adolescence, as a developmental period characterized by more sleep-related problems for individuals with anxiety disorders (Alfano et al., 2010), the present findings suggest that sleep function was associated with anxiety-related symptomatology in childhood, but not adolescence. In addition, contrary to our hypotheses, results of the current study suggest that relatively increased sleep, rather than decreased sleep, obtained by an objective measurement of sleep function, is associated with higher anxiety-related symptomatology in childhood, highlighting increased somnolence in childhood as a potential clinical marker of anxiety symptomatology onset.

The current findings add to a limited but growing body of literature testing concordance between objective measures of sleep function and anxiety in community pediatric samples. In stark contrast to robust patterns of association between subjective sleep function and anxiety in previous studies (e.g., Alfano et al., 2007), actigraphy was not negatively associated with all indices of anxiety symptomatology, as hypothesized. In addition, in a subsample of adolescent participants with available self-reported sleep function data, subjective sleep function and actigraphy measures were not associated. Building on several other studies that have noted a dissociation between subjective and objective reports of sleep function (e.g., Alfano et al., 2015), these findings suggest that there may be divergence in associations between objectively- and subjectively-measured sleep and anxiety symptomatology, particularly in developmental samples.

With regard to discrepancies between qualitative and quantitative indices of actigraphy measurement, results of the present study suggest that the number of hours of sleep a child gets may be a more important indicator of anxiety-related symptomatology than the quality of sleep during those hours. Discord between self-reported and actigraphy-based indices of sleep function may be due, in part, to the fact that sleep patterns change dramatically across development in the age range of the present sample (Colrain & Baker, 2011); therefore, youths may not have an accurate “baseline” from which to record deviations in sleep in a self-report questionnaire. In other words, adolescents’ perception of their own sleep quality may be less accurate given that they are experiencing ongoing changes in sleep during this period of development. Additionally, differences in specific measures used to assess sleep quality may have contributed to discrepant findings across the literature and, since only 13–17-year-olds in our study had qualitative sleep quality data, the restricted age range may have contributed to the observed findings. Further research is needed to continue to test these associations in a broader age range.

Though the current study suggests that the association between sleep and anxiety may be age-dependent, longitudinal research is needed to further probe the directionality of this association. Previous research testing associations between daytime affect and objectively-measured sleep quality sheds light on the bidirectional nature of the relation between sleep quality and symptomatology. Within a sample of clinically anxious youth, increased negative affect was associated with more time spent awake the following night (measured by actigraphy), and more time spent awake at night predicted higher levels of negative affect the following day (Cousins et al., 2011), suggesting that impaired sleep function predicts and results from negative affect, which is characteristic of anxiety disorders (Watson, Clark, & Tellegen, 1988). Examining these processes longitudinally, with a particular focus on the transition from childhood to adolescence, would further elucidate the role of sleep in the emergence of anxiety disorders. Specifically, longitudinal designs will clarify whether decreased sleep results in development or exacerbation of symptoms of anxiety, symptoms of anxiety result in less sleep attainment, or whether both mechanisms contribute to the phenomenon observed in this study.

Limitations of the present study include a variable sampling period for actigraphy data, though results did not change when analyses were conducted in a subsample of participants with at least five days of actigraphy collection. Measurement of actigraphy data may be varied due to the nature of data collection (wearing device during sleep), duration of monitoring (and whether monitoring is continuous or disrupted), weight, and sex (e.g., Brown, Smolensky, D’Alonzo, & Redman, 1990; Tyron, 1987). Further, as previously noted, subjective sleep quality data were only assessed in a subset of participants (age 13–17), precluding an investigation of age-related changes in the association between subjective sleep quality and anxiety-related symptomatology during the transition from childhood to adolescence.

Future research should continue to incorporate both subjective (parent- and child-report) and objective measures of sleep function to assess potential dissociations between objective and subjective measures of sleep in developmental samples. Furthermore, future studies would benefit from assessing additional predictors of discordance between subjective and objective, as well as quantitative versus qualitative, measures of sleep function. Consistent with McMakin & Alfano’s (2015) call for consideration of the dimensionality of anxiety disorders in studies of the association between sleep and anxiety, in order to assess whether the significant association between anxiety and sleep quantity observed in children in the present study is driven by a specific anxiety-related symptom cluster, future studies could assess associations between sleep function and specific clusters of anxiety-related symptoms (e.g., somatic symptoms of anxiety, panic, worry). Furthermore, previous research has posited that sleep and circadian rhythm disruption may interfere with extinction learning via alterations in frontoamygdala circuitry (Dayan et al., 2017; Pace-Schott et al., 2015). Given dynamic changes in this circuitry across development (Gee et al., 2013; Gabard-Durnam et al., 2014; Hare et al., 2008), it is critical to further explore the role of sleep on the developing brain and the emergence of anxiety disorders.

In summary, this study utilized actigraphy to objectively measure sleep function, and results were inconsistent with previous findings on subjectively-rated sleep function and anxiety, highlighting the need for future studies to employ both subjective and objective measures of sleep function during development. Based on the unique associations between sleep and anxiety-related symptomatology during childhood and adolescence observed in the present study, these findings lay the groundwork for future research to further probe associations between multiple domains of sleep function and anxiety across development.

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Table 1.

Descriptive statistics of study variables

Variable	Min-Max	Mean	SD	Variance	Skewness	Kurtosis
Child age	8.27–17.94	12.73	2.88	8.34	0.01	−1.31
Overall symptoms of anxiety	2.00–94.00	41.51	17.39	302.45	0.36	0.15
Average hours of sleep per night	0.17–10.45	5.64	3.26	10.68	−0.80	−0.87
Average onset latency (minutes)	0.00–61.17	13.60	13.56	184.00	1.88	3.71
Average sleep efficiency percentage	53.21–95.21	81.06	9.82	96.44	−1.12	0.67
Average wakefulness after sleep onset (minutes)	14.00–219.69	70.73	46.01	2116.89	1.28	1.26
Average number of awakenings	16.00–56.14	36.53	9.67	93.49	0.09	−0.59

Table 2.

Correlations among all main study variables

	Child age	Overall symptoms of anxiety	Average hours of sleep per night	Average sleep onset latency (minutes)	Average sleep efficiency percentage	Average wakefulness after sleep onset (minutes)	Average number of awakenings
Child age	--						
Overall symptoms of anxiety	−.23*	--					
Average hours of sleep per night	−.34*	.24	--				
Average sleep onset latency (minutes)	.27*	.01	.03	--			
Average sleep efficiency percentage	−.17	−.05	.22*	−.29**	--		
Average wakefulness after sleep onset (minutes)	−.01	−.01	−.11	−.08	−.85**	--	
Average number of awakenings	−.13	−.01	.19	−.14	−.23*	.37**	--