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# Poor Sleep Quality Predicts Deficient Emotion Information Processing over Time in Early Adolescence

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**Study Objectives:** There is deepening understanding of the effects of sleep on emotional information processing. Emotion information processing is a key aspect of social competence, which undergoes important maturational and developmental changes in adolescence; however, most research in this area has focused on adults. Our aim was to test the links between sleep and emotion information processing during early adolescence.
**Design:** Sleep and facial information processing were assessed objectively during 3 assessment waves, separated by 1-year lags.
**Setting:** Data were obtained in natural environments—sleep was assessed in home settings, and facial information processing was assessed at school.
**Participants:** 94 healthy children (53 girls, 41 boys), aged 10 years at Time 1.
**Interventions:** N/A
**Measurements and Results:** Facial information processing was tested under neutral (gender identification) and emotional (emotional expression identification) conditions. Sleep was assessed in home settings using actigraphy for 7 nights at each assessment wave. Waking > 5 min was considered a night awakening. Using multilevel modeling, elevated night awakenings and decreased sleep efficiency significantly predicted poor performance only in the emotional information processing condition (e.g., $b = -1.79$, $SD = 0.52$, confidence interval: *lower boundary* = -2.82, *upper boundary* = -0.076, $t_{(416.94)} = -3.42$, P = 0.001).
**Conclusions:** Poor sleep quality is associated with compromised emotional information processing during early adolescence, a sensitive period in socio-emotional development.
**Keywords:** Sleep, emotion, facial expressions, early adolescence, puberty, actigraphy, development.
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## INTRODUCTION

The onset of puberty, marking the transition from childhood into adolescence, is a period of increased psychosocial challenges as well as increased risk for the development of psychopathology.[1-3] This age period also heralds a set of unique neuromaturational changes, such as changes in brain structure and reorganization of neurological circuitry, that influence and interact with normative cognitive, affective, and social development.[4] The onset of puberty is associated primarily with affective changes, manifested by increased stress responsiveness and emotional reactivity,[5] and has its impact in early adolescence. In contrast, the development of the cognitive control needed to manage these intensifying affective experiences (and the neural systems that underpin them, such as prefrontal and limbic regions and their interconnections) continue to undergo important developmental changes throughout mid to late adolescence, and do not appear to reach full maturity until well into adulthood.[5,6] On one hand, this combination (early affective changes at puberty and the slow gradual emergence of reliable cognitive control) creates a period of lability and vulnerability. On the other hand, this convergence also creates unique opportunities—early adolescence is a crucial time for learning and developing social and emotional skills.

From this perspective, it is important to consider how sleep may impact these affective vulnerabilities and opportunities during this developmental window. Sleep regulation also undergoes important maturational changes in adolescence, namely, delayed retiring and waking times, shortened sleep duration, increased sleepiness, longer weekend sleep periods, and architectural changes in sleep structure.[7,8] When considering the two-process model of sleep regulation,[9] the abovementioned processes represent changes in both process S (the homeostatic sleep-wake balance) and process C (the endogenous clock-like circadian rhythm). Delayed sleep phase in adolescence has been related both to a delay in sleep phase within the circadian rhythm (process C) and to the attenuation of Process S, meaning that as adolescents mature, more wakefulness time can be tolerated before sleepiness increases.[10] The delayed sleep phase begins around the time of puberty onset,[8,10] and its effect on development requires further study.[8] Inadequate sleep can result in mood deterioration, decreased arousal, and negative affect.[11] Because affect regulation plays an important role in psychosocial development in adolescence, it is not surprising that sleep deprivation in this age period has been implicated as increasing risk for psychopathology.[8]

More generally, there is growing evidence that emotional regulation and sleep/arousal regulation are closely intertwined. The psychophysiological systems that govern sleep overlap significantly with those involved in emotion.[11-13] This is exemplified in the robust interrelationships between emotional disorders and sleep complaints in adults,[12-14] children, and adolescents.[15-18] Simi-

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larly, sleep deprivation and poor sleep have detrimental effects on mood among adults, children, and adolescents.[11,19-24] In addition, tasks that simultaneously challenge cognitive and emotional processing appear to be specifically sensitive to sleep deprivation.[8,11]

Despite the high prevalence of sleep problems throughout childhood and adolescence (between 18% and 25% of adolescents exhibit insomnia symptoms or fragmented sleep[25,26]) and the close connection between sleep and emotion regulation, there have been few longitudinal studies focusing on the effect of sleep on emotional processing in early adolescence. Even in adults, surprisingly limited research attention has been given to exploring the specific effects of insufficient sleep on emotional processing, regulation, and perception.[13,24]

Evidence has accumulated in research on adults suggesting that a sleep period helps in consolidating emotional, rather than neutral, memories.[27-31] In these studies, subjects that had been given a chance to sleep (whether at night or using a nap paradigm) after learning had better recognition for previously learned emotional (but not neutral) stimuli. Moreover, even within emotional scenes (e.g., image of a dead body on a sidewalk), sleep enhanced memory of only the emotional objects, and not the neutral backgrounds.[32] In line with these findings, Wagner and colleagues demonstrated that the speed of recognizing emotional facial expressions presented prior to sleep was also significantly improved following sleep.[33] Similar findings on emotional memory consolidation were also found in children.[34] Twenty healthy children, aged 10-13 years, exhibited improved memory following sleep only for emotional declarative memory, and not for procedural memory. An enhancing effect of sleep for non-emotional declarative memory evinced a nonsignificant trend, but was not nearly as robust as for emotional stimuli.

All of these findings on adults and children, indicating an increase in memory consolidation of emotional stimuli following sleep, suggest that sleep deprived individuals or individuals suffering from poor sleep should be expected to show *decreased* ability to successfully recall emotional information. However, there is scant empirical evidence in direct support of this. In a recent study by Atienza and Cantero, sleep deprivation did not have a differential effect on emotional versus neutral image recollection, and in fact, there was a nonsignificant tendency for emotional stimuli to be more resistant to sleep deprivation effects.[35]

In addition to research on memory, a few recent studies on adults have shown the effect of sleep on the perception and processing of emotional stimuli. Sagaspe et al.[36] demonstrated that emotional information may be more sensitive to sleep deprivation effects than neutral information. Recently, Tempesta et al. explored whether sleep deprived individuals judged affective and neutral stimuli differently than controls.[24] They found that sleep deprived subjects rated neutral stimuli more negatively, even when controlling for negative mood induced by sleep deprivation. In studies of affective neural systems, Yoo et al. demonstrated, utilizing functional MRI (fMRI), greater amygdala response to aversive stimuli following sleep deprivation.[37] Similarly, Franzen and colleagues found increased affective reactivity to negative stimuli among sleep deprived individuals, using pupillary responses.[38] These studies all suggest that sleep deprivation impairs emotional information processing or causes such processing to be negatively biased. In contrast, Wagner et al. demonstrated a reversed effect in measures of subjective ratings of negative stimuli.[39] Specifically, late-night sleep, compared to wakefulness, was followed by increased negativity of the rated stimuli.

A few studies on sleep and emotional information processing have focused on facial expression recognition. For example, a recent study by van der Helm and colleagues examined social-affective cognition and showed that sleep deprivation impaired facial emotional expression recognition in women.[40] In men, the same effect was evident only as a trend. Another study, conducted by Pallesen et al., showed a decrease in speed and accuracy of facial emotion recognition following sleep deprivation,[41] but this study did not compare emotion recognition with neutral stimuli. Similarly, Killgore et al. demonstrated a detrimental effect of sleep deprivation in self-reports on the capacity to understand emotions both in oneself and in others.[42]

These studies, conducted on adults, suggest that facial expression recognition is impaired following poor or insufficient sleep. Accurate recognition of facial emotions and expressions is an important aspect of social cognition and social skills,[43,44] and appears to be related to psychopathology and adjustment both in adults[45,46] and in children.[47-50] Moreover, childhood and adolescence are important periods for *learning* and developing these skills. To the best of our knowledge, despite the importance of emotional facial recognition abilities in childhood and adolescence, there are no published studies examining the effect of sleep on face emotion recognition in these age groups. While some might point to the need for experimental evidence (using sleep deprivation paradigms with a great deal of researcher control) to examine these issues, there is also a need for field studies in natural conditions with high ecological validity.

In this study, we attempted to address key gaps in the literature by examining sleep variations in natural environment while utilizing objective assessment measures for both sleep and face-emotion recognition. Our primary aim was to explore the effect of poor sleep quality on face processing over time during this key developmental window of early adolescence. Based on our conceptual model of sleep, emotion, and cognition we predicted that simultaneously challenging both cognitive and emotional processing would be specifically sensitive to sleep deprivation.[8,11] That is, we hypothesized that emotional face processing, when compared to neutral face processing, would be more vulnerable to the malevolent effects of impaired sleep.

## METHODS

### Participants and Procedure

Participants were 94 children (53 girls, 41 boys; age: $M = 10.52$, $SD = 0.32$, $range = 9.92\text{-}11.33$), who completed the first assessment wave (Time 1). Eighty-two children completed Time 2, which was conducted approximately one year later (46 girls, 36 boys; age: $M = 11.54$, $SD = 0.33$); of the Time 2 completers, 71 also completed Time 3, which was approximately one year subsequent to Time 2 assessment (39 girls, 32 boys; age: $M = 12.51$, $SD = 0.31$).

As part of a larger study on neurobehavioral functioning and sleep during the transition to puberty, these 94 children were recruited from regular classes of 4 different elementary schools in the Tel-Aviv area (see a previous publication on the links between sleep and puberty in this sample for more details[51]). The study adhered to appropriate ethical standards and was approved by Tel-Aviv University's Institutional Review Board and by the Israel Ministry of Education. All children and their parents signed informed consent. Each child and parent completed a packet of questionnaires and received an actigraph and a sleep diary for a week of monitoring. Once at each assessment wave, during the week of sleep monitoring, the children completed a computerized task that included a face information processing component at school. Data were collected throughout the school year, which included regular clock time and daylight saving time periods. According to parental reports, none of the children suffered from any chronic medical or psychiatric problems.

### Measures

*Face emotion and face gender processing* were measured once at each assessment wave using *the Balloons* task.[52] This is a computerized neurobehavioral functioning task asking subjects to "pop" balloons ascending from the bottom of the screen. Varying speed and increasing stages of difficulty permit using the same measure across a wide age range, as well as introducing increasing task demands within each assessment. Two types of information processing functions were utilized in this study: face gender processing and face emotion processing. A face is attached to each balloon, and the subject is required to mouse-click according to gender (e.g., only girls) or emotion (e.g., only happy faces). For each of these task conditions, 4 scores are produced: (1) *Hit percent*—the percentage of correct balloons clicked out of all balloons clicked. (2) *Success*—the proportion of successfully completed levels. (3) *Omissions*—the number of correct balloons that were not clicked. (4) *Y* (speed)— the average position of the correct balloons on the y-axis when clicked. A high value indicates a quick response.

In an earlier validation study of the Balloons task, performed on an independent cross-sectional sample of 134 subjects, aged 7 to 13 years, test-retest correlations showed that all of these measures are reliable ($r$ range: 0.37-0.78, $P < 0.001$), across a 1-week span.[52] In addition, all of these measures were sensitive to age, such that older children performed better ($F_{8,250} = 7.83$, $P < 0.001$). This reflects a significant maturational component.[52] Notably, Rosenberg-Kima and Sadeh reported that both the face-gender and the face-emotion tasks were correlated with child behavioral and emotional symptoms, while controlling for age and sex ($r = 0.26$, $P < 0.005$, and $r = -0.16$, *ns*, for face-gender speed and success, respectively; and $r = 0.14$, *ns*, and $r = -0.18$, $P < 0.05$, for face-emotion speed and success, respectively). They were uncorrelated with socioeconomic measures and with academic performance reported by teachers.[52]

In this study, we explored stability over 1- and 2-year periods. Test-retest correlations for the face-gender task of the Balloons, for Times 1-2, 2-3, and 1-3 were: $r = 0.14, 0.30, 0.30$, P = *ns*, 0.01, 0.01, for hit percent, $r = 0.08, 0.27, 0.31$, P < *ns*, 0.05, 0.01, for success, $r = -0.04, -0.05, 0.35$, P < *ns*, *ns*, 0.01, for omissions, and $r = 0.39, 0.52, 0.44$, $P < 0.001$ for Y, respectively. Test-retest correlations for the face-emotion task of the Balloons were: $r = 0.46, 0.46, 0.16$, P < 0.001, 0.001, *ns*, for hit percent, $r = 0.28$, 0.37, 0.34, $P \leq 0.01$ for success, $r = -0.03, 0.04, 0.03$, *ns*, for omissions, and $r = 0.49, 0.44, 0.47$, $P < 0.001$ for Y, respectively.

*Sleep quality* was assessed at each assessment wave via actigraphic measurement. Actigraphy has been established as a valid and reliable method of objective sleep pattern assessment in various ages.[53,54] Sleep diary data were used to detect and remove possible artifacts from actigraphic data. The children were given miniature actigraphs (Mini Motionlogger, Ambulatory Monitoring, Inc) and were instructed to wear these on their non-dominant wrist in the evening when preparing for sleep and remove them in the morning. The actigraph was set to collect data in 1-min epochs at amplifier setting 18, which is the standard mode for sleep-wake scoring. Actigraphic raw data were translated to sleep measures using the actigraphic scoring analysis program (ASA) for an IBM-compatible PC. These sleep measures have been validated against polysomnography with agreement rates for minute-by-minute sleep-wake identification > 90%.[54]

Actigraphic sleep measures used in this study included: (1) sleep efficiency: percent of true sleep time from total sleep period (SEF), and (2) number of night wakings lasting $\geq 5$ min (NW). The sleep diary included information on sleep schedule and subjective sleep quality (i.e., sleep onset time, rise time, number of night wakings and their duration). The sleep diary data were utilized in correcting any potential artifacts of the actigraphic data. Test-retest correlations for these sleep measures for Times 1-2, 2-3, and 1-3 were: $r = 0.70, 0.61, 0.60$, and $r = 0.68, 0.67, 0.58$, for NW and SEF, respectively. All of these correlations were statistically significant at $P < 0.001$.

*Demographic data* were gathered once (at Time 1), via child and parent self-report, including data regarding age at first assessment, sex, physical and mental health, parents' age, education, and work load, and family size, status, and birth order. In addition, children reported puberty levels using the Sexual Maturation Scale, which is based on line drawings of Tanner stages of pubertal development.[55] The developmental aspects of sleep and the links between sleep and pubertal development have been the focus of an earlier publication based on this sample.[51] We averaged the pubic hair scale and the genitals/breast development scale to receive a continuous global puberty score. This score was used in analyses, to control for puberty and to explore potential developmental interactions.

### Data Analyses

The longitudinal design of the study produced a multilevel, or hierarchical, data structure, in which level-1 data measured at 3 time-points were nested within level-2 units (i.e., individuals). We employed multilevel (hierarchical) linear modeling (*MLM/HLM*) through SPSS MIXED MODELS (version 17) to perform the analyses. Each of the 4 balloons scores were predicted by time (assessment wave, centered to Time 1), task type (dummy coding: 0 gender, 1 emotion), sex (effects coding: -1 for girls, 1 for boys), age at first assessment, puberty, a sleep measure, and a sleep by task interaction term. Multicollinearity is problematic in multilevel models even more than in regular linear regression.[56] Thus, we entered night wakings and sleep efficiency separately into different models. Continuous variables (age, puberty, and sleep) were centered. All predictors were entered as fixed effects; and time, task, puberty, and sleep were entered as random effects as well. We used REML estimation and diagonal type covariance structure. Our rationale for using diagonal type covariance structure followed results of *intercept-only models*,[56] suggesting that most of the variance in our Balloons outcomes stemmed from within-subject variance rather than between-subject variance.

Table 1—Correlations, means, and standard deviations of main study measures

| | Time | Night wakings 1 | Night wakings 2 | Night wakings 3 | Sleep efficiency 1 | Sleep efficiency 2 | Sleep efficiency 3 | M | SD |
|---|---|---|---|---|---|---|---|---|---|
| **Gender, hit %** | 1 | -0.14 | -0.19† | -0.15 | 0.12 | 0.17 | 0.15 | 83.79 | 9.70 |
| | 2 | -0.04 | 0.11 | -0.00 | 0.01 | -0.06 | -0.04 | 87.18 | 8.47 |
| | 3 | -0.11 | -0.04 | 0.21† | 0.10 | 0.02 | -0.24* | 88.44 | 6.54 |
| **Gender ,succ.** | 1 | -0.12 | -0.18 | -0.09 | 0.08 | 0.13 | 0.09 | 0.67 | 0.30 |
| | 2 | -0.03 | 0.14 | 0.01 | -0.04 | -0.10 | -0.04 | 0.74 | 0.25 |
| | 3 | -0.11 | -0.01 | 0.09 | 0.06 | -0.01 | -0.14 | 0.82 | 0.28 |
| **Gender, omis.** | 1 | -0.01 | -0.06 | -0.06 | 0.03 | 0.08 | 0.10 | 6.94 | 8.19 |
| | 2 | 0.15 | 0.05 | 0.11 | -0.06 | -0.03 | -0.04 | 8.43 | 23.03 |
| | 3 | -0.04 | -0.01 | -0.01 | 0.05 | -0.03 | -0.03 | 4.39 | 6.91 |
| **Gender, Y** | 1 | 0.06 | 0.12 | -0.00 | -0.03 | -0.16 | 0.01 | 351.94 | 28.12 |
| | 2 | 0.01 | -0.07 | -0.17 | 0.06 | 0.06 | 0.19 | 350.20 | 23.75 |
| | 3 | 0.10 | -0.01 | -0.15 | -0.07 | 0.03 | 0.21† | 361.53 | 27.10 |
| **Emotion, hit %** | 1 | -0.17 | -0.16 | -0.08 | 0.15 | 0.13 | 0.05 | 90.38 | 7.44 |
| | 2 | -0.11 | -0.19† | -0.06 | 0.10 | 0.11 | 0.01 | 91.69 | 8.59 |
| | 3 | -0.21† | -0.28* | -0.21† | 0.14 | 0.20† | 0.16 | 93.90 | 5.37 |
| **Emotion, succ.** | 1 | -0.31** | -0.24* | -0.26* | 0.27** | 0.19 | 0.20† | 0.65 | 0.26 |
| | 2 | -0.09 | -0.21† | -0.07 | 0.05 | 0.13 | 0.00 | 0.67 | 0.25 |
| | 3 | -0.26* | -0.29* | -0.21† | 0.16 | 0.21† | 0.08 | 0.73 | 0.24 |
| **Emotion, omis.** | 1 | 0.38*** | 0.24* | 0.10 | -0.31** | -0.27* | -0.15 | 40.45 | 15.59 |
| | 2 | -0.02 | 0.00 | -0.04 | 0.01 | -0.01 | 0.06 | 36.14 | 11.85 |
| | 3 | 0.10 | -0.04 | 0.08 | -0.04 | 0.01 | 0.03 | 34.69 | 13.47 |
| **Emotion, Y** | 1 | -0.06 | -0.12 | -0.14 | 0.08 | 0.09 | 0.19 | 343.58 | 25.48 |
| | 2 | -0.05 | -0.06 | -0.12 | 0.06 | 0.05 | 0.15 | 352.59 | 22.38 |
| | 3 | 0.10 | 0.06 | -0.11 | -0.05 | -0.06 | 0.17 | 360.05 | 25.43 |
| **M** | | 1.64 | 1.57 | 1.57 | 93.68 | 93.67 | 93.40 | | |
| **SD** | | 1.18 | 1.23 | 1.01 | 4.02 | 4.21 | 3.58 | | |

***P < 0.001, **P < 0.01, *P < 0.05, †P < 0.10. Omis, omissions; succ, success. Y, speed (a high value indicates a quick response). Means and standard deviations for sleep variables are presented at the bottom of the table. Means and standard deviations for Balloons variables are presented at the right side of the table.

First we were interested in general developmental trends for each of the balloons measures. Next, we explored the interaction between sleep and task, in order to explore differential effects of sleep on face-emotion vs. face-gender information.

## RESULTS

Missing data stemming from dropout in this study are most likely "ignorable non-response," which does not bias results in multilevel models.[57,58] However, to the extent that it might not be, we performed analyses suggested by Hedeker and Gibbons[59] and recommended by Atkins,[57] in which a dichotomous variable representing dropouts versus completers was added to the model, and its interactions with variables of interest were tested. None of these effects were statistically significant, meaning that missing data were unlikely to have affected results.

Table 1 presents correlations between sleep measures (NW, SEF) and Balloons measures for all assessments waves. The table also includes means and standard deviations for each of these measures. As can be seen in the table, sleep scores were correlated mainly with face-emotion processing measures, rather than face-gender processing measures. Night wakings ranged from a minimum of 0.17, 0.10, and 0.00, to a maximum of 5.00, 5.17, and 4.14, at times 1, 2, and 3, respectively. Sleep efficiency ranged from 81.66, 82.45, and 82.96, to 98.97, 99.00, and 99.15, respectively.

Before exploring the effects of sleep on facial information processing, we sought to examine general developmental trends in the Balloons measures during the period of the study.

### Developmental Trends in Information Processing

Tables 2, 3, 4, and 5 depict models for hit percent, success, omissions, and Y, respectively. For each table, the upper section represents the model when night wakings were the sleep variable, and the bottom section represents the model when sleep

**Table 2**—Models predicting hit percent for number of night wakings (NW) and sleep efficiency (SEF)

**NW** **-2 log likelihood: 3151.96** **Parameters: 19**

**Estimates of fixed effects for hit percent**

| Parameter | estimate | std. error | df | t | P | lower b. | upper b. |
|---|---|---|---|---|---|---|---|
| Intercept | 85.07 | 0.72 | 532.61 | 118.92 | 0.00 | 83.66 | 86.47 |
| Time | 1.33 | 0.51 | 607.58 | 2.63 | 0.01 | 0.34 | 2.33 |
| Task | 5.62 | 0.57 | 350.03 | 9.81 | 0.00 | 4.49 | 6.74 |
| Sex | 0.92 | 0.41 | 1506.80 | 2.24 | 0.03 | 0.11 | 1.72 |
| Age | -0.98 | 1.29 | 1401.03 | -0.76 | ns | -3.51 | 1.54 |
| Puberty | 0.85 | 0.50 | 1002.16 | 1.70 | ns | -0.13 | 1.83 |
| Night waking | 0.45 | 0.47 | 406.42 | 0.95 | ns | -0.48 | 1.38 |
| Waking*task | -1.79 | 0.52 | 416.94 | -3.42 | 0.00 | -2.82 | -0.76 |

**SEF** **-2 log likelihood: 3146.47** **Parameters: 19**

**Estimates of fixed effects for hit percent**

| Parameter | estimate | std. error | df | t | P | lower b. | upper b. |
|---|---|---|---|---|---|---|---|
| Intercept | 84.94 | 0.81 | 251.01 | 105.35 | 0.00 | 83.35 | 86.53 |
| Time | 1.46 | 0.54 | 286.58 | 2.72 | 0.01 | 0.41 | 2.52 |
| Task | 5.70 | 0.62 | 140.00 | 9.23 | 0.00 | 4.48 | 6.92 |
| Sex | 0.87 | 0.50 | 85.26 | 1.75 | ns | -0.12 | 1.85 |
| Age | -0.50 | 1.54 | 92.08 | -0.32 | ns | -3.57 | 2.57 |
| Puberty | 0.77 | 0.56 | 205.83 | 1.37 | ns | -0.34 | 1.87 |
| Slp. Efficiency | -0.15 | 0.15 | 128.19 | -1.04 | ns | -0.44 | 0.14 |
| efficiency*task | 0.41 | 0.16 | 211.84 | 2.56 | 0.01 | 0.09 | 0.73 |

**Table 3**—Models predicting success for number of night wakings (NW) and sleep efficiency (SEF)

**NW** **-2 log likelihood: 74.88** **Parameters: 19**

**Estimates of fixed effects for success**

| Parameter | estimate | std. error | df | t | P | lower b. | upper b. |
|---|---|---|---|---|---|---|---|
| Intercept | 0.71 | 0.03 | 183.27 | 27.77 | 0.00 | 0.66 | 0.77 |
| Time | 0.03 | 0.02 | 211.19 | 1.70 | ns | -0.01 | 0.07 |
| Task | -0.06 | 0.02 | 148.56 | -2.70 | 0.01 | -0.11 | -0.02 |
| Sex | 0.03 | 0.02 | 81.87 | 1.85 | ns | -0.00 | 0.06 |
| Age | -0.04 | 0.05 | 88.52 | -0.79 | ns | -0.14 | 0.06 |
| Puberty | 0.03 | 0.02 | 193.03 | 1.45 | ns | -0.01 | 0.07 |
| Night waking | 0.01 | 0.02 | 138.46 | 0.33 | ns | -0.03 | 0.04 |
| Waking*task | -0.06 | 0.02 | 249.61 | -3.10 | 0.00 | -0.10 | -0.02 |

**SEF** **-2 log likelihood: 85.61** **Parameters: 19**

**Estimates of fixed effects for success**

| Parameter | estimate | std. error | df | t | P | lower b. | upper b. |
|---|---|---|---|---|---|---|---|
| Intercept | 0.71 | 0.03 | 188.53 | 27.23 | 0.00 | 0.66 | 0.76 |
| Time | 0.04 | 0.02 | 207.20 | 1.91 | ns | -0.00 | 0.08 |
| Task | -0.06 | 0.02 | 146.05 | -2.58 | 0.01 | -0.11 | -0.01 |
| Sex | 0.03 | 0.02 | 87.18 | 1.65 | ns | -0.01 | 0.06 |
| Age | -0.04 | 0.05 | 92.92 | -0.69 | ns | -0.14 | 0.07 |
| Puberty | 0.03 | 0.02 | 203.78 | 1.34 | ns | -0.01 | 0.06 |
| Slp. Efficiency | -0.00 | 0.01 | 123.04 | -0.21 | ns | -0.01 | 0.01 |
| efficiency*task | 0.01 | 0.01 | 249.29 | 2.35 | 0.02 | 0.00 | 0.03 |

efficiency was the sleep variable. Statistics reported in this section represent the models in which night wakings were the sleep variable. Similar effects emerged in the sleep efficiency models, unless stated otherwise. As can be seen in the tables, time had a statistically significant effect when predicting hit percent, omissions, and Y ($b$ = 1.33, $SD$ = 0.51, $t_{(607.58)}$ = 2.63, P < 0.01; $b$ = -1.37, $SD$ = 0.69, $t_{(209.14)}$ = -1.99, P < 0.05; and $b$ = 8.57, $SD$ = 2.02, $t_{(175.84)}$ = 4.25, P < 0.001, respectively), suggesting an improvement over time beyond age, sex, puberty levels or task type. Task type had a statistically significant effect when pre-

**Table 4**—Models predicting omissions for number of night wakings (NW) and sleep efficiency (SEF)

| | Parameter | estimate | std. error | df | t | P | lower b. | upper b. |
|---|---|---|---|---|---|---|---|---|
| **NW** | **-2 log likelihood: 3582.27** | **Parameters: 19** | | | | | | |
| | **Estimates of fixed effects for omissions** | | | | | | | |
| | Intercept | 6.84 | 0.89 | 148.79 | 7.72 | 0.00 | 5.09 | 8.59 |
| | Time | -1.37 | 0.69 | 209.14 | -1.99 | 0.05 | -2.73 | -0.01 |
| | Task | 31.39 | 1.03 | 107.56 | 30.60 | 0.00 | 29.36 | 33.42 |
| | Sex | 0.01 | 0.54 | 85.29 | 0.02 | ns | -1.07 | 1.09 |
| | Age | 1.10 | 1.71 | 95.57 | 0.64 | ns | -2.29 | 4.49 |
| | Puberty | -0.41 | 0.70 | 161.61 | -0.58 | ns | -1.78 | 0.97 |
| | Night waking | -0.13 | 0.52 | 157.26 | -0.25 | ns | -1.16 | 0.90 |
| | Waking*task | 2.36 | 0.92 | 191.17 | 2.58 | 0.01 | 0.55 | 4.17 |
| **SEF** | **-2 log likelihood: 3591.19** | **Parameters: 19** | | | | | | |
| | **Estimates of fixed effects for omissions** | | | | | | | |
| | Intercept | 6.89 | 0.88 | 148.35 | 7.79 | 0.00 | 5.14 | 8.64 |
| | Time | -1.42 | 0.69 | 208.57 | -2.07 | 0.04 | -2.78 | -0.06 |
| | Task | 31.30 | 1.03 | 107.00 | 30.48 | 0.00 | 29.27 | 33.34 |
| | Sex | 0.03 | 0.55 | 85.17 | 0.05 | ns | -1.06 | 1.11 |
| | Age | 1.02 | 1.71 | 94.85 | 0.59 | ns | -2.38 | 4.41 |
| | Puberty | -0.35 | 0.70 | 160.18 | -0.51 | ns | -1.73 | 1.02 |
| | Slp. Efficiency | -0.01 | 0.15 | 156.70 | -0.07 | ns | -0.31 | 0.29 |
| | efficiency*task | -0.42 | 0.26 | 179.78 | -1.61 | ns | -0.94 | 0.10 |

**Table 5**—Models predicting Y (speed) for number of night wakings (NW) and sleep efficiency (SEF)

| | Parameter | estimate | std. error | df | t | P | lower b. | upper b. |
|---|---|---|---|---|---|---|---|---|
| **NW** | **-2 log likelihood: 4087.59** | **Parameters: 19** | | | | | | |
| | **Estimates of fixed effects for Y** | | | | | | | |
| | Intercept | 344.54 | 2.54 | 161.29 | 135.80 | 0.00 | 339.53 | 349.55 |
| | Time | 8.57 | 2.02 | 175.84 | 4.25 | 0.00 | 4.59 | 12.55 |
| | Task | -2.43 | 1.51 | 103.19 | -1.61 | ns | -5.42 | 0.56 |
| | Sex | -11.12 | 1.95 | 84.24 | -5.71 | 0.00 | -15.00 | -7.25 |
| | Age | 1.21 | 6.01 | 85.69 | 0.20 | ns | -10.73 | 13.15 |
| | Puberty | -2.55 | 2.03 | 244.27 | -1.26 | ns | -6.54 | 1.44 |
| | Night waking | 0.59 | 1.63 | 79.71 | 0.36 | ns | -2.66 | 3.83 |
| | Waking*task | -0.84 | 1.36 | 166.38.28 | -0.62 | ns | -3.53 | 1.85 |
| **SEF** | **-2 log likelihood: 4094.43** | **Parameters: 19** | | | | | | |
| | **Estimates of fixed effects for Y** | | | | | | | |
| | Intercept | 344.92 | 2.53 | 161.80 | 136.27 | 0.00 | 339.92 | 349.92 |
| | Time | 8.33 | 2.01 | 170.79 | 4.14 | 0.00 | 4.36 | 12.30 |
| | Task | -2.40 | 1.52 | 215.23 | -1.58 | ns | -5.40 | 0.60 |
| | Sex | -11.37 | 1.95 | 85.34 | -5.83 | 0.00 | -15.25 | -7.49 |
| | Age | 0.93 | 6.01 | 86.06 | 0.16 | ns | -11.01 | 12.88 |
| | Puberty | -2.39 | 2.03 | 241.30 | -1.18 | ns | -6.38 | 1.61 |
| | Slp. Efficiency | -0.22 | 0.44 | 59.85 | -0.49 | ns | -1.10 | 0.67 |
| | efficiency*task | 0.17 | 0.39 | 232.00 | 0.42 | ns | -0.61 | 0.94 |

dicting hit percent, success, and omissions ($b = 5.62$, $SD = 0.57$, $t_{(350.03)} = 9.81$, $P < 0.001$; $b = -0.062$, $SD = 0.023$, $t_{(148.56)} = -2.70$, $P < 0.01$; and $b = 31.39$, $SD = 1.03$, $t_{(107.56)} = 30.60$, $P < 0.001$, respectively), according to which gender processing had elevated success and fewer omissions, but emotion processing had a higher hit percent. Sex had a statistically significant effect when predicting Y ($b = -11.12$, $SD = 1.95$, $t_{(84.24)} = -5.71$, $P < 0.001$), according to which girls perform faster. In addition, only when using night-wakings in the model (and not sleep efficiency), sex had a statistically significant effect when predicting hit percent

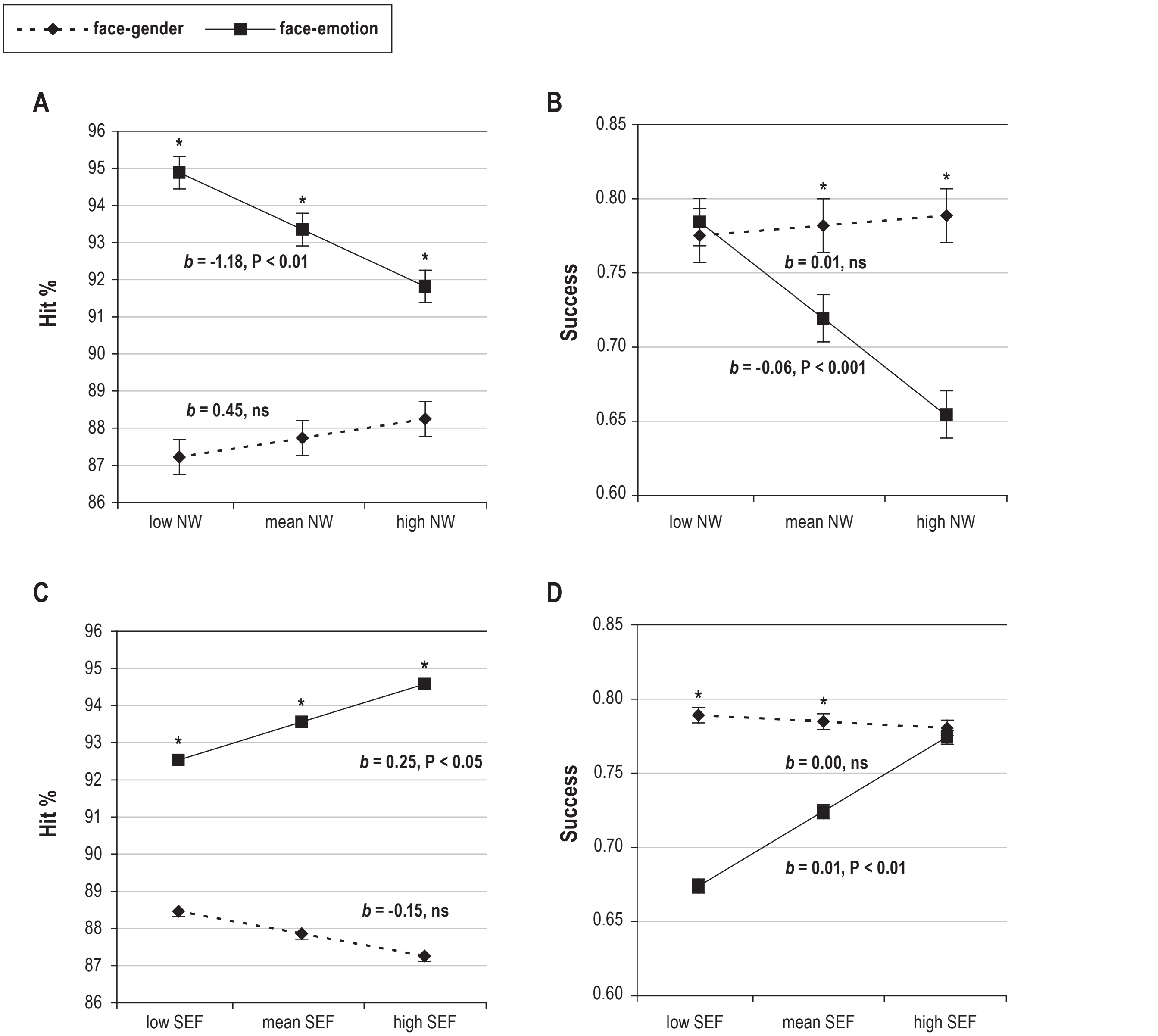


**Figure 1**—Effect of night wakings **(A, B)** and sleep efficiency **(C, D)** on hit percent **(A, C)** and success **(B, D)**, for face-emotion versus face-gender conditions. High versus low sleep scores are based on 1 standard deviation above and below the sample mean, respectively. Significant differences between conditions are marked with an asterisk.

($b$ = 0.92, $SD$ = 0.41, $t_{(1506.80)}$ = 2.24, P < 0.05), with boys having higher hit percents. Puberty did not show any statistically significant effects.

### Sleep Effects

As can be seen in the top parts of Tables 2 through 5, when using night wakings as the sleep variable, the sleep by task interaction was statistically significant in 3 of the models ($b$ = -1.79, $SD$ = 0.52, $t_{(416.94)}$ = -3.42, P = 0.001, for hit percent, Table 2; $b$ = -0.063, $SD$ = 0.02, $t_{(249.61)}$ = -3.10, P < 0.01, for success, Table 3; and $b$ = 2.36, $SD$ = 0.92, $t_{(191.17)}$ = 2.58, P = 0.01, for omissions, Table 4). Probes revealed that for each of these measures, sleep was a statistically significant predictor when the task was face-emotion processing ($b$ = -1.18, $SD$ = 0.44, $t_{(119.82)}$ = -2.71, P < 0.01; $b$ = -0.06, $SD$ = 0.02, $t_{(122.93)}$ = -3.60, P < 0.001, and $b$ = 2.20, $SD$ = 0.81, $t_{(215.42)}$ = 2.71, P < 0.01, respectively), but was nonsignificant when the task was face-gender processing ($b$ = 0.45, $SD$ = 0.47, $t_{(406.42)}$ = 0.95, *ns*; $b$ = 0.01, $SD$ = 0.02, $t_{(138.46)}$ = 0.33, *ns*; and $b$ = -0.13, $SD$ = 0.52, $t_{(157.26)}$ = -0.25, *ns*, respectively). The effects of night wakings on hit percent and success are illustrated in Figures 1A and 1B (respectively). These illustrations demonstrate that face-emotion information processing levels change as a function of night waking scores, while face-gender information processing is not significantly affected by differing night waking scores.

As can be seen in the bottom parts of Tables 2 through 5, when using sleep efficiency as the sleep variable, the sleep by task interaction was statistically significant in two of the models

($b = 0.41$, $SD = 0.16$, $t_{(211.84)} = 2.56$, P = 0.01, for hit percent, Table 2; and $b = 0.01$, $SD = 0.01$, $t_{(249.29)} = 2.35$, P < 0.05, for success, Table 3). Probes revealed that for each of these measures, sleep was a statistically significant predictor when the task was face-emotion processing ($b = 0.25$, $SD = 0.13$, $t_{(210.44)} = 2.01$, P < 0.05; and $b = 0.01$, $SD = 0.00$, $t_{(107.11)} = 2.69$, P < 0.01, respectively), but was nonsignificant when the task was face-gender processing ($b = -0.15$, $SD = 0.15$, $t_{(128.19)} = -1.04$, *ns*; and $b = 0.00$, $SD = 0.01$, $t_{(123.04)} = -0.21$, *ns*, respectively). The effects of sleep efficiency on hit percent and success are illustrated in Figures 1C and 1D (respectively). Again, these illustrations show that face-emotion information processing levels change as a function of sleep efficiency scores, while face-gender information processing is not significantly affected by differing sleep efficiency scores.

## DISCUSSION

Over the past decade there has been growing evidence supporting the view of adolescence as a period of biobehavioral challenges that create vulnerabilities as well as opportunities.[2,60] The onset of puberty typically brings about a dramatic set of physical, cognitive, and psychosocial changes. These changes include rapid brain, hormonal, sexual, and physical development, increasingly complex social interactions and the development of romantic interest, new fears and anxieties, coupled with increased self-consciousness, enhanced risk-seeking behaviors, and other novel experiences which bring about emotional turmoil and stress, as well as positive experiences and learning.[5,8,51] As described in the introduction, the affective and social changes at the onset of puberty, combined with dramatic changes in sleep patterns, highlight the importance of considering the interactions between sleep and emotion processes during this developmental window—particularly given the evidence for bi-directional effects between sleep and emotion processing.[8,11]

This study is the first to directly assess the links between sleep and neutral versus emotional face information processing using a longitudinal design and objective measures during this sensitive age period of the transition into adolescence. Our main findings support the primary research hypothesis: children with elevated night wakings and decreased sleep efficiency exhibited lower performance in a face-emotion information processing task over time. Neutral facial information processing (face-gender) was not predicted by sleep over time. These findings were evident only in the accuracy measures of the Balloons task (hit percent, success, and omissions), and did not emerge in regard to speed of performance (represented by the Y measure). These findings are compatible with the pattern of results shown in Table 1, in which sleep variables were mainly correlated with the face-emotion task, and not with the face-gender task. The results of this study fit well with previous literature which found that sleep plays an important role in emotional, but not neutral, information processing.[27-32,34,36] Moreover, this study extends these results from adulthood to childhood and early adolescence, and does so within the context of a longitudinal design and while controlling for a host of potentially intervening variables, namely, puberty levels and within-sample variation in age and gender.

As noted above, our results were obtained only with accuracy, and not speed, outcome measures. Possibly, poor sleep quality affects a subset of cognitive functions, such as those requiring more complex integration of cognitive and affective processes that require precision, and perhaps greater attentional control, rather than more automatic functioning, as manifested in reaction time. Such a pattern is consistent with previous literature, suggesting that sleep deprivation and impairment may primarily affect complex tasks such as those that require rapid integration of cognitive and affective processing.[11] It is also noteworthy that mean sleep efficiency and night waking scores suggested that overall, this sample of early adolescents slept reasonably well. This was to be expected, as this was a non-clinical sample. Nevertheless, this highlights the importance of our results: even minor sleep disruptions, in a non-clinical sample, are associated with decreased emotional information processing abilities. This underscores the importance of good sleep in normal development during adolescence.

Interpreting causality in our design must be done with caution. On one hand, it is important to acknowledge that issues of cause and effect cannot be determined when sleep is not manipulated experimentally. On the other hand, the longitudinal design of this study, indicating that sleep and emotional processing co-vary over time, is compatible with a directional assumption whereby poor sleep appears to bring about poor emotional processing. The results are consistent with the idea that sufficient good sleep is needed for proper functioning of neural systems that underpin key aspects of social-affective processes such as those needed to quickly and accurately recognize specific affective facial expressions.

These results are provocative and potentially of clinical significance, not only because they extend the previous evidence for the well-established link between emotional and sleep problems, but also because they point to the risk for negative spirals—in which emotional and behavioral problems worsen sleep difficulties, and these, in turn, may intensify emotional impediments. As mentioned in the introduction, this developmental window is also a key time for social and emotional learning. Focusing specifically on face recognition, functional magnetic resonance imaging (fMRI) evidence has recently accumulated suggesting that such skills still undergo significant maturational changes in early adolescence.[5] Thus, the high rates of youth obtaining insufficient or poor sleep may not only be compromising opportunities for this kind of learning, but also youth who are already struggling with social and emotional difficulties may further compromise their functioning because of these effects.[47-50] For example, in delicate social situations, that require sensitivity to a friend's feelings getting hurt, a good sleeper might be more attuned to the friend's subtle facial changes than the poor sleeper, and thus exercise a more appropriate response. Early adolescence is a time when youth are striving to achieve social success and status in ways that can have high-stakes consequences.

These findings also point to a testable hypothesis regarding an opportunity for early intervention: Increasing/improving sleep in high-risk youth and/or youth already struggling with social and emotional difficulties may help to buffer or improve the developmental trajectory. Clinical implications of this study point to the significance of addressing sleep quality in troubled children and adolescents as an avenue for research into early intervention strategies for high-risk youth.

Our results also have methodological implications for future research. Since most of the Balloons measures show improvements over time, as cognitive abilities develop, this suggests that the Balloons task is sensitive to such maturational changes during the transition to adolescence. These findings extend our earlier report on the sensitivity of this test to maturation in pre-adolescence school years, in a cross-sectional sample of 7- to 13-year-olds.[52] Another main effect was found for task type (face-gender versus face-emotion), exhibiting elevated performance for face-gender in 2 of the measures, but elevated performance for face-emotion for one additional measure. Thus, increased difficulty of the face-emotion task cannot be regarded as an alternative explanation to our sleep-related findings. Another main effect emerged for sex. While girls performed the Balloons tasks faster, boys had higher hit percents. This result replicates earlier findings reported on the Balloons task.[52] It is also worthwhile to mention that our results regarding a specific effect of sleep on face-emotion, but not face-gender, processing, supports the validity of this relatively new neurobehavioral functioning task as a measure enabling objective comparison between emotional and neutral stimuli.

Some limitations of the study should be noted. First, our sample of children consisted mainly of families with a medium to high socioeconomic status, and thus caution should be taken in generalizing these results. Second, 23 children dropped out of the study between Times 1 and 3, which might have caused a bias in results; however, this is unlikely based on missing data analyses. Finally, although the longitudinal design and use of multilevel modeling go beyond a cross sectional correlation and reveal an effect of sleep on emotional processing over time, utilizing within-subject variance, still, our study is a correlational one and therefore causality cannot be ascertained.

In conclusion, our study provides initial evidence for an effect of sleep on emotional information processing in childhood and adolescence, using objective measures for both sleep quality and face information processing, and comparing neutral and emotional stimuli over three years. Future research should examine the potential utility of addressing sleep problems to improve compromised social skills related to emotion information processing.

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## DISCLOSURE STATEMENT

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## REFERENCES

1. Spear LP. The adolescent brain and age-related behavioral manifestations. Neurosci Biobehav Rev 2000;24:417-63.
2. Steinberg L, Dahl R, Keating D, Kupfer DJ, Masten AS, Pine D. The study of developmental psychopathology in adolescence: Integrating affective neuroscience with the study of context. In: Cicchetti D, Cohen DJ, eds. Developmental psychopathology. New York: John Wiley & Sons, 2006:710-41.
3. Walker EF. Adolescent neurodevelopment and psychopathology. Curr Dir Psychol Sci 2002;11:24-8.
4. McGivern RF, Andersen J, Byrd D, Mutter KL, Reilly J. Cognitive efficiency on a match to sample task decreases at the onset of puberty in children. Brain Cogn 2002;50:73-89.
5. Dahl RE, Gunnar MR. Heightened stress responsiveness and emotional reactivity during pubertal maturation: Implications for psychopathology. Dev Psychopathol 2009;21:1-6.
6. Lewis DA. Development of the prefrontal cortex during adolescence: Insights into vulnerable neural circuits in schizophrenia. Neuropsychopharmacology 1997;16:385-98.
7. Crowley SJ, Acebo C, Carskadon MA. Sleep, circadian rhythms, and delayed phase in adolescence. Sleep Med 2007;8:602-12.
8. Dahl RE, Lewin DS. Pathways to adolescent health: Sleep regulation and behavior. J Adolesc Health 2002;31:175-84.
9. Borbély AA. A two process model of sleep regulation. Hum Neurobiol 1982;1:195-204.
10. Jenni OG, Achermann P, Carskadon MA. Homeostatic sleep regulation in adolescents. Sleep 2005;28:1446-54.
11. Dahl RE. The regulation of sleep and arousal: development and psychopathology. Dev Psychopathol 1996;8:3-27.
12. Peterson MJ, Benca RM. Sleep in mood disorders. Psychiatr Clin North Am 2006;29:1009-32.
13. Walker MP, van der Helm E. Overnight therapy? The role of sleep in emotional brain processing. Psychol Bull 2009:135:731-48.
14. Benca RM, Obermeyer WH, Thisted RA, Gillin JC. Sleep and psychiatric disorders: A meta-analysis. Arch Gen Psychiatry 1992;49:651-68.
15. Dahl RE, Harvey AG. Sleep in children and adolescents with behavioral and emotional disorders. Sleep Med Clin 2007;2:501-11.
16. Lofthouse N, Gilchrist R, Splaingard M. Mood-related sleep-problems in children and adolescents. Child Adolesc Psychiatr Clin North Am 2009;18:893-916.
17. Ong SH, Wickramaratne P, Tang M, Weissman MM. Early childhood sleep and eating problems as predictors of adolescent and adult mood and anxiety disorders. J Affect Disord 2006;96:1-8.
18. Wong MM, Brower KJ, Zucker RA. Childhood sleep problems, early onset of substance use and behavioral problems in adolescence. Sleep Med 2009;10:787-96.
19. Dinges DF, Pack F, Williams K, et al. Cumulative sleepiness, mood disturbance, and psychomotor vigilance performance decrements during a week of sleep restricted to 4-5 hours per night. Sleep 1997;20:267-77.
20. Meijer AM, Habekothe HT, van den Wittenboer GLH. Time in bed, quality of sleep and school functioning of children. J Sleep Res 2000;9:145–53.
21. Pilcher JJ, Huffcutt AI. Effects of sleep deprivation on performance: A meta-analysis. Sleep 1996;19:318-326.
22. Sadeh A, Lavie P, Scher A. Maternal perceptions of temperament of sleep-disturbed toddlers. Early Educ Dev 1994;5:311-22.
23. Settineri S, Vitetta A, Mento C, et al. Construction of a telephone interview to assess the relationship between mood and sleep in adolescents. Neurol Sci 2010;31:459-65.
24. Tempesta D, Couyoumdjian A, Curcio G, et al. Lack of sleep affects the evaluation of emotional stimuli. Brain Res Bull 2010;82:104-8.
25. Ohayon MM, Roberts RE, Zulley J, Smirme S, Priest RG. Prevalence and patterns of problematic sleep among older adolescents. J Am Acad Child Adolesc Psychiatry 2000;39:1549-56.
26. Sadeh A, Raviv A, Gruber R. Sleep patterns and sleep disruptions in school-age children. Dev Psychol 2000:36:291-301.
27. Hu P, Stylos-Allan M, Walker MP. Sleep facilitates consolidation of emotional declarative memory. Psychol Sci 2006;17:891-8.
28. Nishida M, Pearsall J, Buckner RL, Walker MP. Prefrontal theta during REM sleep enhances emotional memory. Cereb Cortex 2009;19:1158–66.
29. Sharot T, Phelps EA. How arousal modulates memory: Disentangling the effects of attention and retention. Cogn Affect Behav Neurosci 2004;4:294-306.
30. Wagner U, Gais S, Born J. Emotional memory formation is enhanced across sleep intervals with high amounts of rapid eye movement sleep. Learn Mem 2001;8:112–9.
31. Wagner U, Hallschmid M, Rasch B, Born J. Brief sleep after learning keeps emotional memories alive for years. Biol Psychiatry 2006;60:788-90.
32. Payne JD, Stickgold R, Swanberg K, Kensinger EA. Sleep preferentially enhances memory for emotional components of scenes. Psychol Sci 2008;19:781-8.

33. Wagner U, Kashyap N, Diekelmann S, Born J. The impact of post-learning sleep vs. wakefulness on recognition memory for faces with different facial expressions. Neurobiol Learn Mem 2007;87:679-87.
34. Prehn-Kristensen A, Goder R, Chirobeja S, Breβmann I, Ferstl R, Baving L. Sleep in children enhances preferentially emotional declarative but not procedural memories. J Exp Child Psychol 2009;104:132-139.
35. Atienza M, Cantero JL. Modulatory effects of emotion and sleep on recollection and familiarity. J Sleep Res 2008;17:285-94.
36. Sagaspe P, Sanchez-Ortuno M, Charles A, et al. Effects of sleep deprivation on color-word, emotional, and specific stroop inference and on self-reported anxiety. Brain Cogn 2006;60:76-87.
37. Yoo SS, Gujar N, Hu P, Jolesz FA, Walker MP. The human emotional brain without sleep - a prefrontal amygdala disconnect. Curr Biol 2007;17:R877-8.
38. Franzen PL, Buysse DJ, Dahl RE, Thompson W, Siegle GJ. Sleep deprivation alters pupillary reactivity to emotional stimuli in healthy young adults. Biol Psychol 2009;80:300-5.
39. Wagner U, Fischer S, Born J. Changes in emotional responses to aversive pictures across periods rich in slow-wave sleep versus rapid eye movement sleep. Psychosom Med 2002;64:627-34.
40. van der Helm E, Gujar N, Walker MP. Sleep deprivation impairs the accurate recognition of human emotions. Sleep 2010;33:335-42.
41. Pallesen S, Johnsen BH, Hansen A, et al. Sleep deprivation and hemispheric asymmetry for facial recognition reaction time and accuracy. Percept Mot Skills 2004;98:1305-14.
42. Killgore WDS, Kahn-Greene ET, Lipizzi EL, Newman RA, Kamimori GH, Balkin TJ. Sleep deprivation reduces perceived emotional intelligence and constructive thinking skills. Sleep Med 2008;9:517-26.
43. Herba C, Phillips M. Annotation: Development of facial expression recognition from childhood to adolescence: Behavioural and neurological perspectives. J Child Psychol Psychiatry 2004;45:1185-98.
44. McClure EB. A meta-analytic review of sex differences in facial expression processing and their development in infants, children, and adolescents. Psychol Bull 2000;126:424-53.
45. Leppanen JM. Emotional information processing in mood disorders: a review of behavioral and neuroimaging findings. Curr Opin Psychiatry 2006;19:34-9.
46. Phillips ML, Drevets WC, Rauch SL, Lane R. Neurobiology of emotion perception II: Implications for major psychiatric disorders. Biol Psychiatry 2003;54:515-28.
47. Crick NR, Dodge KA. A review and reformulation of social information-processing mechanisms in children's social-adjustment. Psychol Bull 1994;115:74-101.
48. Custrini RJ, Feldman RS. Children's social competence and nonverbal encoding and decoding of emotions. J Clin Child Psychol 1989;18:336-42.
49. Leppanen JM, Hietanen JK. Emotion recognition and social adjustment in schoolaged girls and boys. Scand J Psychol 2001;42:429-35.
50. Nowicki S, Duke MP. The association of children's nonverbal decoding abilities with their popularity, locus of control, and academic-achievement. J Genet Psychol 1992;153:385-93.
51. Sadeh A, Dahl RE, Shahar G, Rosenblat-Stein S. Sleep and the transition to adolescence: A longitudinal study. Sleep 2009;32:1602-9.
52. Rosenberg-Kima RB, Sadeh A. Attention, response inhibition, and face-information processing in children: The role of task characteristics, age and gender. Child Neuropsychol 2010;16:388-404.
53. Sadeh A, Acebo C. The role of actigraphy in sleep medicine. Sleep Med Rev 2002;6:113-24.
54. Sadeh A, Sharkey KM, Carskadon MA. Activity-based sleep-wake identification: an empirical test of methodological issues. Sleep 1994;17:201-7.
55. Taylor SJ, Whincup PH, Hindmarsh PC, Lampe F, Odoki K, Cook DG. Performance of a new pubertal self-assessment questionnaire: a preliminary study. Paediatr Perinat Epidemiol 2001;15:88-94.
56. Tabachnick BG, Fidell LS. Using multivariate statistics, 5th ed. Boston: Allyn and Bacon, 2007.
57. Atkins DC. Using multilevel models to analyze couple and family treatment data: Basic and advanced issues. J Fam Psychol 2005;19:98-110.
58. Schafer JL, Graham JW. Missing data: Our view of the state of the art. Psychol Methods 2002;7:147-77.
59. Hedeker D, Gibbons RD. Application of random-effects pattern-mixture models for missing data in longitudinal studies. Psychol Methods 1997;2:64-78.
60. Forbes EE, Dahl RE. Pubertal development and behavior: hormonal activation of social and motivational tendencies. Brain Cogn 2010;72:66-72.