Daily affective experiences predict objective sleep outcomes among adolescents

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SUMMARY

Adolescence is a sensitive period for changes in both sleep and affect. Although past research has assessed the association between affect and sleep among adolescents, few studies have examined both trait (typical) and day-to-day changes in affect, and fewer still have specifically examined negative social evaluative emotions (e.g. embarrassment) in relation to sleep. Both between- and within-person variations in daily affect were examined in relation to four objectively-measured sleep outcomes (sleep hours; sleep latency; sleep efficiency; and length of wake bouts) among adolescents. Participants ($N = 77$ high-school students; 42.9% female; M = 14.37 years) wore an actiwatch and completed daily-diaries for 3 days. The results of hierarchical linear models (controlling for age, gender, race, ethnicity, parental employment status, income, puberty and caffeine) indicated that negative social evaluative emotions and high-arousal affective experiences generally predicted poor sleep outcomes, whereas low-arousal affective experiences were associated with good sleep outcomes. Specifically, at the person level, adolescents reporting higher negative social evaluative emotions had shorter average sleep hours, and those experiencing higher anxiety–nervousness had longer wake bouts. In addition, individuals experiencing more dysphoria (sad, depressed, lonely) had longer average sleep hours and shorter wake bouts, while those experiencing more calmness had shorter sleep latencies. At the within-person level, individuals had longer sleep latencies following days that they had experienced high-arousal positive affect (e.g. excitement), and had longer wake bouts following days they had experienced more negative social evaluative emotions. The results highlight the detrimental effects of negative social evaluative emotions and high-arousal affective states for adolescent sleep.

INTRODUCTION

Adolescence is a sensitive period for changes in sleep behaviours (Carskadon, 2011). Adolescents report shorter sleep hours, later bedtimes and more irregular sleep–wake timing compared with children (Wolfson and Carskadon, 1998). These changes in sleep–wake patterns are thought to be due to biological changes during puberty that result in a shift towards a later circadian timing at about age 13 years (Spear, 2000; Tonetti *et al.*, 2008). Additionally, social factors, such as media use, work and extracurricular activities, increased academic workload, and early class start times also contribute to changes in sleep–wake patterns during adolescence (Carskadon, 2011). In addition to being a sensitive period for sleep, adolescence is also characterized by important developmental changes in affective processes (Birditt and Fingerman, 2003). Findings from neuroscience studies, for example, show greater brain activation in response to emotionally laden content among adolescents relative to adults (Monk *et al.*, 2003). Within the literature there is overwhelming evidence to support heightened emotional arousal and reactivity among adolescents relative to children and adults (Spear, 2000). Importantly, affect regulation has been shown to have significant implications for various aspects of psychosocial functioning, based on both concurrent and longitudinal findings (Bandura *et al*., 2003), and thus remains an important aspect of overall well-being, particularly during the sensitive age period of adolescence.

The recently published sleep recommendations from the US National Sleep Foundation indicate that adolescents (14–17 year olds) need 8–10 h of sleep per night (National Sleep Foundation, 2015). However, findings consistently show that adolescents based on samples across North America, Europe, and Asia generally do not meet the minimal recommended sleep hours (Gradisar *et al*., 2011). Past research based on both experimental and correlational studies shows a consistent significant link between sleep and affect across the lifespan. Among a sample of 11–14 year olds, shorter sleep hours were significantly correlated with higher levels of depressive symptoms (Fredriksen *et al*., 2004) – a finding that has been confirmed among emerging adults and older adults. Short sleep hours also have been significantly linked to greater feelings of anxiety (Liu and Zhou, 2002). Moreover, Winsler *et al.* (2015) recently found that adolescents who reported getting 1 h less sleep during the weekdays were at a significantly greater risk for reporting increased feelings of hopelessness and suicidal ideation. Similarly, subjective reports of poor sleep quality (i.e. difficulty initiating or maintaining sleep, degree of restfulness upon waking, and night awakenings, etc.) have been significantly linked to higher scores on negative affect, depressive symptoms, anxiety and perceived stress (Baglioni *et al*., 2010). Moreover, findings from experimental studies indicate that sleep restriction leads to more impulsive behaviours among emerging adults, particularly in response to negative stimuli (Anderson and Platten, 2011). Sleep restriction has been shown to increase one's propensity to make more risky decisions, as evidenced by higher cost–benefit ratio scores in the context of a lab-based computerized risk-taking task (Rossa *et al*., 2014). Of note, good sleep has been linked to non-clinical forms of affect, including positive affect states such as feeling happy, joyful and cheerful (van Zundert *et al*., 2015). Thus, given the importance of adequate sleep for optimal psychosocial functioning, particularly during sensitive periods of development, understanding the factors that predict poor sleep among adolescents remains a critical area of research for developmental psychologists.

Although experimental studies of sleep deprivation and its resulting negative influence on emotional functioning provide critical information on the importance of adequate sleep for emotional well-being, these studies do not provide a test of the alternative pathway (i.e. the effect of emotional functioning on sleep outcomes). Importantly, some evidence suggests that the nature of the association between sleep and emotional well-being is bidirectional (Baglioni *et al*., 2010; Kouros and El-Sheikh, 2015; Vandekerckhove and Cluydts, 2010). Therefore, this study adds to the growing body of literature that examines the alternative pathway of the predictive effect of emotional functioning on sleep hours. Furthermore, given the multi-faceted nature of sleep, researchers have found it necessary to incorporate additional sleep parameters beyond sleep hours, such as sleep efficiency, sleep latency and number of awakenings – all of which have been linked to psychosocial functioning (Cousins *et al*., 2011; Kouros and El-Sheikh, 2015). In the present study, four sleep parameters are assessed (sleep hours, sleep latency, sleep efficiency, and length of wake bouts), which allow the examination of how affect experiences throughout the day are implicated in different aspects of adolescent sleep behaviours at night.

The majority of the past studies examining sleep and negative affect have examined between-person differences in sleep, either in experimental or correlational studies (Anderson and Platten, 2011; Winsler *et al*., 2015). These approaches do not examine within-person variations in affect in relation to sleep. To address this gap, some researchers have conducted multiple assessments of sleep and affect across a number of days in order to examine day-to-day or within-person variations in sleep and affect. Kalmbach *et al.* (2014), for example, measured sleep and affect across 14 days, and found that higher than average negative affect during the day (for a given individual) was significantly associated with subjective/self-reports of both shorter sleep hours and poorer sleep quality that night. Importantly, some of these studies have specifically examined bidirectional associations between sleep and affect. In one recent study Kouros and El-Sheikh (2015) found that among a community sample of children assessed across 7 consecutive days, longer sleep latency predicted worse next-day mood and, in turn, worse mood predicted both longer sleep latency and higher sleep activity that night.

The present study extends past research by assessing a broad range of emotions, including negative social evaluative emotions (NSEE). NSEE refer to feelings of rejection, shame and embarrassment, and thus are rooted in the context of interpersonal relationships (Leary, 2001). Given the importance of peer relationships during adolescence (La Greca and Harrison, 2005), examining NSEE in relation to sleep may be particularly important during this age period (Dahl and Lewin, 2002). The present study examines both between-person differences as well as daily variations in NSEE. Additionally, the present study examines both high-arousal (e.g., anxiety–nervousness) and low-arousal (e.g., dysphoria) negative affective experiences as well as high-arousal (e.g., excited, happy, energetic) and low-arousal (e.g., calm) positive affective experiences, in relation to adolescent sleep. Furthermore, although some past studies have examined the link between positive affect and sleep behaviours the majority of these studies have been conducted with emerging or older adult samples (Kalmbach *et al*., 2014; McCrae *et al*., 2008; but also see Dagys *et al*., 2012). To address this gap, the present study examined daily positive affective states in relation to sleep outcomes among a sample of adolescents.

The purpose of the present 3-day daily-diary study was to examine the effects of daily affective experiences on four sleep outcomes among a sample of adolescents. Hierarchical linear modelling (HLM) was employed, which allowed for the examination of time-varying (i.e. day-to-day) effects of affective experiences during the day on sleep outcomes that night. Additionally, we examined non-time varying (i.e. between-person) differences in sleep outcomes. We acknowledge the possibility that bidirectional associations are likely, such that sleep the night before may predict next-day affect. However, due to limited days of data (i.e., 2 days in which affect data were collected after sleep), the current paper focused on affective predictors of sleep later that night.

Based on the hyper-arousal model of insomnia, which states that physiological and cognitive arousal are key mechanisms that lead to difficulties with initiating and maintaining sleep (Riemann *et al*., 2010), it was hypothesized that low-arousal affective states would predict better sleep outcomes, while high-arousal affective states would predict worse sleep outcomes, regardless of valence. Additionally, given the importance of interpersonal relationships for adolescents, it was hypothesized that NSEE would be particularly strong predictors of poor sleep outcomes.

MATERIALS AND METHODS

Participants and procedures

Participants were a subsample ($N = 77$) of high-school students (11–18 years old) who were part of the larger multi-method study ($N = 379$) on adolescent adjustment. Participants were recruited from three diverse public schools in a Midwestern city in the USA, and completed measures as part of a full-day data collection session at a local university. Measures from the larger study included assessments of chronic and everyday life stressors, emotional functioning, and executive functioning. The participants for the present study were a subsample of adolescents who were invited to participate in the sleep component of the study. Specifically, these participants wore actiwatches and completed paper-copy daily morning (with instructions to be completed within 30 min of waking) and evening diaries (with instructions to be completed just before bedtime) for 3 days (Sunday–Tuesday). Evening diaries included questions on adolescents' daily experiences, while morning diaries included questions on adolescents' sleep from the previous night. The study was approved by the Northwestern and DePaul University Ethics boards, and participants provided informed consent prior to participation.

Missing data analysis

Of the 131 participants (approximately 35% of the larger sample) who were invited to participate in the sleep and daily-diary component of the study, 63% had sleep data from actigraphy, 79% returned morning diaries and 89% returned their evening diaries. For the purposes of the present study, only participants who had complete sleep actigraphy data ($N = 77$) were selected. As a result, there were no missing data on the sleep parameters for the participants in the subsample. Of these participants, missing data on the affect variables coded from the evening diaries at Level 1 (i.e. for all data points across 3 days for all 77 participants) ranged from 0 to 16.8%. At Level 2 (i.e. when scores on the affect variables were averaged across the 3 days for each participant), missing data ranged from 0 to 13%. Missing data for the affect variables (and covariates) were estimated using the full information maximum likelihood (FIML) estimation method. The FIML retains cases that have missing data, thus avoiding the biased parameter estimates that can occur with pair-wise or list-wise deletion (Schafer & Graham, 2002).

Measures

Covariates

Questions on a demographic questionnaire assessed participants' age; gender (0 = female, 1 = male); race ('Black or African–American', 'Asian or Asian–American', 'American Indian or Alaskan Native', 'Native Hawaiian or Other Pacific Islander', 'White or Caucasian', 'Mixed' or 'Other'); ethnicity (0 = 'Not Hispanic or Latino', 1 = 'Hispanic or Latino'); and parental employment status ('Does your mother (father) have a job?'; 0 = employed, 1 = unemployed), while income was assessed from a parent questionnaire. Caffeine use was assessed with the following survey item: 'How many caffeinated drinks (coffee or soft drinks with caffeine in them e.g. coke, pepsi or mountain dew) did you have today?' Puberty was assessed with five items for females (e.g. growth in height, body hair, skin changes, breast development, and presence of menstrual cycle) and five items for males (e.g. growth in height, body hair, skin changes, deepening of voice, and facial hair), based on the Pubertal Development Scale (Peterson *et al*., 1988). Response options ranged from 1 = not yet started to 4 = seems completed. Scores were averaged across the five items, with higher scores indicating higher pubertal development.

Daily affective experiences

As part of their evening diaries, participants were asked to rate the extent to which they had experienced a list of 17 items, based on their overall daily experiences, with response options ranging from 1 = not at all to 5 = very much. Results of a principal components analysis with varimax rotation yielded the following five multi-item components: (i) NSEE (judged, rejected, embarrassed, ashamed, $\alpha = 0.89$); (ii) dysphoria (sad, depressed, lonely, $\alpha = 0.87$); (iii) anxious–nervous, $\alpha = 0.82$; (iv) angry–irritable, $\alpha = 0.77$; and (v) high-arousal positive affect (HAPA; excited, happy, energetic, $\alpha = 0.80$). Additionally, the following two single items that did not load highly on any one specific component were included as separate predictors in the model: (vi) calm; and (vii) tired.

Objective sleep measures

Participants wore an Actiwatch Score (Phillips Respironics) on their non-dominant hand for 3 days. The Actiwatch is a wrist-band accelerometer that records movement during wakefulness and sleep. The Actiware-Sleep software (version 3.4, MiniMitter/Philips Respironics)-validated algorithm was used to score the data (Oakley, 1997). This algorithm calculates a number of sleep parameters using 1-min epochs and based on significant movement after at least 10 min of inactivity. The following four sleep outcomes were calculated: (i) sleep hours: actual amount of time spent asleep, minus periods of awakening; (ii) sleep latency: the amount of time between bedtime and sleep onset; (iii) sleep efficiency: percentage of actual sleep time as a function of time in bed; and (iv) length of wake bouts: average duration of wake bouts between sleep start and sleep end.

Plan of analysis

In order to account for the nested nature of the data (i.e. days nested within persons), a two-level HLM using HLM software (version 6.0) was analysed. This approach accounts for the fact that the data points are not independent of each other because there are multiple assessment days per individual (Raudenbush and Bryk, 2002). Level 1 reflects associations between proposed predictor and outcome variables at the day-to-day level within each individual. In other words, at Level 1, how sleep is impacted each night is examined based on participants' affective states that day; day-to-day variations in sleep are predicted from day-to-day variations in affect. Level 2, on the other hand, reflects associations between proposed predictor and outcome variables at the person-level. In other words, at Level 2, how average sleep parameters (averaged across the 3 assessment days) are related to individual differences in affective states (also averaged across the 3 assessment days) are examined. Using this approach, the four sleep outcomes (see Measures) were predicted both at the day-to-day level (Level 1) and the person-level (Level 2) from the affect variables. Level 1 variables were group-mean centred, and Level 2 variables were grand-mean centred. The following dummy-coded variables were uncentred at Level 2: gender, race, ethnicity, and parental employment status. In all four regression models (one for each sleep outcome): age (grand-mean centred), gender, race, ethnicity, parental employment status, caffeine use, and pubertal development were included as covariates.

Level 1: model

$$\begin{aligned}\text{Sleep outcome}_{ti} = {} & \Pi_{0i} + \Pi_{1i} * (\text{Caffeine}_{ti}) + \Pi_{2i} * (\text{NSEE}_{ti}) \\ & + \Pi_{3ti} * (\text{Dysphoric}_{ti}) + \Pi_{4i} * (\text{HAPA}_{ti}) \\ & + \Pi_{5i} * (\text{Calm}_{ti}) + \Pi_{6i} * (\text{Anxious} \\ & - \text{Nervous}_{ti}) + \Pi_{7i} * (\text{Angry} - \text{Irritable}_{ti}) \\ & + \Pi_{8i} * (\text{Tired}_{ti}) + e_{ti}\end{aligned}$$

Level 2: model

$$\begin{aligned}\Pi_{0i} = {} & \beta_{00} + \beta_{01} * (\text{Age}) + \beta_{02} * (\text{Gender}) + \beta_{03} * (\text{Black}) \\ & + \beta_{04} * (\text{Mixed}) + \beta_{05} * (\text{Other}) + \beta_{06} * (\text{Hispanic}) \\ & + \beta_{07} * (\text{Mom not employed}) + \beta_{08} \\ & * (\text{Dad not employed}) + \beta_{09} * (\text{Income}) + \beta_{10} \\ & * (\text{Caffeine}) + \beta_{11} * (\text{Pubertal Development}) + \beta_{12} \\ & * (\text{NSEE}) + \beta_{13} * (\text{Dysphoric}) + \beta_{14} * (\text{HAPA}) + \beta_{15} \\ & * (\text{Calm}) + \beta_{16} * (\text{Anxious-Nervous}) + \beta_{17} \\ & * (\text{Angry-Irritable}) + \beta_{18} * (\text{Tired}) + r_{0i}\end{aligned}$$

RESULTS

Descriptives

Descriptive statistics for all study variables are presented in Table 1. Participants ($N = 77$) ranged in age from 11 to 18 years (M = 14.37, SD = 1.95). African–American/Black (35%) and White (20.5%) were the two most prevalent racial groups, and the majority (63%) of participants indicated being of Non-Hispanic ethnicity. Average pubertal development was significantly higher for females (M = 3.16, SD = 0.68) relative to males (M = 2.60, SD = 0.81), $t_{75} = 3.190$, $P = 0.002$. Overall, actigraph-recorded average bedtimes and wake times were 23:00 and 07:00 hours, respectively. Adolescents obtained an average of 6 h, 6 min sleep;

Table 1 Means, standard deviations and ranges for all study variables

Variables	*Mean (SD)*	*Range*
Age	14.37 (1.95) years	11–18 years
Gender	50.8% female	n/a
Mom employed	79.3%	n/a
Dad employed	81.7%	n/a
Income	2.70 (1.25)	1–6
Race	Black (35%), White (20.5%), Mixed (17.1%), Other (27.4%)	n/a
Ethnicity	Non-Hispanic (63%)	n/a
Caffeine	0.86 (1.08)	0.00–5.00
Puberty	2.84 (0.80)	1.00–4.00
Dysphoria	1.50 (0.63)	1.00–5.00
Angry–irritable	1.75 (0.73)	1.00–5.00
Anxious–nervous	1.62 (0.68)	1.00–5.00
Tired	2.92 (0.99)	1.00–5.00
NSEE	1.25 (0.46)	1.00–5.00
HAPA	2.60 (0.77)	1.00–5.00
Calm	3.22 (1.04)	1.00-5.00
Sleep hours	6.10 (0.96)	3.98–8.12
Sleep latency (min)	23.40 (24.60)	0.00–109.20
Sleep efficiency (%)	80.99 (7.39)	60.90–91.83
Length of wake bouts (min)	1.80 (0.60)	1.20–4.20

HAPA, high-arousal positive affect; NSEE, negative social evaluative emotions. $N = 77$.

Table 2 Results of HLMs of between and within daily affect predictors of sleep outcomes

Fixed effect	*Sleep hours* *Coefficient (SE)*	*Sleep latency* *Coefficient (SE)*	*Sleep efficiency* *Coefficient (SE)*	*Average length of wake bouts* *Coefficient (SE)*
Intercept 1, π_0				
Intercept 2, β_{00}	0.303 (0.203)	−0.422 (0.155)	0.560 (0.220)	−0.261 (0.249)
Person-level predictors				
NSEE, β_{012}	−0.372 (0.129)**	0.231 (0.145)	−0.134 (0.168)	0.085 (0.157)
Dysphoric, β_{013}	0.327 (0.157)*	−0.085 (0.130)	0.221 (0.147)	−0.335 (0.123)**
HAPA, β_{014}	−0.004 (0.117)	0.380 (0.161)*	0.163 (0.001)	0.139 (0.124)
Calm, β_{015}	0.214 (0.121)†	−0.440 (0.138)**	0.260 (0.141)$^{+}$	0.059 (0.114)
Anxious–nervous, β_{016}	−0.020 (0.110)	−0.193 (0.136)	0.152 (0.163)	0.357 (0.150)*
Angry–irritable, β_{017}	−0.106 (0.122)	−0.135 (0.174)	−0.057 (0.196)	0.249 (0.172)
Tired, β_{018}	−0.111 (0.136)	0.136 (0.165)	−0.040 (0.189)	−0.057 (0.122)
Within-person predictors				
NSEE, β_{20}	0.014 (0.151)	0.146 (0.165)	−0.157 (0.132)	0.302 (0.141)*
Dysphoric, β_{30}	−0.040 (0.094)	0.078 (0.132)	0.029 (0.105)	−0.056 (0.160)
HAPA, β_{40}	0.005 (0.113)	0.248 (0.120)*	−0.179 (0.105)†	0.021 (0.184)
Calm, β_{50}	0.061 (0.081)	−0.026 (0.120)	0.054 (0.104)	−0.181 (0.109)†
Anxious–nervous, β_{60}	0.119 (0.110)	−0.106 (0.162)	0.126 (0.133)	0.198 (0.149)
Angry–irritable, β_{70}	−0.064 (0.086)	−0.036 (0.108)	−0.050 (0.092)	−0.105 (0.101)
Tired, β_{80}	0.041 (0.112)	0.155 (0.088)†	−0.047 (0.075)	0.020 (0.132)

HAPA, high-arousal positive affect; NSEE, negative social evaluative emotions.
*$P < 0.05$, **$P < 0.01$, $^{\dagger}P < 0.10$.

average sleep latency was approximately 23 min, while average length of wake bouts was just under 2 min, and average sleep efficiency was approximately 81%. Results of a MANOVA indicated no significant gender differences on the sleep outcomes, $\lambda = 0.998$, $F_{4,72} = 0.031$, $P = 0.998$.

Sleep hours

Table 2 shows the results of the predictive effects of both person-level and day-to-day affective experiences for each of the four sleep outcomes. At the person-level, higher NSEE predicted shorter sleep hours, $B = -0.372$, SE = 0.129, $P = 0.005$; whereas higher dysphoria predicted longer sleep hours, $B = 0.327$, SE = 0.157, $P = 0.041$. At the person-level, higher levels of calmness were associated with longer sleep hours at the trend level, $B = 0.214$, SE = 0.121, $P = 0.081$.

Sleep latency

At the person-level, higher feelings of calmness predicted shorter sleep latency, $B = -0.440$, SE = 0.138, $P = 0.002$; whereas HAPA predicted longer sleep latency both at the person-level, $B = -0.380$, SE = 0.161, $P = 0.022$ and at the day-level, $B = 0.248$, SE = 0.120, $P = 0.041$. At the within-person level, there was a trend for longer sleep latencies on days when adolescents reported feeling more tired, $B = 0.155$, SE = 0.088, $P = 0.081$.

Sleep efficiency

At the person-level, there was a trend-level finding, such that higher feelings of calmness predicted higher sleep efficiency, $B = 0.260$, SE = 0.141, $P = 0.071$. There was also a trend for lower sleep efficiency following days when adolescents reported higher HAPA, $B = 0.179$, SE = 0.105, $P = 0.092$.

Length of wake bouts

At the person-level, higher feelings of anxious–nervousness predicted longer wake bouts, $B = 0.357$, SE = 0.150, $P = 0.020$; whereas higher feelings of dysphoria predicted shorter wake bouts, $B = -0.335$, SE = 0.123, $P = 0.008$. At the within-person level, higher NSEE predicted longer wake bouts, $B = 0.302$, SE = 0.141, $P = 0.034$. At the within-person level, there was a trend-level finding for shorter wake bouts following days when adolescents reported higher feelings of calmness, $B = -0.181$, SE = 0.109, $P = 0.099$.

DISCUSSION

The purpose of the present study was to examine the predictive effects of daily affect experiences on four objectively-measured sleep outcomes among a sample of adolescents. Results indicated that NSEE had negative implications for adolescents' sleep hours and duration of wake bouts during sleep. Feelings of low-arousal affective experiences (regardless of valence) were associated with more favourable sleep outcomes, while high-arousal affective experiences (regardless of valence) were associated with less favourable sleep outcomes. Results indicated that adolescents' NSEE predicted poorer sleep outcomes both at the between-person (shorter sleep hours) and within-person-levels (longer wake bouts). Adolescence is a sensitive period for the development of peer relationships, and such relationships are crucial to adolescent identity development and psychosocial functioning (Blakemore, 2008). The results of the present study showed that when adolescents' social relationships give way to feelings of perceived social judgement, the experience negatively impacts sleep behaviours. Among their sample of 7–14 year olds, Alfano *et al.* (2010) found that cognitive arousal (e.g. 'I think about things that happened during the day') prior to sleep onset was significantly correlated with disturbed nocturnal sleep. Thus, increased levels of cognitive arousal may be one mechanism linking NSEE and poor sleep. Ruminating over negative aspects of social experiences also may explain the link between NSEE and poor sleep (Thomsen *et al.*, 2003). There is some evidence that more interpersonal difficulties with peers are significantly associated with poor subjective sleep quality (Sarchiapone *et al.*, 2014). NSEE have also been linked to elevations in the stress hormone cortisol (Dickerson *et al.*, 2004), and elevated evening cortisol, in turn, has been associated with shorter sleep hours (Zeiders *et al.*, 2011), suggesting one possible biological pathway by which NSEE are associated with shorter sleep. The present study extends past research by suggesting that NSEE may be particularly important aspects of adolescents' emotional experience to consider in relation to objective sleep outcomes.

Moreover, as hypothesized, low-arousal affective experiences predicted more favourable sleep outcomes. Specifically, dysphoria predicted longer sleep hours and shorter wake bouts at the person-level. Feeling calm predicted shorter sleep latency (and was associated with higher sleep efficiency, longer sleep hours and shorter wake bouts at the trend-level). The two predictors, dysphoria and calm, being opposite in valence may be associated with sleep outcomes in different ways. For example, the significant link between dysphoria and longer sleep hours may be due to the use of sleep as a coping mechanism among those who are overwhelmed by sadness, depressed mood and loneliness. Indeed, long sleep has been noted as a marker of depression, and also may be a side-effect of anti-depressant medications (Thase, 2006). Importantly, findings indicated that feeling calm was protective for adolescent sleep (e.g. shorter sleep latency). As a low-arousal positive affective state, feeling calm may protect against cognitive intrusions, which have been shown to interfere with sleep initiation and maintenance (Alfano *et al.*, 2010). Similarly, Howell *et al.* (2008) found that mindfulness was significantly associated with higher subjective reports of good sleep among the sample of young adults. Future research should examine the specific sources of calmness among adolescents to better delineate the ways in which school administrators and parents can support adolescents in experiencing increased feelings of calmness, as a means of improving sleep.

Furthermore, results of within-person analyses indicated that adolescents reported longer sleep latency on days when they reported higher than average HAPA. Additionally, adolescents who typically report experiencing higher levels of HAPA also reported longer sleep latencies across the 3 days (person-level). There was also a trend-level finding for lower sleep efficiency on days when adolescents reported higher HAPA states. The fact that excitement makes it more difficult for adolescents to fall asleep should not be surprising, given the overwhelming empirical support for heightened arousal and poor sleep (Riemann *et al.*, 2010) However, associations between adolescent positive emotion and objective sleep have not been extensively explored in past research on adolescent emotion and sleep, which has tended to focus on negative affective states (Winsler *et al.*, 2015). Not surprisingly, feelings of anxious–nervousness predicted longer wake bouts (index of difficulty maintaining sleep) at the person-level. The physiological implications of these highly arousing affective states (regardless of valence) may interfere with adolescents' ability to initiate and maintain sleep (Cohen and Pressman, 2006). Increased cognitive arousal also may help explain these findings (Alfano *et al.*, 2010).

The results of the present study should be interpreted in light of the study's limitations. First, participants in the present study completed daily-diary measures and wore an actiwatch for 3 days. Future research should test the model in the present study with a sample of adolescents assessed across a longer number of days (including weekends) in order to draw comparisons between the effects of the predictors on school-night versus weekend sleep. Secondly, it was noted that, in terms of participant compliance to diary reports, there was no objective way to determine whether participants completed their diaries daily, or retroactively completed diaries for a string of days simultaneously. However, all participants received a Participant Instruction Booklet with detailed information about the study's procedures, with emphasis on the importance of adhering to the study's daily protocol. Additionally, no additional compensation was given for higher diary completion rates, thus possibly removing any incentive to retroactively complete multiple diaries simultaneously. Nevertheless, it is suggested that future studies should employ an objective measure (e.g. automated dated stamp) for determining participant compliance with completion of daily-diaries.

Third, given the correlational nature of the data, the current findings cannot speak for any causal associations between variables. The nature of the associations between affective experiences and sleep variables are likely bidirectional (Baglioni *et al.*, 2010). In fact, empirical evidence from experimental studies shows that sleep restriction/deprivation negatively impacts affect/emotion reactivity (Baum *et al.*, 2014), perhaps due to reduced connectivity between the medial-prefrontal cortex and the amygdala (Yoo *et al.*, 2007). Furthermore, within the context of daily-diary studies, evidence indicates significant bidirectional associations between poor sleep and negative emotional functioning (Kouros and El-Sheikh, 2015). Thus, one limitation of the present study was the lack of assessment of bidirectional associations between the proposed affect predictors and sleep outcomes. The lack of assessment of bidirectional associations in the present study was due to the limited number of assessment days and relatively small sample size. It is proposed, therefore, that future research should include more days of testing in order to assess the predictive effect of objectively measured sleep parameters on a range of next day affective states (ranging in both arousal and valence), in addition to assessing how these various affective states throughout the day impact same day sleep. Moreover, it will be important for future studies to specifically assess the timing of adolescents' affective experiences and examine how this relates to sleep behaviours. For example, are high-arousal affective experiences more detrimental to adolescent sleep if experienced later in the day (i.e. closer to bedtime) compared with earlier in the day? Relatedly, future research-based long-term longitudinal designs are further needed to specifically test for mediating pathways that account for the significant effects found between the various affective states and sleep parameters in the present study. Fourth, given the homogeneity of the sample, findings may not be generalizable to other populations such as emerging or older adults, or individuals with clinical levels of sleep and mood disorders.

Despite these limitations, the present study makes a number of important contributions to past research. Importantly, the use of daily assessments of various affective experiences and sleep outcomes was incorporated. This approach provides insight into how day-to-day variability in adolescents' everyday affective experiences relates to daily variability in sleep (within-person), as well as how more relatively stable individual differences in affective experiences relate to individual differences in sleep (between-person). In terms of the current predictors, assessments of both high-arousal and low-arousal negative and positive affective experiences were included, and the role of NSEE in adolescent sleep was specifically examined. The current findings highlight the need for researchers to further investigate the mechanisms through which NSEE negatively impact adolescent sleep. Evidence was found that highly arousing affective states (regardless of valence) generally had detrimental effects on adolescent sleep, while low arousing affective states were linked to better sleep outcomes. The results of the present study can be used to educate adolescents, parents and school administration about the different aspects of adolescents' daily experiences that have significant implications for sleep behaviours, in hopes of improving adolescent sleep. Given the crucial role that sleep plays for optimal psychosocial functioning across the lifespan, researchers should continue investigating sources of variability in adolescents' affective experiences and further examine mechanisms that explain the associations among affective experiences and sleep during adolescence.

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AUTHOR CONTRIBUTIONS

RT was involved in the conception of the present study, analysed the data and drafted the manuscript. SBC conducted preliminary analyses of the data. KG was involved in the design of the larger study and collection of data. EKA was involved in the conception of the study, collection of data, analysed the data and edited the manuscript.

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