THE EFFECT OF SLEEP TIMING AND CHRONOTYPE ON CHILDREN'S EMOTIONAL RESPONSES TO SLEEP RESTRICTION

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Abstract

Sleep serves as an essential foundation in physical growth, cognitive development, socio-emotional competence, and psychological health. Inadequate sleep during childhood is routinely linked with a host of negative outcomes. Understanding of how early sleep patterns shape children's emotional lives is not well understood, but experimental studies using sleep-restriction protocols document deleterious effects on children's emotional experiences, reactions and regulation when sleep is inadequate. It is also known that sleep loss does not impact individuals' emotional responses uniformly and group-averaged responses to inadequate sleep, while useful, do not provide insight into differential emotional vulnerability. Despite overwhelming evidence that inadequate sleep poses serious risks to children's physical and mental health, limited research has explored individual factors that moderate sleep-based risk. This is especially true of pre-pubertal children. Two factors of relevance, an eveningness chronotype and later sleep timing, remain to be examined as potential moderators of children's emotional functioning following inadequate sleep. The purpose of this study is to examine chronotype and habitual sleep timing as potential individual risk factors in a sample of 7- to 11-year-old pre-pubertal children (N = 53) studied previously. Subsequent aims will examine whether parent-reported chronotype and actigraphy-assessed timing of sleep across a typical week moderated children's subjective and objective emotional responses after a night of adequate sleep, and after two consecutive nights of restricted sleep.

The Effect of Circadian Timing and Chronotype on Children's Emotional Responses to Sleep Restriction

As revealed by an increased sleep need early in life, sleep serves as an essential foundation in physical growth, cognitive development, socio-emotional competence, and psychological health (Kahn et al., 2013; Quach et al., 2013; Rasch & Born, 2013; Walker, 2009). Accordingly, inadequate sleep during childhood is routinely linked with a host of negative outcomes, including affective problems and disorders (Alfano & Gamble, 2009). Understanding of how early sleep patterns shape children's emotional lives is not well understood, but experimental studies using sleep-restriction protocols document deleterious effects on children's emotional experiences, reactions and regulation when sleep is inadequate (Alfano et al., 2020; Gruber et al., 2012; Vriend et al., 2013). Yet, it is also known that sleep loss does not impact individuals' emotional responses uniformly (Lara-Carrasco et al., 2009; Van Dongen et al., 2005; Wagner et al., 2002) and group-averaged responses to inadequate sleep, while useful, do not provide insight into differential emotional vulnerability. Because few studies have examined individual vulnerability to sleep loss in child samples, the current study aims to examine two established risk factors associated with elevated emotional risk in adolescents and adults: chronotype and sleep timing.

Effects of Inadequate Sleep on Children's Behavior and Emotion

Inadequate nightly sleep is common among children in the U.S. (Smaldone et al., 2007) and well known to have detrimental consequences for behavior, academic achievement, physical growth and mental health (Rana et al., 2019; Spruyt, 2019; Turnbull et al., 2013). In concert with a wealth of cross-sectional and longitudinal studies, experimental findings provide evidence of causal relationships, although a majority of child-based studies have focused on the adolescent years, when both sleep and emotional/behavioral risk are elevated (Carskadon, 2011). For example, Dagys et al., (2012) found decreased positive affect (but not increased negative affect) in 10- to 16-year-old youth following two nights of sleep restriction compared to when rested. Another study by Reddy et al. (2017) examined the impact of sleep restriction on emotional outcomes among healthy adolescents (13 to 17 years) randomized to one night of sleep restriction or ideal sleep. Similar to Dagys et al. (2012) sleep restricted teens reported decreased positive affect only. Sleep restricted teens also reported greater emotional reactivity to negative affective images. McMakin et al. (2016) conducted two different studies to examine the impact of sleep restriction on adolescents' (11.5 to 15.0 years) affective functioning. Contrary to other studies, adolescents demonstrated greater negative affect in addition to decreased positive affect following sleep restriction compared to rested sleep.

Experimental data are more limited in child (i.e., pre-pubertal) samples, but a few investigations have been conducted. For example, using two nights of partial sleep restriction among 7 to 11 years children, Alfano and colleagues (2020) found more profound changes in positive compared to negative emotion, including reduced arousal and emotional expression in response to positive affective stimuli. In addition, during a task where children were asked to try to hide all expressions of emotion (i.e., expressive suppression), respiratory sinus arrhythmia (RSA) increased in response to both positive and negative movie clips, suggesting that children experienced greater difficulty in regulating (hiding) their emotions when tired. RSA measures cardiac activity of the parasympathetic nervous system and reflects the variations in inter-beat intervals of the heart rate across respiration (Porges, 1995; 2007). Changes in RSA during an emotionally stressful or challenging task (from a resting state) are thought to reflect emotion regulatory ability. Specifically, greater increases in RSA are associated with more internalizing symptoms in school-aged children, whereas decreases in RSA are associated with better regulatory control (Hinnant et al., 2009; Porges et al., 2007).

In another experimental study including 7- to 11-year old children, Gruber et al. (2012) also examined the impact of one hour of nightly sleep restriction compared to one hour sleep extension across one week on emotional lability and restless-impulsive behavior. According to parent and teacher reports, results showed both decreased alertness and emotional regulation capabilities when children were sleep restricted (Gruber et al., 2012). Collectively, it is clear that inadequate sleep adversely impacts multiple aspects of children's emotional processing during the pre-pubertal years.

Chronotype and Affective Risk in Children

An individual's chronotype is conceptualized as the preference for diurnal activity (Horne & Ostberg, 1976; Roenneberg et al., 2003). Chronotype exists on a continuum with 'morningness' and 'eveningness' at either end. Individuals with an evening chronotype exhibit increased activity later in the day, often resulting in delayed sleep onset and wake times compared to a morning chronotype (Dagys et al., 2012). Although partly genetically-based, chronotype is also influenced by development, such that young children commonly favor a morning chronotype but, as children transition into school-aged years, an evening chronotype becomes prominent (Randler et al., 2017; Wickersham, 2006). Although the developmental shift to an eveningness chronotype is most evident after the pubertal transition (Carskadon, 2011), a shift toward an eveningness preference has been found to emerge during the pre-pubertal years. For example, Werner and colleagues (2009) showed that prepubertal children (4 to 11 years) start to develop a delayed sleep/wake pattern as evidenced by oversleep of about 15 minutes on free days compared to scheduled days. Among a sample of 4.5 year olds, eveningness types had later bedtimes and wake times on weekdays and weekends, and shorter sleep time on weekdays compared to children who had earlier chronotypes (Jafar et al., 2016). Thus, similar to teens, prepubertal children with a later chronotype may be more susceptible to insufficient sleep.

In addition to sleep-related risks, both adolescents and children with an eveningness chronotype have significantly more emotional and behavioral difficulties compared to youth with a morningness chronotype (Van Der Heijden et al., 2013). For example, in addition to poorer sleep-wake patterns and greater complaints in daytime sleepiness, Giannotti et al. (2002) found that adolescents (14.1 to 18.6 years) with an eveningness chronotype had poorer academic achievement and reported more emotional reactivity compared to those with a morningness chronotype. Additionally, Gau et al. (2004) showed that youth 10 to 16 years of age with an eveningness chronotype tend to exhibit more depressive and anxious mood relative to morningness chronotypes.

An eveningness chronotype has also been shown to amplify (i.e., moderate) the effects of inadequate sleep on emotional outcomes among adolescents. In the study by Dagys et al., (2012), adolescents with an evening chronotype reported lower positive affect compared to the morning chronotypes both when sleep restricted and when rested, whereas there were no differences in negative affect between morning and evening chronotypes in either condition. An eveningness chronotype may similarly amplify the effects of inadequate sleep on emotional outcomes at younger ages, but experimental studies in pre-adolescent children are lacking.

Sleep Timing and Affective Risk in Children

Chronotype and timing of sleep periods are the behavioral manifestations of underlying circadian rhythms. The circadian system regulates rhythmicity in the human body across a roughly 24-hour period including the timing of sleep and wake periods. Circadian rhythms receive input from the external environment (e.g., light, temperature) and internal biological processes (e.g., core body temperature, melatonin secretion) (Ko & Takahashi, 2006; Reppert & Weaver, 2002). The superchiasmatic nucleus is the primary brain region that orchestrates circadian timing and serves as the biological ‘clock’ for humans (Reppert & Weaver, 2002). Better understanding of how sleep and circadian timing relates to affective processes in children could have implication for the detection and treatment of affective disorders in youth (Reppert & Weaver, 2002). To date however, studies in pre-pubertal children are rare.

During adolescence, duration of sleep typically declines due to a confluence of factors including a shift in circadian timing and slowing of homeostatic sleep pressure that result in delayed bedtimes (Carskadon et al., 1998; Wolfson & Carskadon, 1998). Environmental influences are also salient, such as increased academic demands, involvement in various social, sports, and other activities, as well as increased electronic usage (Harbard et al., 2016). Early school start times contribute to short sleep durations on school nights followed by ‘catch up’ sleep on weekends (Wheaton et al., 2016). Consequences and correlates of these sleep-based changes in teens include increased depressive and anxiety symptoms, declines in academic performance, high rates of daytime tiredness, and peer problems (Kortesoja et al., 2020; Shochat et al., 2014). Few studies, by comparison, have examined sleep timing in relation to pre-pubertal children’s emotional functioning, particularly in the context of restricted sleep.

Summary & Specific Aims

Despite overwhelming evidence that inadequate sleep poses serious risks to children’s physical and psychological health, limited research has explored individual factors that moderate (i.e., heighten or lessen) sleep-based risk. This is especially true of pre-pubertal children. Two factors of particular relevance, an eveningness chronotype and later sleep timing, remain to be examined as potential moderators of children's emotional functioning following inadequate sleep. The purpose of this study was to examine chronotype and habitual sleep timing as potential individual risk factors in a sample of 7- to 11-year-old pre-pubertal children studied previously (Alfano et al., 2020). Specifically, we examined whether parent-reported chronotype and actigraphy-assessed timing of sleep across a typical week, moderated children's subjective and objective emotional responses after a night of adequate sleep and after two consecutive nights of restricted sleep. Specific emotional outcomes examined included self-report and objective (facial expressions) emotional arousal to affective images, and self-reported and objective (RSA, facial expressions) ability to suppress emotion (i.e., expressive suppression). Based on results from the original study by Alfano et al., (2020) and the extant literature, our aims and hypotheses were as follows:

Aim 1: Examine relationships among chronotype, sleep timing, and emotional processing among healthy pre-pubertal children when rested. We hypothesized that, after a night of adequate sleep, a greater eveningness chronotype and later habitual sleep timing will be associated with: a) lower self-reported and facial expressions of emotional arousal in response to positive images; and b) lower self-reported regulation of emotions, greater expressions of emotional arousal, and greater increases in RSA during an emotion regulatory task.

Aim 2: Examine chronotype as a moderator of the effects of sleep restriction on children's subjective and objective emotional responses. We hypothesized that, compared to when rested, children with a greater eveningness chronotype will evidence: a) lower self-reported and facial expressions of emotional arousal in response to positive images; and b) lower self-reported regulation of emotions, greater facial expressions of emotional arousal, and greater increases in RSA during an emotion regulatory task when sleep restricted.

Aim 3: Examine habitual sleep timing as a moderator of the effects of sleep restriction on children's subjective and objective emotional responses. We hypothesized that, compared to when rested, children with later sleep timing will evidence: a) lower self-reported and facial expressions of emotional arousal in response to positive images; and b) lower self-reported regulation of emotions, greater facial expressions of emotional arousal, and greater increases in RSA during an emotion regulatory task when sleep restricted.

Methods

Participants

The sample consisted of N=53 pre-pubertal (Tanner stage 1 or 2) children between the ages of 7 to 11 years [mean = 9.04, standard deviation (SD) = 1.43] recruited in Houston, Texas through flyers and postcard mailings. The sample (female = 56.6%; *n* = 30) was relatively diverse including 60.4% Caucasian, 30.2% African American, 3.8% Asian American, 5.7% Biracial/Other, 28.3% Hispanic/Latino. See Table 1 for all demographic characteristics. In service of recruiting children with a range of affective symptoms, recruitment ads targeted children 'who get sad or nervous sometimes'. Inclusion criteria required children to live with their primary caretaker, speak English, and have a minimum IQ of 80. Children were ineligible if they had any current psychiatric diagnoses, chronic medical conditions that might impact to sleep, any suspected or official diagnosis of a medical or behavioral sleep disorder, use of any over the counter supplements or medication for sleep, and/or reports of current of past suicidal ideation. See Alfano et al. (2020) for a full description.

Procedure

Study procedures were approved by the Institutional Review Board of the University of Houston. Interested families completed an initial phone screen to determine basic eligibility requirements. Eligible families were then invited to complete an in-person assessment where consent/assent was obtained. At the assessment, families completed a sleep interview to ensure the absence of any sleep disorders, as well as structured psychiatric interviews. All interviews were conducted by trained doctoral students or postdoctoral fellows and reviewed by a licensed clinical psychologist. Both the child and parent completed a series of questionnaires, and child IQ was assessed with the Wechsler Abbreviated Scale of Intelligence (Wechsler, 2011).

After the initial assessment, all children completed one night of sleep monitoring at home via unattended polysomnography (PSG). PSG recordings were used to confirm the absence of sleep disorders and standardize sleep prior to the first (rested) emotional assessment. Children were prepared at home for PSG and given bed and wake times of 21:00 to 07:00 (10 hours in bed). The next morning, children and parents returned to the lab (5hrs after waking) for a baseline emotional assessment. After the assessment, children were given an actigraph to wear for 9 consecutive nights, including two partial sleep restriction on nights 8 and 9. Children slept normally on the first 7 nights of assessment. On the first sleep restriction night, families were reminded via phone call to restrict their child’s sleep to 7 hours (23:00 to 06:00) and instructed to not allow their child to nap the next day (verified with actigraphy). That night (Saturday) parents and children came to the sleep lab to complete the second night of sleep restriction which included PSG monitoring. Families arrived around 21:00 and children were prepared for PSG monitoring. Children were allowed to sleep for a total of 6 hours (from 0:00 to 06:00). In the morning, children were given breakfast prior to completing their second emotional assessment, again 5 hours after waking. All procedures were identical to the baseline assessment which used matched and counterbalanced stimuli. After study completion, parents were given detailed information to help their child return to a regular sleep schedule, as well as being financially compensated for their time.

Measures

Actigraphy. Motion Logger actigraphs (Ambulatory Monitoring Inc., Ardsley, NY) were used to measure and collect sleep data in this study. Actigraphs are wrist worn devices that can record movement and is an accelerometer-based sleep tracker that can continuously collect data over extended periods of time to estimate wake and sleep periods. The participants were instructed to wear their watch for 24hrs on a daily basis and to press the event marking button for each time they go to sleep at night, as well as when they wake up in the morning. Daily sleep logs were also documented by the participants to adjust for any irregular recordings in the actigraph data. There were no signs of daytime napping in this current sample. Actigraphy data was collected in 1-minute epochs, consistent with most pediatric research (Meltzer et al., 2012), using the zero-crossing mode and scored using the Sadeh algorithm (Sadeh et al., 1994). Average median sleep point (MSP) across the week of normal sleep will be used to examine sleep timing in the current study.

Questionnaires

Children's Chronotype Questionnaire (CCTQ; Werner et al., 2009). This is a parent-report questionnaire that consists of a multi-item morningness/eveningness (ME) summed scale score that has been validated across children (4-11 years old) to reflect preferences for morning-types (≤ 23), intermediate-types (24-32), and evening-types (≥33) among Asian and Caucasian populations (Ishihara et al., 2014; Simpkin et al., 2014; Werner et al., 2009). The responses from the ME scale score are calculated by summing the responses of items 17 to 26 (a = 1, b = 2, c =

3, d = 4, e = 5) from the original questionnaire (Werner et al., 2009) with the exception of items 17, 18, 24, and 25 being reverse scored (a = 5, b = 4, c = 3, d = 2, e = 1). The reliability of this scale was shown to be good ($\alpha = 0.72$). Chronotype will be examined as a continuous moderator variable in the current study.

Emotional assessment tasks

Both emotional assessments included the same tasks using two matched, counterbalanced sets of emotional stimuli. Both emotional assessments were conducted in the same room using the same equipment and lighting, and began 5 hours after the participant's set wake time. During the session, the participants were seated in front of a 22-inch computer monitor, with a 1080p high-definition webcam mounted on top of the monitor, and a research assistant provided instructions, as well as recording subjective ratings of the participants. BioPac MP150 unit and Acqknowledge 4.4 acquisition software (Biopac, Goleta, CA Inc.) was utilized to obtain HR and RSA recordings. The Observer XT software was used for physiological and video recordings which were time synchronized with the presented stimuli. At the beginning of each assessment, heart rate (HR) and RSA were recorded during a 5-minute resting baseline period.

Affective images. Both positive (n = 5) and negative images (n = 9) from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2005) were presented to participants on a computer screen. Each image was displayed for 6 seconds preceded by a fixation cross for 3 seconds. To ensure matching across the two assessments, arousal and valence ratings for these images were matched across both assessments based on previously published norms and content (Lang et al., 2005).

Emotional movie clips. Age-appropriate emotional movie clips, ranging from 80 to 190 seconds, were chosen for the participants to watch. Both positive (n = 3) and negative (n = 3) movie clips were included aimed at eliciting a range of positive and negative emotions. In each, the emotional content developed and intensified throughout the clip. For both assessments, each movie clip was matched to a clip of similar length and emotional content, randomly counterbalanced. Before each clip began, participants were instructed to focus on the screen the entire time and suppress their facial expressions (*"Pretend there is someone watching you and you do not want them to know how you are feeling. If you have any feelings while you watch the movie, please do not let those feelings show."*). In between each emotional movie clip, there was a brief 1-minute interval where the participants watched a neutral clip to clear their current thoughts and feelings (Gross & Levenson, 1995).

Subjective Measures of Emotion and Emotion Regulation

Emotional ratings. The Self-Assessment Manikin (SAM; Bradley & Lang, 1994) is a nonverbal pictorial scale that is commonly used to obtain participant's affective ratings on both valence and arousal based on a variety of stimuli. The current study includes SAM arousal ratings only based on findings from Alfano et al. (2020) which did not detect any effects of sleep restriction on valence ratings. The children provided these ratings after viewing each IAPS image. The ratings consisted of a 9-point Likert-type scale with higher ratings indicating stronger arousal or negative valence. The mean scores for both positive and negative stimuli ratings were calculated.

Expressive suppression. After each movie clip, participants were asked to rate how difficult it was to suppress their expressions from 0 (not hard at all) to 10 (very hard).

Objective Measures of Emotion

Emotional expression. For both the IAPS image and emotional movies tasks, participant's facial expression was recorded and analyzed through the FaceReader 4.0 software

(Noldus, Leesburg, VA Inc.). To ensure consistent and necessary lighting conditions, professional grade lighting equipment was installed in the assessment rooms. The FaceReader 4.0 software uses the Viola-Jones algorithm (Viola & Jones, 2001) to detect facial features and models the face by using the Active Appearance method (Cootes, Edwards, & Taylor, 1998). Activation values were calculated for six basic emotions for each single frame (30 frames per second), as well as the summary scores for valence and arousal. The reliability of this program with human coding has agreement rates that ranges from 84.8% to 95.9%, suggesting good reliability. Each participant's facial features and expressions were calibrated, during the resting baseline period, to account for individual differences. The average score for each frame were calculated for the last minute of each emotional movie clip and for 6 second of each IAPS image.

Psychophysiological assessment. During the movie task, HR and RSA were both monitored. Two ECG Ag-AgCl electrodes were used to collect the data based on established guidelines. ECG recordings were analyzed for the last minute of each emotional movie clip, as well as during the resting baseline. Any segments of data that consisted of excessive artifacts, ectopic, or missing beats were excluded. The Fast Fourier Transformation was used to calculate RSA to estimate high frequency HR variability (HF-HRV) and extract high-frequency signal components. For analyses, HF-HRV values were log transformed and frequency bands were adjusted based on participant's age-related changes in respiration.

Data Analytic Plan

All analyses were conducted using SPSS version 26 and based on the full sample of 53 participants. We first examined bivariate correlations between our two moderator variables and demographic characteristics to inform the inclusion of appropriate covariates in regression models. Given the number of tests, a p-value of <.01 will be used as the criterion for statistical significance, similar to Alfano et al. (2020).

For Aim 1, a series of linear regression models were used to investigate whether chronotype and/or habitual sleep timing served as significant (continuous) predictors of emotional outcomes after a night of adequate sleep. Covariates were entered on the first step of models as appropriate and both predictors were entered on the second step as predictors. Dependent variables included self-reported arousal in responses to positive and negative IAPS images, facial expressions in responses to positive and negative IAPS images, self-reported suppression in responses to positive and negative movies, facial expressions in responses to positive and negative movies, and RSA in responses to positive and negative movies. Significant prediction of emotional outcomes were determined by whether the p-value for the F-test of overall significance in chronotype and/or habitual sleep timing were less than our significance level set at the p-value of <.01. The model fit for each of the steps were evaluated with the F statistic and change in R squared.

For Aims 2 and 3, chronotype and sleep timing were examined as potential moderators of the effects of sleep restriction on children's subjective and objective emotional responses. A moderator is a variable that specifies conditions under which a given predictor (X) is related to an outcome (Y). Moderation is inferred when the moderating variable changes the direction or magnitude of the relationship between X and Y. For within-person repeated measures models in this study, we used the MEMORE macro for SPSS by Montoya (2019) which estimated interactions and conditional effects for moderation models. We planned to probe significant interactions using the Johnson-Neyman procedure, which provides the two values of the moderator at which the slope of the predictor goes from non-significant to significant. We first ensured that distributions of variables of interest meet assumptions for this procedure (e.g., homogeneity of regression slopes). If heterogeneity of regression slopes is detected (i.e., the assumption is violated) significant interactions were probed using percentiles, as recommended by Hayes (2018).

Power. Given the nature of our small sample size we consider this study to be exploratory, therefore, we will report both p values and effect sizes. See Tables 3 and 4. In the absence of previous studies, we conservatively assumed small effect sizes. Based on these estimates, sample size calculations conducted with G*Power 3.1.9 software (Faul, Erdfelder, Lang & Buchner, 2007) indicated a sample size of N = 52 yields 80% power to detect a small effect size.

Results

Preliminary Analyses

Bivariate correlations between demographic and moderator variables revealed that child age was significantly associated with average chronotype preference and sleep timing ($r = .281$, $p<.05$; $r = .340$, $p<.05$). Age was therefore included as a covariate in all models. See Table 2. Chi square tests confirmed chronotype did not significantly differ by gender χ^2 (2) = 1.20, $p = 0.558$, pubertal status, χ^2 (4) = 3.75, $p = .441$, or race/ethnicity, χ^2 (4) = 7.75, $p = 0.257$. Additionally, skew and kurtosis were examined for chronotype and sleep timing. Variables did not require transformation based on evidence of normality. A Bonferroni correction was applied to reduce the likelihood of Type I error.

Aim 1: Chronotype, Sleep Timing, and Affect in Rested Condition

We conducted 10 separate two-step hierarchical regression models with child age as a covariate in the first step and both predictors in the second step of the model. All models were non-significant indicating neither chronotype nor sleep timing served to predict any emotion-based outcome after a night of adequate sleep. See Table 3.

Aim 2: Chronotype, Affect, and Sleep Restriction

Chronotype was examined as a potential moderator of emotional outcomes following two nights of sleep restriction. Dependent variables were compared at time 1 (rested condition) and time 2 (sleep restricted condition). Chronotype did not serve as a significant moderator of emotional outcomes after 2 nights of sleep restriction based on subjective measures. Similarly, chronotype was a non-significant moderator of emotional outcomes based on objective measures of emotion, including emotional expression and RSA. See Table 4.

Aim 3: Sleep Timing, Affect, and Sleep Restriction

Similar to Aims 2, sleep timing did not serve to moderate the effects of sleep restriction on subjective or objective emotional responses after sleep restriction. See Table 4.

Post Hoc Analyses

Following other studies in children and adolescents, we also wanted to examine chronotype using cutoff scores to compare children with extreme morningness versus extreme eveningness chronotype. For example, Dagys et al. (2012) examined chronotype utilizing cutoff scores based on the two outer quartiles of the Children's Morningness-Eveningness Preferences Scale (Carskadon et al., 1993) and Almeida et al. (2023) examined the 20th and 80th percentiles as cutoff points on the CCTQ. Accordingly, we compared children who scored in the two outer quartiles on the CCTQ on self-reported and facial expressions of emotional arousal and self-reported and objective regulation of emotions. Analyses of covariance (controlling for age) were used to compare the groups in all outcomes. Again, consistent with findings for Aim 2, extreme chronotype preferences did not moderate subjective or objective emotional outcomes. See Table 5.

Discussion

Healthy sleep is essential for optimal physical and emotional health across the lifespan (Kahn et al., 2013; Quach et al., 2013; Rasch & Born, 2013; Alfano & Gamble, 2009; Walker, 2009). The pubertal years are a period of particular importance, often referred to as a 'critical window' for both sleep and emotional health (McMakin & Alfano, 2015) given increased rates of both types of problems during the teenage years. Two specific risk factors for sleep and psychiatric disorders, previously identified in adolescents and adults, are chronotype and habitual sleep timing (Dagys et al., 2012; Talbot et al., 2010). However, the role of these individual level factors in increasing risk among younger (i.e., pre-pubertal) age groups have rarely been investigated. Therefore, the purpose of this study was to examine chronotype and habitual sleep timing's association with subjective and objective emotional responses in a sample of 7- to 11-year-old children both when rested and sleep restricted.

Contrary to our hypothesis, greater eveningness chronotype and later habitual sleep timing was non-significantly related with self-reported or facial expressions of emotional arousal in response to IAPS images when children were well rested. Likewise, for an emotional movies task during which children were asked to suppress all emotions, neither variable predicted self-reported emotion regulation, expressions of emotions, or changes in RSA from a resting baseline. Conversely, in a sample of 10- to 16-year-old youth, Dagys et al. (2012) found greater eveningness chronotype was associated with lower self-reported positive affect (but not negative affect) when youth were rested. Differences between studies are likely best understood within a developmental framework including the influence of both biological and socio-environmental factors. Regarding the latter, parents are more likely to set and adhere to earlier sleep schedules for younger children compared to older youth, influencing chronotype (Nicholson et al., 2022). In contrast, adolescents often have greater autonomy over their sleep schedules, which are more likely to be delayed due to increased demands in academics, extracurricular activities, peer connections, and part-time employment (Nicholson et al., 2022).

From a biological perspective, the pubertal transition is associated with reliable homeostatic and circadian sleep changes that shift preferred sleep and wake times later (Laberge et al., 2001; Thorleifsdottir et al., 2002; Carskadon et al., 1993). Still, research has found the shift to a later chronotype begins prior to the pubertal transition (Werner et al., 2009). Importantly, in our sample of pre-pubertal children (Tanner stages 1 and 2), chronotype was normally distributed, though the standard deviation (*SD=.57*) was smaller than that found in adolescent studies such as the 2012 study by Dagys and colleagues (*SD=1.52*). This suggests less variability in chronotype at younger ages, which may relate to both socio-environmental and biological factors. It is also important to point out that we relied on parental report of chronotype in this study, whereas studies in adolescents have typically utilized self-reports. It is nonetheless possible that parents are not fully aware of children's preference for sleep timing.

Our second and third aims were to examine whether children's chronotype or later habitual sleep timing moderated emotional responses after two nights of partial sleep restriction. Again, moderation effects of subjective and objective emotional outcomes were not found, contrary to findings reported by Dagys et al. (2012) and others. Consistent with the reduced variability in chronotype observed in our sample, variability in mid-sleep point (MSP) (*SD=0:58 minutes*) was smaller in our study than reported among samples of adolescents (e.g., Merikanto et al., 2017). Parental-enforced sleep schedules, fewer academic and psychosocial demands may be particularly protective against later sleep timing in pre-pubertal children and may explain non-significant relationships found in this age group. Likewise, a recent study among 6- to 12-year-old child reported significant associations between an eveningness chronotype, greater sleep disturbances, and greater electronic devices use (Eid et al., 2020). Although beyond the scope of this study, the influence of these socio-environmental factors on chronotype and habitual sleep timing in pre-pubertal children remains an important area for future study.

The timing of our emotional assessment may also be salient. Results from a recent study examining chronotype and mood fluctuations across the day among 7- to 11-year-old children found significant changes in overall momentary emotional states dependent upon the combined relationship between time of day (e.g., when assessment occurred that day) and chronotype preferences (Almeida et al., 2023). For example, during the morning assessment children shared similar overall momentary mood states for both morningness and eveningness (Almeida et al., 2023). However, significant differences emerged during the afternoon assessment where an eveningness chronotype reported better mood, while children with a morningness chronotype reported worse mood (Almeida et al., 2023). Therefore, findings from Almeida et al. (2023) suggests that the lack of significance in our sample may be due to the inappropriate timing of our emotional assessment. In our study, emotional assessments were conducted in the middle of the day, thus may not have accurately captured the negative emotional outcomes that may arise later in the day for children with a morningness chronotype.

Finally, we also conducted post hoc tests to examine if children with extreme morningness and eveningness chronotype preferences moderated subjective measures and objective measures of emotional processing. Consistent with Aim 2, extreme chronotype preferences did not moderate self-reported and facial expressions of emotional arousal, and self-reported and objective regulation of emotions. Although not surprising, post hoc analyses supports our second aim and further warrants the need to better understand the lack of moderation effects of chronotype, in conjunction with aforementioned socio-environmental factors, to emotional responses after sleep restriction among pre-pubertal children.

Limitations

There are several limitations in our study. First, our sample included healthy pre-pubertal children and findings cannot be generalized to clinical samples. Additionally, the overall lack of significant findings reported may be due to our relatively small sample size and inadequate power as opposed to non-significant effects. Secondly, reduced variability in chronotype and sleep timing was evident in our sample compared to estimates typically found in adolescent samples. We therefore conducted post-hoc tests including children falling into the outer quartiles on the CCTQ only, however results remained unchanged. Future studies based on larger sample sizes are nonetheless necessary. It will also be meaningful for future research to investigate the role of in socio-environmental (e.g., sociocultural, home, school) and individual (e.g., biological, cognitive, and social) level factors in combination with chronotype and sleep timing among pre-pubertal children. Finally, in addition to parent rather than child-report of chronotype, our study utilized self-report measures of emotion during two experimental tasks which captured state-based emotions as opposed to more trait-based emotional outcomes which require additional investigation.

Conclusion

In conclusion, a gradual developmental shift toward an eveningness chronotype begins in childhood and is associated with elevated sleep and affective risk. The pre-pubertal years may offer a window of prevention in this regard, prior to a range of socio-environmental and biological factors that converge to elevate these risks in adolescence and adulthood. To the best of our knowledge, this was the first study to examine chronotype and habitual sleep timing as potential moderators to the effects of sleep restriction on emotional processing. Future studies including larger samples of pre-pubertal are needed to better understanding the timing and impacts of chronotype and sleep timing on affect risk.

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Table 1. Demographic Variables, Anxiety Symptoms, and Baseline Sleep Characteristics of Study Sample

N	53
Age: *M(SD)*	9.08(1.34)
Female: *n*(%)	30(56.6)
Race/Ethnicity: *n*(%)	
Caucasian	32(60.4)
African-American	16(30.2)
Asian-American	2(3.8)
Biracial/Other	3(5.7)
Hispanic/Latino	15(28.3)
Yearly Household Income: *n*(%)	
<$20K	3(5.7)
$20-$60K	18(34.0)
$60-$100K	17(32.1)
>$100,000	15(28.3)
Actigraphy Sleep During Baseline Week	
TST: *M(SD)*	612.8(47.5)
SE: (%)	94.7(3.9)
WASO: *M(SD)*	29.0(22.7)
RCADS Anxiety Scores *M(SD)*	24.49(17.89)

TST= total sleep time in minutes; SE=sleep efficiency; WASO=wake after sleep onset in minutes; RCADS=Revised Children Anxiety and Depression Scales raw scores.

Table 2. Descriptive statistics and Spearman's rho correlations between Children's Chronotype Questionnaire, Mid-Sleep Point for time in bed, Revised Children Anxiety and Depression Scales

	M (SD)	2.	3.	4.	5.	6.
1. CCTQ (Average)	2.63 (.569)	1.00[b]	.19	.28[a]	-.04	-.12
2. CCTQ (Total)	28.96 (6.31)		.184	.28[a]	-.04	-.12
3. Avg Mid-Sleep Point for time in bed (TIB; hours)	2.57 (0.97)			.34[a]	.177	-.26
4. Child Age	9.08 (1.34)				.31[a]	-.30[a]
5. Pubertal Status	1.83 (0.58)					-.054
6. RCADS Anxiety Scores	24.49(17.89)					

CCTQ = Children's Chronotype Questionnaire; RCADS= Revised Children Anxiety and Depression Scales raw scores. [a]$p < .05$; [b]$p < .01$.

Table 3. Summary of Hierarchical Regression Analyses for CCTQ and Sleep Timing Predicting Emotional Responses

Emotional Assessment Dependent Variables		Model 1:				Model 2:							
		Child Age				CCTQ			Sleep timing				
		B	*SE B*	β	R^2	*B*	*SE B*	β	*B*	*SE B*	Β	R^2	Cohen's f^2
Subjective Reports													
Positive IAPS Arousal		.581	.226	.342	.117	-.573	.552	-.145	.002	.005	.048	.137	.023
Negative IAPS Arousal		.142	.169	.118	.014	-.593	.409	-.211	.003	.004	.095	.060	.049
Positive Movies Suppression		-.320	.238	-.185	.034	-.221	.596	-.054	-.004	.006	-.105	.048	.015
Negative Movies Suppression		-.362	.193	-.253	.064	-.288	.483	-.086	-.003	.005	-.089	.079	.016
Objective Reports													
Positive IAPS Facial Expressions		-.014	.012	-.191	.036	.015	.029	.088	.000	.000	.245	.098	.069
Negative IAPS Facial Expressions		-.023	.011	-.326	.106	.007	.027	.040	.000	.000	.152	.128	.025
Positive Movies Facial Expressions		-.010	.007	-.224	.050	.011	.018	.096	.000	.000	.186	.089	.043
Negative Movies Facial Expressions		-.015	.007	-.340	.115	.004	.017	.040	.000	.000	.135	.133	.021
Positive Movies RSA		.018	.054	.047	.002	-.067	.136	-.074	.000	.001	-.023	.008	.006
Negative Movies RSA		.009	.053	.025	.001	-.090	.134	-.101	.000	.001	-.012	.010	.009

$p < .05$; $p < .01$, $p < .001$.

Table 4. Results of the moderation analysis: Test of factors that moderate changes in emotional processing after sleep restriction

Moderator	Chronotype						Sleep Timing					
	F	***R^2***	***b***	***t (df)***	***p***	Cohen's *f^2*	***F***	***R^2***	***b***	***t (df)***	***p***	Cohen's *f^2*
Positive IAPS Arousal	0.013	0.000	0.054	0.114 (49)	0.910	0.000	0.227	0.005	-0.002	-0.477 (49)	0.636	0.005
Negative IAPS Arousal	2.726	0.053	-0.634	-1.651(49)	0.105	0.056	0.398	0.008	0.002	0.631 (49)	0.531	0.008
Positive IAPS Facial Expressions	0.287	0.008	-0.014	-0.535 (33)	0.596	0.008	1.433	0.042	0.000	1.197 (33)	0.240	0.044
Negative IAPS Facial Expressions	1.682	0.046	-0.046	-1.297 (35)	0.203	0.048	0.587	0.017	-0.000	-0.766 (35)	0.449	0.017
Positive Movies Suppression	0.765	0.015	-0.451	-0.874 (51)	0.386	0.015	0.080	0.002	0.001	0.283 (51)	0.778	0.002
Negative Movies Suppression	0.550	0.011	-0.351	-0.741 (51)	0.462	0.001	0.070	0.001	-0.001	-0.264 (51)	0.793	0.001
Positive Movies Facial Expressions	0.199	0.005	0.009	0.446 (40)	0.658	0.005	0.924	0.023	0.000	0.961 (40)	0.342	0.024
Negative Movies Facial Expressions	0.347	0.009	-0.010	-0.589 (40)	0.559	0.009	0.090	0.002	0.000	0.300 (40)	0.766	0.002
Positive Movies RSA	0.021	0.000	0.017	0.144 (49)	0.886	0.000	1.466	0.029	-0.001	-1.211 (49)	0.232	0.029
Negative Movies RSA	0.003	0.000	0.006	0.053 (48)	0.958	0.000	1.286	0.026	-0.001	-1.134 (48)	0.263	0.027

Table 5. Post-hoc results of the chronotype moderation analysis: Test of factors that moderate changes in emotional processing after sleep restriction

Moderator	Chronotype					
	F	***R^2***	***b***	***t (df)***	***p***	Cohen's f^2
Positive IAPS Arousal	1.738	0.070	0.048	1.318 (23)	0.200	0.075
Negative IAPS Arousal	0.816	0.034	-0.029	-0.903 (23)	0.376	0.035
Positive IAPS Facial Expressions	0.148	0.009	-0.001	-0.385 (16)	0.706	0.009
Negative IAPS Facial Expressions	2.589	0.132	-0.004	-1.609 (17)	0.126	0.152
Positive Movies Suppression	0.230	0.009	-0.022	-0.479 (24)	0.636	0.009
Negative Movies Suppression	0.003	0.000	-0.002	-0.050 (24)	0.960	0.000
Positive Movies Facial Expressions	0.482	0.026	0.001	0.694 (18)	0.496	0.027
Negative Movies Facial Expressions	0.352	0.019	-0.001	-0.594 (18)	0.560	0.019
Positive Movies RSA	0.056	0.002	0.003	0.237 (23)	0.815	0.002
Negative Movies RSA	0.158	0.007	0.005	0.398 (23)	0.694	0.007

Table 6. Bivariate Correlations between Study Variables when Rested at Time 1

Variable	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12.**	**13.**	**14.**
1. Child Age	--													
2. Child Gender	-.01	--												
3. CCTQ Avg	.28*	.11	--											
4. Sleep Timing Avg	.34*	.01	.19	--										
5. T1 - Negative Images	.12	-.02	-.16	.10	--									
6. T1 - Positive Images	.34*	-.25	-.04	.14	.30*	--								
7. T1 - Positive Movies Suppression	-.18	.19	-.11	-.16	-.09	-.56**	--							
8. T1 -Negative Movies Suppression	-.25	.10	-.16	-.17	-.15	-.42**	.35**	--						
9. T1 - RSA Positive Movies	.05	-.14	-.06	-.01	.17	-.06	.07	.06	--					
10. T1 - RSA Negative Movies	.03	-.15	-.09	-.01	.19	-.06	.08	.04	.97**	--				
11. T1 - Facial Expr Positive Movies	-.22	.04	.03	.07	-.14	-.23	.21	-.03	-.13	-.08	--			
12. T1 - Facial Expr Negative Movies	-.34*	-.24	-.05	-.01	-.03	-.26	.04	.06	-.04	-.04	.64**	--		
13. T1 - Facial Expr Positive Images	-.19	-.29	.04	.15	-.09	-.22	.22	.06	.25	.19	.31	.58**	--	
14.T1 - Facial Expr Negative Images	-.32*	-.15	-.05	.02	-.01	-.24	.16	-.06	.03	.00	.29	.65**	.78**	--

Note. $^{***}p < .001$, $^{**}p < .01$, $^{*}p < .05$. CCTQ Avg = Children's Chronotype Questionnaire Average Score; Avg Mid-Sleep Point = Average Mid-Sleep Point for time in bed; T1 - Negative Images = self-reported arousal in response to negative IAPS images at time 1; T1 - Positive Images = self-reported arousal in response to positive IAPS images at time 1; T1 - Positive Movies Suppression = self-reported suppression in responses to positive movies at time 1; T1 -Negative Movies Suppression = self-reported suppression in responses to negative movies at time 1; T1 - RSA Positive Movies = RSA in responses to positive movies at time 1; T1 - RSA Negative Movies = RSA in responses to negative movies at time 1; T1 - Facial Expr Positive Movies = facial expressions in responses to positive movies at time 1; T1 - Facial Expr Negative Movies = facial expressions in responses to negative movies at time 1; T1 - Facial Expr Positive Images = self-reported suppression in responses to positive movies at time 1; T1 - Facial Expr Negative Images = self-reported suppression in responses to negative movies at time 1.

Table 7. Bivariate Correlations between Study Variables when Rested at Time 2

Variable	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12.**	**13.**	**14.**
1. Child Age	--													
2. Child Gender	-.01	--												
3. CCTQ Avg	.28*	.11	--											
4. Avg Mid-Sleep Point	.34*	.01	.19	--										
5. T2 - Negative Images	.13	-.05	.05	-.01	--									
6. T2 - Positive Images	.37**	-.19	-.01	.19	.17	--								
7. T2 - Positive Movies Suppression	-.06	.19	.00	-.20	-.10	-.57**	--							
8. T2 -Negative Movies Suppression	-.11	.25	-.05	-.13	-.37**	-.27*	.55**	--						
9. T2 - RSA Positive Movies	.23	-.23	-.09	.15	.14	-.05	.08	-.08	--					
10. T2 - RSA Negative Movies	.17	-.20	-.12	.13	.10	-.06	.13	.03	.94**	--				
11. T2 - Facial Expr Positive Movies	-.23	.02	-.03	-.10	.10	-.18	.31*	.21	.32*	.30	--			
12. T2 - Facial Expr Negative Movies	-.3	-.06	.00	-.09	.10	-.04	.06	.00	.20	.13	.74**	--		
13. T2 - Facial Expr Positive Images	-.55**	.02	.06	-.03	.08	-.55**	.12	.00	.08	.11	.53**	.59**	--	
14.T2 - Facial Expr Negative Images	-.33*	.11	.16	.16	-.16	-.372*	.14	.07	-.05	.06	.04	-.15	.69**	--

Note. $^{***}p < .001$, $^{**}p < .01$, $^{*}p < .05$. CCTQ Avg = Children's Chronotype Questionnaire Average Score; Avg Mid-Sleep Point = Average Mid-Sleep Point for time in bed; T2 - Negative Images = self-reported arousal in response to negative IAPS images at time 2; T2 - Positive Images = self-reported arousal in response to positive IAPS images at time 2; T2 - Positive Movies Suppression = self-reported suppression in responses to positive movies at time 2; T2 -Negative Movies Suppression = self-reported suppression in responses to negative movies at time 2; T2 - RSA Positive Movies = RSA in responses to positive movies at time 2; T2 - RSA Negative Movies = RSA in responses to negative movies at time 2; T2 - Facial Expr Positive Movies = facial expressions in responses to positive movies at time 2; T2 - Facial Expr Negative Movies = facial expressions in responses to negative movies at time 2; T2 - Facial Expr Positive Images = self-reported suppression in responses to positive movies at time 2; T2 - Facial Expr Negative Images = self-reported suppression in responses to negative movies at time 2.