The Association Between Puberty, Emotional Difficulties, and Sleep Problems

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Abstract

Puberty is a period of developmental maturation that is often characterized by difficulties with sleep and emotion. However, the nature of the relation, if any, between pubertal development and emotional difficulties and sleep problems is unclear. The current three-year longitudinal study aimed to investigate whether adolescents' pubertal status, level of sleep problems, and level of emotional difficulties at Time 1 predict subsequent changes in the developmental trajectories of sleep problems and emotional difficulties. Participants (N = 1284) aged 7-14 years completed a survey measuring their demographics, pubertal status, emotional difficulties, and sleep problems. The results showed that for both boys and girls, puberty was not associated with increases in emotional difficulties over time. Meanwhile, pubertal development was related to increases in sleep problems over time for girls, but not boys. Thus, the latter stages of puberty may be a time of onset for sleep problems in girls.

Keywords: puberty, emotional difficulties, sleep, adolescent development

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Introduction

Puberty is a developmental period of maturation that defines the transition from childhood to adolescence (Dorn et al., 2019). This stage of development often is characterized by difficulties with sleep and emotion (see Franco et al., 2020; Guyer et al., 2016 for reviews). It is possible that puberty may be a critical explanatory variable of various developmental processes within and across persons. In fact, Dorn et al. (2019) theorized that puberty may be an important developmental period for the prevention and intervention of various physical and mental health conditions. Thus, it is important to understand how puberty is associated with changes in sleep and emotion. The present study aims to examine longitudinal relations among pubertal status, emotional difficulties, and sleep problems.

Pubertal development has been shown to accompany changes in emotional difficulties, particularly in emotional reactivity and emotion regulation (Guyer et al., 2016). Emotional reactivity refers to the characteristics of an emotional response, including the following: (1) sensitivity, the strength of the stimuli necessary to elicit the emotion; (2) intensity, the peak arousal of the emotion; and (3) duration, the length of time to return to a baseline emotional state (Becerra et al., 2019; Nock et al., 2008). Meanwhile, emotion regulation is defined as the ability to monitor, evaluate, and change emotional responses (McRae & Gross, 2020). It has been theorized that the link between emotional reactivity and emotion regulation may be bidirectional, with difficulties in one associated with increased difficulties in the other (Baglioni et al., 2010). Indeed, emotional reactivity and emotion dysregulation are highly correlated, and thus are often combined into a broader construct called emotional difficulties (e.g. Baglioni et al., 2010; Reddy et al., 2017; Tavernier & Willoughby, 2015). According to the Maturational Imbalance Model

(Casey et al., 2008), the increase in emotional difficulties during puberty may be due to the differing developmental trajectories of the prefrontal and limbic brain regions. The model suggests that the limbic region, associated with socioemotional processing, matures at a faster rate than the prefrontal region, associated with cognitive control. As a result, the adolescent brain may become functionally biased towards the limbic system during periods of high arousal, leading to increased emotional reactivity and decreased emotion regulation (Casey et al., 2008). Casey and colleagues have proposed that this difference in the rate of maturation among different brain regions may be driven by puberty.

Alternatively, Bronfenbrenner's Ecological Systems Theory posits that an individual's development is dependent on the interaction of various ecosystems, each broader than the last. These include the microsystem (e.g. family, school, peers), the exosystem (e.g. extended family, government, socioeconomic conditions), the macrosystem (e.g. culture), and the chronosystem (e.g. environmental changes over the lifespan) (Bronfenbrenner, 1977). According to this theory, a child's development is not dictated simply by the maturation of the brain or by the child's environment, but by the complex interaction of the two. When considering this approach, it is possible that the development of emotional difficulties during pubertal development is thus a result of an interaction between rapid biological changes and similarly sudden social changes, such as gaining more autonomy and transitioning to high school.

Past research has demonstrated an increase in the sensitivity and intensity of emotional responses throughout puberty, with some studies suggesting peaks in the mid- to late stage of puberty (e.g. Moore et al., 2012; Quevedo et al., 2009; Silk et al., 2009; Vijayakumar et al., 2019). As with emotional reactivity, pubertal development has been associated with an increase in emotion dysregulation (Ladouceur, 2012). Past research suggests that, in studies containing

samples from early adolescence to middle adulthood, an individual's repertoire of emotion regulation strategies tends to be at its lowest in middle adolescence (Zimmerman & Iwanski, 2014), coinciding with the pubertal period. An fMRI study conducted by Vijayakumar et al. (2019) has found an increase in left amygdala activation, an area associated with emotional reactivity (Schneider et al., 1997), when processing angry facial expressions during puberty. Vijayakumar et al. (2019) also found a decrease in nucleus accumbens activation, which has been previously shown to mediate the relation between ventrolateral prefrontal cortex (vlPFC) activity, a brain region associated with emotion regulation, and the success of reappraising emotions (Wager et al., 2008). This suggests that as nucleus accumbens activation decreases throughout puberty, the success of adolescents' emotion reappraisal may also decrease. Similarly, another fMRI study also found that mid-/late pubertal adolescents demonstrated less vlPFC activity when viewing fearful faces compared to pre-/early adolescents (Forbes et al., 2011).

However, not all studies find an association between pubertal development and increased emotional difficulties. For example, using an fMRI face-processing paradigm, Forbes et al. (2011) found that mid-/late pubertal adolescents, compared to pre-/early pubertal adolescents, exhibited less amygdala reactivity when viewing neutral faces, suggesting that pre-/early pubertal adolescents may more readily interpret neutral stimuli as threatening, and thus may be more emotionally reactive than their more developed counterparts. Alloy et al. (2016) also found no association between pubertal status and emotion regulation. Indeed, an experimental study conducted by Boivin et al. (2017) suggests that pubertal development may not be directly responsible for the increase in emotional difficulties during this period found by most studies. In their study, Boivin and colleagues used a mouse model in which mice either were given

hormones to induce early puberty or underwent surgery to prevent puberty altogether. They found that female mice did not show changes in their depression- and anxiety-related behaviours in either case (Boivin et al., 2017). However, male mice showed an increase in anxiety-related behaviour when puberty was prevented. Thus, based on the current literature, it is unclear how pubertal development and emotional difficulties are related.

When sex differences are examined, some research suggests that adolescent boys and girls differ in their levels of emotional difficulties. Past research has found that girls tend to be more emotionally reactive than boys, likely due to their earlier pubertal timing (Guyer et al., 2016). An ERP study conducted by Yang et al. (2018) found that puberty intensifies reactivity to negative stimuli for girls, but not for boys. Furthermore, Domes et al. (2010) found that males tended to up-regulate, or strengthen, their negative emotional responses more than females. When considered together, the literature suggests that although boys are initially less emotionally reactive than girls, they are more likely to demonstrate a strengthening of the intensity of their negative emotions. Thus, both boys and girls may demonstrate heightened emotional difficulties during pubertal development.

In addition to emotional difficulties, puberty has been associated with a delayed phase preference, thought to be driven by the combination of a delayed circadian rhythm and a slower build-up of homeostatic sleep pressure (Carskadon et al., 1993; Jenni et al., 2005). As adolescents progress through puberty, they tend to feel sleepy later in the night, resulting in an eveningness orientation, or an inclination to go to bed at a later time and wake up later (Foley et al., 2018; Pieters et al., 2010). This change can be problematic, however, when adolescents must wake up early to attend school or participate in extracurricular activities. In this way, puberty has been associated with increased sleep problems, in part due to a conflict between adolescents'

delayed phase preference and the need to wake up early to attend school (Carskadon et al., 1993). Past research has consistently demonstrated that a more advanced pubertal status is associated with a variety of poor sleep indicators, including a later weekday and weekend bedtime, delayed sleep onset, reduced sleep time, increased number of night awakenings, and excessive daytime sleepiness (e.g. Carskadon et al., 1993; Holm et al., 2009; Lin et al., 2018; Liu et al., 2019; Pieters et al., 2010; Sadeh et al., 2009).

Although there is a general consensus that adolescents experience more sleep problems as they progress through puberty, the exact nature of those problems is sometimes questioned. For example, Laberge et al. (2001) did not find an association between pubertal status and adolescents' weekday bedtimes and wake times. However, the authors did find that more advanced pubertal adolescents went to bed later and woke up later on week*ends*. Similarly, Holm et al. (2009) did not find a significant relation between pubertal status and sleep onset. Instead, the authors found that more advanced pubertal adolescents slept less than their less advanced counterparts. Thus, the relation between pubertal development and different types of sleep problems is uncertain. However, for the purpose of this study, I was interested in how puberty is related to sleep problems *overall*, rather than to specific types of sleep problems. Furthermore, using a structural equation modeling approach, Sadeh et al. (2009) examined how puberty and sleep problems are related over two years. Although they found a within-time association between pubertal status and various sleep problems, the same was not true for change over time. The authors found that pubertal status at Time 1 did not predict sleep problems at Time 2 (Sadeh et al., 2009). These results suggest that although pubertal development and increased sleep problems may occur at the same time, puberty may not be the main factor related to the increases in sleep problems. Therefore, based on the current literature, it is unclear what role pubertal

development plays in the increase of sleep problems during this period.

When sex differences are examined, the results also have been mixed. Some studies report that girls tend to sleep longer and with less fragmentation than boys (Franco et al., 2020), while others report that girls sleep less than boys during weekdays and have a greater discrepancy between their weekday and weekend sleep durations (Foley et al., 2018; Lin et al., 2018). A study by Liu et al. (2019) also found that, compared to boys, girls were more vulnerable to excessive daytime sleepiness during puberty. Furthermore, some studies have found significant associations between pubertal development and an eveningness orientation for girls, but not for boys (Carskadon et al., 1993; Foley et al., 2018). In contrast, some studies find no sex differences in sleep problems during puberty (Pieters et al., 2010; Sadeh et al., 2009). Thus, although both boys and girls may exhibit sleep problems during puberty, it is unclear whether sex differences exist and how they may manifest.

Considering that both sleep problems and emotional difficulties are thought to increase during puberty, it is possible that their trajectories are associated with one another. Past research with children and adults has demonstrated a positive, bidirectional relationship between sleep problems and emotional difficulties, such that higher levels of one variable predict increases in the other (e.g. Baum et al., 2014; Reidy et al., 2016; Reynolds & Alfano, 2016; Tavernier et al., 2015). However, this association has not been examined during pubertal development, a time when difficulties with both sleep and emotion are hypothesized to increase (Franco et al., 2020; Guyer et al., 2016). Furthermore, although past research has demonstrated associations between puberty and the development of both sleep problems and emotional difficulties separately, these associations have not been considered together.

The aim of this three-year longitudinal study is to build on past research by investigating

whether adolescents' pubertal status, level of sleep problems, and level of emotional difficulties at Time 1 predict subsequent changes in the developmental trajectories of sleep problems and emotional difficulties. Based on the mixed findings of previous literature, my research questions were exploratory.

Methods

Participants

The current sample included participants (N = 1284, age range = 7-14, 49.8% female) from several elementary and high schools in southern Ontario, Canada. Students were part of a larger study examining the relationship between wellbeing and youth health-risk behaviours and were surveyed annually for three years. Parent report indicated that 84.0% of the children and adolescents were White, 1.7% were Black, 2.1% were Asian, 2.8% were Hispanic, 0.9% Indigenous, and 7.6% were Mixed (an additional 0.9% of parents indicated that they preferred not to answer the question). Data on socioeconomic status indicated that the mean levels of education for parents was between "completed an associate degree/diploma" and "completed an undergraduate degree".

Procedure

Students were invited to participate in the study through visits to schools. The survey was split into two sections to reduce fatigue, with both sections completed within a one-month period between January and April. All the variables included in the current study, however, were in the second section of the survey. Trained research assistants administered the surveys to all students in classrooms during school hours. All students were provided a cardboard exam divider to help

provide privacy during the survey and received gifts (e.g., backpacks, pencils) as compensation. All students who completed the survey in the first year were invited to participate again in subsequent years. Participants provided informed assent, while their parents provided informed consent. This study was approved by the University Research Ethics Board.

Missing Data Analysis

Missing data occurred within each assessment because some participants did not answer every question in the survey (1.77%, 2.76%, and 2.36% missing in Years 1, 2, and 3 respectively) and because some participants did not complete the survey each year (see Table 1 for a summary of the latter missing data). A MANOVA examining whether there were any differences on the study variables between participants who completed one, two, or three waves of the survey was significant, Wilks = 7.865, $p < .001$, $\eta^2 = .036$. Participants who were present at only one of the three time points had higher scores on emotional difficulties and sleep problems, as well as a more advanced pubertal status than participants who were present at all three time points. Missing data were imputed using the expectation-maximization algorithm (EM) with all study variables included in the analysis. EM retains cases that have missing data, and thus avoids the biased parameter estimates that can occur with pairwise or listwise deletion (Schafer & Graham, 2002).

Measures

Demographics. Sex, age, and parental education were assessed at Time 1. It is important to note the limitation that sex was defined as male or female, with no intersex or other option. Meanwhile, age was measured in years, and parental education was defined as the average of

each parent or guardian's score on a scale of 1 (*did not finish high school*) to 6 (*graduate/professional degree*).

Pubertal Status. Pubertal status was assessed from Years 1 to 3 using the Pubertal Development Scale (PDS; Petersen et al., 1988). The PDS is a self-report measure that assesses pubertal-specific physiological changes. For boys, the PDS measures changes in body hair, facial hair, and voice. For girls, the PDS measures changes in body hair, menarche, and breast development. All items were rated on a 4-point scale from 1 (*not yet started changing*) to 4 (*change seems complete*). The PDS has been shown to demonstrate good reliability and validity (Carskadon & Acebo, 1993; Petersen et al., 1988). For boys, scores were summed such that a score of 3 was considered pre-puberty, a score of 4 or 5 (with no 3-point responses) was considered early puberty, a score of 6 to 8 (with no 4-point responses) was considered mid-puberty, and a score of 9 or more was considered late puberty. For girls, a summed score of 2 and no menarche was considered pre-puberty, a score of 3 and no menarche was considered early puberty, a score of 4 or more and no menarche was considered mid-puberty, and any score with menarche was considered late puberty (see Carskadon & Acebo, 1993 for scoring scheme).

Emotional Difficulties. Emotional difficulties were measured from Years 1 to 3 using a composite of two scales, namely the Emotional Reactivity Scale (ERS; Nock et al., 2008) and the Difficulties with Emotion Regulation Scale (DERS; Gratz & Roemer, 2004). The ERS asked participants to rate their level of agreement with statements regarding their emotional reactions ("My feelings get hurt easily"; "When I am angry/upset, it takes me a long time to calm down"; "When something bad happens, other people tell me I overreact") on a scale of 1 (*almost never*) to 4 (*almost always*). Cronbach's alpha across the three years ranged from 0.694 to 0.720. The DERS assessed how often participants had difficulty employing various emotion regulation

strategies when they are upset or stressed (“I have difficulty concentrating”; “I have difficulty thinking about anything else”; “I start to feel bad about myself”). All items were rated on a 4-point scale from 1 (*almost never*) to 4 (*almost always*). Cronbach’s alpha across the three years ranged from 0.786 to 0.852. The ERS and the DERS were significantly correlated, with correlations ranging between .551 and .575 across the three years, $p < .001$. Principal components analyses (PCA) including all of the ERS and DERS items, conducted separately for Years 1 and 2 revealed a one-factor solution explaining between 52.2% and 45.1% of the variance in item response respectively. The PCA from Year 3, however, revealed a two-factor solution, with the only item loading onto the second factor being the reverse-coded “I know that I can find a way to feel better”. The two-factor solution explained 61.3% of the variance in item response, while the one-factor solution in Year 3 explained 45.8% of the variance. Given that the results from Year 1 and 2 indicated a one-factor solution, we elected to keep the Year 3 items together as one factor as well. Thus, scores on the ERS and the DERS were averaged to form a composite measure of emotional difficulties, with higher scores indicating more emotional difficulties.

Sleep Problems. Sleep problems were assessed from Years 1 to 3 using items from the Insomnia Severity Index (ISI; Morin, 1993). Participants reported the severity of their problems regarding falling asleep, staying asleep, getting up in the morning, and being sleepy during the day on a 4-point scale from 1 (*almost never*) to 4 *(almost always*). The ISI has exhibited good reliability and validity (Morin et al., 2011; Bastien et al., 2001). Responses were scored as a composite of the four sleep items, with higher scores indicating more sleep problems. Cronbach’s alphas across the three years ranged from 0.644 to 0.742.

Plan of Analysis

I conducted growth curve analyses using Mplus 8 (Muthén & Muthén, 2012) to examine the 3-year association among pubertal status, emotional difficulties, and sleep problems. The growth curve analyses assessed whether the linear trajectories of emotional difficulties, sleep problems, and pubertal status changed across the three years and by examining whether participants' pubertal status at Year 1 predicted changes in emotional difficulties and sleep problems over time, whether sleep problems at Year 1 predicted changes in emotional difficulties over time, and whether emotional difficulties at Year 1 predicted changes in sleep problems over time. Specifically, the model factor loadings on all latent intercept factors were fixed at 1 for all three years. The factor loadings on all latent slope factors were fixed at 0 for the first year, 1 for the second year, and 2 for the third year. All latent factor means, variances, and covariances were freely estimated, as were all residual variances. However, for both boys and girls, pubertal status in Year 3 showed a non-significant residual variance. As per recommendations by Bengt Muthén (2005) for non-significant variances, pubertal status in Year 3 was fixed to 0 for both the boys' and girls' growth curve model. Model fit was evaluated using the comparative fit index (CFI) and the root mean squared error of approximation (RMSEA; Bentler, 1995). As recommended by Hu and Bentler (1999), CFI values greater than .95 and RMSEA estimates less than .06 were simultaneously used as the criteria for a well-specified or close-fitting model. Due to previously reported sex differences in pubertal development, emotional difficulties, and sleep problems (Susman et al., 2010; Domes et al., 2010; Guyer et al., 2016; Franco et al., 2020), analyses were conducted separately by sex. Thus, the final statistical analysis consisted of one growth curve model for boys and one model for girls (see Figure 1). All analyses controlled for participants' age and parental education by including both variables as correlates of all latent intercept factors

and as predictors of all latent slope factors. The results are reported as model estimates with corresponding 95% confidence intervals and p-values.

Results

Table 2 presents means and standard deviations for the study variables. Bivariate correlations of the study variables are provided in Figure 2. All measures showed acceptable skewness and kurtosis. Age was significantly correlated with pubertal status, emotional difficulties, and sleep problems at all time points for girls, such that older girls were more likely to report a more advanced pubertal status and more difficulties with sleep and emotion (all p's < .01). For boys, age was significantly correlated with pubertal status at all time points, with older boys more likely to report a more advanced pubertal status (all p's < .01). Unlike the girls, however, the boys' age was significantly correlated only with sleep problems in Year 3, such that older boys were more likely to report greater difficulty with sleep (p < .05). Parental education was significantly correlated with both emotional difficulties and sleep problems at all time points for both boys and girls, such that those with higher parental education were more likely to report fewer emotional difficulties and sleep problems (all p's < .05 for emotional difficulties and all p's < .01 for sleep problems).

Boys

Model Results. Latent growth curve modeling was used to estimate individual trajectories of pubertal status, emotional difficulties, and sleep problems across the three years. Two latent factors were estimated for each variable: the intercept (starting point) and slope (rate of change over time). The model for boys had a CFI of .992 and an RMSEA of .038, indicating a close-fitting model (Hu & Bentler, 1999). The model indicated that there was significant

variability in the intercepts for emotional difficulties, sleep problems, and pubertal status (all *p*'s < .001), indicating that boys differed in their levels of these variables at Time 1. Furthermore, the means of the slopes for pubertal status and sleep problems were positive (0.480 and 0.058 respectively) and significantly different from zero (all *p*'s < .001), indicating that, on average, there was an increase in pubertal status and sleep problems over time. In contrast, the mean of the slope for emotional difficulties was not significantly different from zero ($p = .073$). There was significant variability in the slopes for pubertal status ($p < .001$) and emotional difficulties ($p = .006$), indicating that the rate of change over time for these variables differed among boys. The variability in the slope for sleep problems, however, was not significant ($p = .073$), suggesting that the rate of change over time did not differ significantly among the boys. Tables 3 through 6 and Figure 3 present the full model results.

Associations with Pubertal Status. The growth curve model demonstrated that the intercept of pubertal status was not significantly associated with the slope of emotional difficulties, $B = .029$ [-.016, .074], $p = .202$. Unexpectedly, the intercepts of pubertal status and emotional difficulties also did not significantly covary, $B = -.032$ [-.081, .017], $p = .203$. This may be due to the more limited variance in initial pubertal status for boys, as 46.4% of the sample was in pre-puberty at Time 1.

Similarly, the intercept of pubertal status was not significantly associated with the slope of sleep problems, $B = -.023$ [-.072, .027], $p = .363$. The intercepts of pubertal status and sleep problems also did not significantly covary, $B = -.002$ [-.050, .046], $p = .924$. Again, this may be due to the more limited variance in initial pubertal status for boys, as 46.4% of the sample was in pre-puberty at Time 1. Furthermore, the slope of pubertal status did not covary with the slope of emotional difficulties, $B = -0.001$ [-.011, .009], $p = .832$, or the slope of sleep problems, $B =$ -

.003 [-.023, .009], p = .562.

Sleep Problems and Emotional Difficulties. The growth curve model showed that the intercept of sleep problems was significantly associated with the slope of emotional difficulties, B = -.150 [-.228, -.072], p < .001. I found that the more sleep problems a participant had at Time 1, the less steep their increase in emotional difficulties was over time. Similarly, the intercept of emotional difficulties was significantly associated with the slope of sleep problems for boys, B = -.109 [-.170, -.047], p = .001. The more emotional difficulties a participant had at Time 1, the less steep their increase in sleep problems over time. Both the intercepts and slopes of sleep problems and emotional difficulties also covaried significantly, B = .177 [.140, .213], p < .001 and B = .018 [.008, .028], p < .001 respectively. Thus, participants with higher levels of sleep problems at Time 1 were also likely to have higher levels of emotional difficulties at that time. Furthermore, those with steeper increases in their level of sleep problems were more likely to experience steeper increases in their levels of emotional difficulties.

Age Removed. Correlations between age and pubertal status were high at all time points, ranging from .647 to .732 (all p's < .01). Consequently, the model was rerun without age and similar results were found. The only difference between the model with and without age was that, in the model without age, the intercept of pubertal status was significantly associated with the slope of emotional difficulties, B = .028 [.000, .055], p = .047.

Girls

Model Results. Latent growth curve modeling was used to estimate individual trajectories of pubertal status, emotional difficulties, and sleep problems across the three years. Two latent factors were estimated for each variable: the intercept (starting point) and slope (rate of change over time). The model for girls had a CFI of .986 and an RMSEA of .056, indicating a

close-fitting model (Hu & Bentler, 1999). The model indicated that there was significant variability in the intercepts for emotional difficulties, sleep problems, and pubertal status (all *p*'s < .001), indicating that girls differed in their levels of these variables at Time 1. Furthermore, the means of the slopes for pubertal status, emotional difficulties, and sleep problems were positive (0.469, 0.061, and 0.084 respectively) and significantly different from zero (all *p*'s < .001), indicating that, on average, there was an increase in pubertal status, emotional difficulties, and sleep problems over time. Overall, there was significant variability in the slopes for pubertal status, emotional difficulties, and sleep problems (all *p*'s < .001), indicating that the rate of change over time differed among girls. Tables 7 through 10 and Figure 4 present the full model results.

Associations with Pubertal Status. Similar to the boys, the results of the girls' growth curve model showed that the intercept of pubertal status was not significantly associated with the slope of emotional difficulties, *B* = -.011 [-.054, .033], *p* = .627. However, the intercepts of emotional difficulties and pubertal status covaried significantly, *B* = .186 [.118, .255], *p* < .001. Therefore, based on my results, although girls with a more advanced pubertal status had higher levels of emotional difficulties than girls with a less advanced pubertal status at Time 1, it appears that puberty itself may not be related to an increase of emotional difficulties during this period.

However, the intercept of pubertal status was significantly associated with a steeper slope of sleep problems, *B* = .083 [.035, .130], *p* = .001. In other words, a more advanced pubertal status at Time 1 was associated with a steeper increase in sleep problems over time. The intercepts of pubertal status and sleep problems also significantly covaried, *B* = .095 [.030, .160], *p* = .004. Furthermore, the slope of pubertal status did not covary with the slope of emotional

difficulties, B = .004 [-.005, .012], p = .391. However, the slope of pubertal status did covary with the slope of sleep problems, B = .079 [.065, .093], p < .001.

Sleep Problems and Emotional Difficulties. Contrary to the boys, the results of the girls' growth curve model revealed that the intercept of sleep problems was not significantly associated with the slope of emotional difficulties, B = -.054 [-.111, .003], p = .065. However, the intercept of emotional difficulties was significantly associated with the slope of sleep problems for girls, B = -.117 [-.167, -.066], p < .001. Specifically, the more emotional difficulties a participant had at Time 1, the less steep their increase in sleep problems over time. As with the boys, the intercepts of sleep problems and emotional difficulties covaried significantly for the girls, B = .212 [.171, .252], p < .001. Thus, participants with higher levels of sleep problems at Time 1 were also likely to have higher levels of emotional difficulties at that time.

Age Removed. Correlations between age and pubertal status were high at all time points, ranging from .637 to .809 (all p's < .01). Consequently, the model was rerun without age and no differences between the model with and without age were found.

Discussion

Puberty is a developmental period thought to be associated with increases in difficulties with sleep and emotion (Franco et al., 2020; Guyer et al., 2016). Despite similar timing in the onset and exacerbation of these issues, previous research has not examined the association of pubertal development with sleep problems and emotional difficulties among adolescents. The current study aimed to address this gap in the literature by investigating the longitudinal relationships among pubertal status, sleep problems, and emotional difficulties. Specifically, the present study examined whether adolescents' pubertal status, level of sleep problems, and level

of emotional difficulties at Time 1 would predict subsequent changes in the developmental trajectories of sleep problems and emotional difficulties.

Contrary to most previous studies, I did not find a significant increase in emotional difficulties over the three years for boys. This discrepancy in results may be partially explained by the fact that my sample was fairly homogenous in terms of demographics. My participants consisted of boys who did not report many challenges with emotion, as the mean remained fairly low at all time points, ranging from 1.972 to 1.993. Consequently, the results of this study must be considered with this lack of change in emotional difficulties among boys in mind.

When associations between pubertal status and emotional difficulties were considered, for both boys and girls, the results were the same. Specifically, the intercept of pubertal status was not associated with changes in emotional difficulties over time, in line with previous research that found no relation between puberty and increased emotional difficulties (e.g. Alloy et al., 2016; Boivin et al., 2017; Forbes et al., 2011). This finding suggests that puberty may not be related to the increase in emotional difficulties observed in other studies at this developmental stage. Instead, it is possible that a third variable not measured in this study is associated with both pubertal development and emotional difficulties. One potential explanation is the various hormonal and neural changes associated with both variables. For example, increases in the volume and activation of the bilateral hippocampus have been linked to advanced pubertal status and increased emotional difficulties separately (Ellis et al., 2019; Vijayakumar et al., 2019). Future studies would benefit from investigating the potential roles of these variables in the onset of pubertal development and emotional difficulties together.

The results between boys and girls diverged when considering the association between pubertal status and sleep problems. For boys, the intercept of pubertal status was not associated

with changes in sleep problems over time. As with emotional difficulties, these results suggest that, for boys, puberty may not be directly related to difficulties with sleep that may arise at this developmental stage. My results are similar to those of Sadeh et al. (2009), who also found that pubertal status did not predict subsequent changes in sleep problems over time. Although my results appear to contradict some past research that has found a relation between puberty and sleep problems, it is important to note that most studies in this area investigate a single type of sleep problem, most often bedtimes, wake times, and sleep times. These studies often find associations between puberty and bedtimes, wake times, and sleep times (e.g., Carskadon et al., 1993; Foley et al., 2018; Lin et al., 2018). However, my measure of sleep problems was more holistic, covering a variety of challenges, including sleep onset, night awakenings, inertia upon waking, and excessive daytime sleepiness. When studies include more holistic measures of sleep problems, such as Sadeh et al. (2009), the results tend to be more mixed. For example, although Pieters et al. (2010) found that pubertal development was associated with an eveningness preference, they also found no relation between puberty and sleep onset. Consequently, it is possible that pubertal status may be associated with sleep time, but not with sleep problems more generally. Thus, any associations with sleep problems may be specific to the consequences of sleeping less. For example, adolescents who sleep less may also exhibit excessive daytime sleepiness as a result, but may not generally have difficulties falling or staying asleep. However, further research is needed to explore this possibility.

Meanwhile, for girls, the intercept of pubertal status was associated with steeper increases in sleep problems over time. This suggests that as girls progress through puberty, they may be more vulnerable than boys to developing sleep problems. Findings from Liu et al. (2019) may help explain the difference in results between boys and girls. The researchers found that an

eveningness preference among girls, but not among boys, was associated with both an advanced pubertal status and increased excessive daytime sleepiness. However, morningness acted as a protective factor, such that girls with a morningness orientation were less likely to report excessive daytime sleepiness regardless of pubertal status (Liu et al, 2019). Thus, girls, in particular, may be especially vulnerable to developing sleep problems such as excessive daytime sleepiness during pubertal development, as several studies have found an association between a delayed phase preference (i.e., an eveningness preference) and pubertal status in girls, but not in boys (Carskadon et al., 1993; Foley et al., 2018; Liu et al., 2019). This has implications for the implementation of interventions for sleep problems, which may be best targeted to girls in early puberty. One such potential intervention lies in the realm of education, specifically school start times. Girls' development of an eveningness preference may conflict with the increasingly earlier school start times at this stage in development. Consequently, delaying school start times may be an effective intervention for preventing the onset of sleep problems for girls during puberty. Furthermore, the slope of pubertal status covaried with the slope of sleep problems over time, suggesting that the speed with which girls progress through puberty may be related to their development of sleep problems. This highlights an important issue for research on pubertal development. To better parse the associations between puberty and other variables, it is crucial to measure both pubertal status and the rate of pubertal development to tease apart potentially disparate relationships.

Finally, when examining the relation between emotional difficulties and sleep problems during puberty, we found that higher levels of sleep problems at Time 1 were associated with slower increases in emotional difficulties over time for boys, but not girls. The inverse direction was also found, in that higher levels of emotional difficulties at Time 1 were associated with

slower increases in sleep problems over time for both boys and girls. Unexpectedly, participants with lower levels of emotional difficulties or sleep problems at Time 1 showed more rapid increases in the other variable than those with initially higher levels. It is possible that these results demonstrate a regression to the mean, whereby those with lower scores are moving more quickly towards a potentially normative level for each variable. Studies with a more heterogeneous sample may potentially observe more variability in emotional difficulties and sleep problems over time.

Due to the high correlation between age and pubertal status in my sample, I ran the models both with and without age. For girls, no differences were found between the models. For boys, the models were similar with the exception that, in the model without age, pubertal status at Time 1 was significantly associated with a steeper, positive slope of emotional difficulties over time. Based on my results, it is unclear whether the association with emotional difficulties is attributable to pubertal-specific processes or other biological or social factors. It may be possible that the link to emotional difficulties is due to increased testosterone during puberty (Matchock et al., 2007), as heightened testosterone levels have been previously associated with lower emotion regulation in adult males (Volman et al., 2011). However, it may also be the case that the association with emotional difficulties is due to the increase in bullying and aggressive behaviour observed during the transition to high school (Pellegrini, 2002; Pellegrini & Long, 2002), which accompanies the pubertal period. This transitory period has important implications for education, as educators may be able to play a significant role in the reduction emotional problems in boys by intervening in observed instances of bullying and aggression. Future studies would benefit from teasing apart the biological and social changes that occur during this transition.

While this study contributes to my understanding of sleep problems and emotional difficulties during puberty, it is important to acknowledge its limitations. First, the results may have limited generalizability, as the participants represent a relatively homogenous sample in terms of demographics. Consequently, the results may differ when other factors associated with the study variables are considered. For example, my sample consisted primarily of adolescents from middle class backgrounds. However, research has linked a lower socioeconomic status to earlier onset of puberty, heightened emotional difficulties, and increased sleep problems (e.g. Arim et al., 2011; Bøe et al., 2012; Bøe et al., 2014). Thus, my results may not be generalizable to adolescents from lower socioeconomic backgrounds. Second, there was more limited variance in initial pubertal status for the boys, with 46.4% being in pre-puberty at Time 1. Consequently, my results may under-represent the relations between pubertal status and emotional difficulties and sleep problems for boys. Third, the measure of emotional reactivity did not include questions on positive emotions. Previous studies have found that positive emotional reactivity may play a stronger role than negative emotional reactivity in the relation with sleep problems in adolescence (Alfano et al., 2020; Short et al., 2020; Simon et al., 2020). In other words, researchers have demonstrated that lower positive emotional reactivity (e.g. fewer, less intense, and short-lived positive emotions) may be more strongly related to adolescent sleep problems than heightened negative emotional reactivity (e.g. frequent, more intense, and long-lasting negative emotions). It is important to note that positive and emotional reactivity do not exist as opposite ends of a continuum, such that increases in one lead to decreases in the other. It is possible, for example, for an individual to have both blunted positive *and* negative emotional reactivity simultaneously. Such an individual would be described as being unable to experience heightened emotions in general. Thus, given the differential associations of positive and negative

emotional reactivity found in past studies, future research would benefit from including both positive and negative emotional reactivity in measurements of emotional difficulties.

Despite its limitations, this study was the first to use a longitudinal design to investigate the associations among pubertal status, sleep problems, and emotional difficulties together in one model. I found that emotional difficulties did not increase significantly across the three years for boys, perhaps due to the homogenous nature of my sample. Keeping this lack of significant change in emotional difficulties over time for boys in mind, my results suggest that, for both boys and girls, puberty may not be related to increases in emotional difficulties at this age period. Pubertal development may also not be related to increases in sleep problems for boys. Meanwhile, the latter stages of puberty may be a time of onset for sleep problems in girls. Based on these findings, interventions meant to prevent the onset of sleep problems in girls may be most effective when implemented in the early stages of puberty. Furthermore, I found that, as in childhood and adulthood (e.g., Alfano, 2016; Baum et al., 2014; Reidy et al., 2016; Reynolds & Tavernier et al., 2015), sleep problems and emotional difficulties continue to share a bidirectional relation during puberty. Overall, the results of this study highlight the importance of an early and targeted approach to intervention for sleep problems in girls.

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Table 1
Missing data for the study variables from Year 1 to Year 3.

	Year 1	Year 2	Year 3
Percent of students who completed the second section of the survey[1]	84.5	81.8	74.5
Percent of students that did not start study until Year 2	6.4	N/A	N/A
Percent of students that were absent from class on day the second section of survey was done	9.1	9.0	10.5
Percent missing because RA mistakenly did not invite students to complete second section of the survey	0	1.2	3.7
Percent of students that declined to complete the second section of the survey	0	0.8	0.2
Percent of students that dropped out of the study	0	0.7	0.6
Percent of students that moved out of the school district with no contact information	0	6.5	10.5

Total % of students (N = 1284)	100	100	100

Note. [1]Each year the survey was split into two parts that were completed at different time periods in order to prevent student fatigue. All study variables were contained in the second section of the survey. Abbreviations are N/A = Not applicable.

Table 2
Study variables.

		Overall (*N* = 1284)	Boys (*N* = 644)	Girls (*N* = 640)
	Scale	Mean ± SD	Mean ± SD	Mean ± SD
Age (Years)	N/A	10.713 ± 1.734	10.602 ± 1.685	10.826 ± 1.778
Parental Education	1 – 6	4.104 ± 0.723	4.132 ± 0.766	4.077 ± 0.676
Pubertal Status T1	1 – 4	2.219 ± 1.140	1.910 ± 0.955	2.530 ± 1.224
Pubertal Status T2	1 – 4	2.699 ± 1.077	2.357 ± 0.957	3.041 ± 1.082
Pubertal Status T3	1 – 4	3.183 ± 0.911	2.887 ± 0.874	3.479 ± 0.849
Emotional Difficulties T1	1 – 5	2.047 ± 0.666	1.993 ± 0.650	2.101 ± 0.678
Emotional Difficulties T2	1 – 5	2.045 ± 0.619	1.988 ± 0.588	2.103 ± 0.644
Emotional Difficulties T3	1 – 5	2.079 ± 0.591	1.972 ± 0.527	2.187 ± 0.632
Sleep Problems T1	1 – 5	2.117 ± 0.688	2.077 ± 0.685	2.157 ± 0.689
Sleep Problems T2	1 – 5	2.181 ± 0.657	2.134 ± 0.605	2.223 ± 0.702
Sleep Problems T3	1 – 5	2.259 ± 0.667	2.194 ± 0.629	2.325 ± 0.697

Note. Abbreviations are SD = Standard deviation; T = Time.

Table 3
Latent growth curve parameter means and variances for boys.

Parameter	Mean	*p*-value of Mean	Variance	*p*-value of Variance
Pubertal $Status_{int}$	1.905	.000	0.852	.000
Pubertal $Status_{slope}$	0.480	.000	0.152	.000
Emotional $Difficulties_{int}$	1.806	.000	0.315	.000
Emotional $Difficulties_{slope}$	0.023	.073	0.031	.006
Sleep $Problems_{int}$	2.077	.000	0.234	.000
Sleep $Problems_{slope}$	0.058	.000	0.023	.073
Age	10.601	.000	2.833	.000
Parental Education	4.132	.000	0.586	.000

Note. Abbreviations are int = Intercept.

Table 4
Covariance among latent growth curve parameters for boys.

Parameter	1	2	3	4	5	6	7	8
1. Pubertal $Status_{int}$	-							
2. Pubertal $Status_{slope}$	-0.160***	-						
3. Emotional $Difficulties_{int}$	-0.032	0.004	-					
4. Emotional $Difficulties_{slope}$	0.024*	-0.001	-0.058***	-				
5. Sleep $Problems_{int}$	-0.002	-0.010	0.177***	-0.035***	-			
6. Sleep $Problems_{slope}$	0.029*	-0.003	-0.034***	0.018***	-0.027	-		
7. Age	1.177***	-0.126***	-0.068	0.046*	-0.095*	0.086***	-	
8. Parental Education	-0.033	0.009	-0.084***	0.015	-0.085***	0.001	0.051	-

Note. Parameters are unstandardized estimates. *p < .05. **p < .01. ***p < .001. Abbreviations are int = Intercept.

Table 5
Correlations among latent growth curve parameters for boys.

Parameter	1	2	3	4	5	6	7	8
1. Pubertal $Status_{int}$	-							
2. Pubertal $Status_{slope}$	-0.444***	-						
3. Emotional $Difficulties_{int}$	-0.062	0.017	-					
4. Emotional $Difficulties_{slope}$	0.146	-0.016	-0.584***	-				
5. Sleep $Problems_{int}$	-0.005	-0.051	0.650***	-0.414***	-			
6. Sleep $Problems_{slope}$	0.204	-0.056	-0.401**	0.655*	-0.368**	-		
7. Age	0.758***	-0.192***	-0.072	0.154*	-0.117*	0.335**	-	
8. Parental Education	-0.047	0.031	-0.195***	0.108	-0.230***	0.012	0.039	-

Note. Parameters are unstandardized estimates. *$p < .05$. **$p < .01$. ***$p < .001$. Abbreviations are int = Intercept.

Table 6
Associations between latent growth curve parameters for boys.

	Slope of Emotional Difficulties				Slope of Sleep Problems			
	B [95% CI]	SE	*β* [95% CI]	*p*	*B* [95% CI]	SE	*β* [95% CI]	*p*
Pubertal Status$_{int}$	0.029 [-0.016, 0.074]	0.023	0.152 [-0.086,0.391]	.202	-0.023 [-0.072, 0.027]	0.025	-0.138 [-0.443, 0.167]	.363
Emotional Difficulties$_{int}$	-	-	-	-	-0.109 [-0.170, -0.047]	0.031	-0.397 [-0.689, -0.105]	.001
Sleep Problems$_{int}$	-0.150 [-0.228, -0.072]	0.040	-0.410 [-0.647, -0.172]	.000	-	-	-	-
Age	-0.001 [-0.025, 0.023]	0.012	-0.010 [-0.241, 0.221]	.931	0.038 [0.011, 0.064]	0.013	0.414 [0.063, 0.766]	.005
Parental Education	0.005 [-0.029, 0.039]	0.017	0.022 [-0.126, 0.169]	.773	-0.018 [-0.055, 0.019]	0.019	-0.089 [-0.279, 0.102]	.348

Note. Abbreviations are SE = Standard error; int = Intercept.

Table 7
Latent growth curve parameter means and variances for girls.

Parameter	Mean	*p*-value of Mean	Variance	*p*-value of Variance
Pubertal $Status_{int}$	2.536	.000	1.414	.000
Pubertal $Status_{slope}$	0.469	.000	0.211	.000
Emotional $Difficulties_{int}$	1.917	.000	0.410	.000
Emotional $Difficulties_{slope}$	0.061	.000	0.050	.000
Sleep $Problems_{int}$	2.154	.000	0.324	.000
Sleep $Problems_{slope}$	0.084	.000	0.051	.000
Age	10.826	.000	3.155	.000
Parental Education	4.076	.000	0.456	.000

Note. Abbreviations are int = Intercept.

Table 8
Covariance among latent growth curve parameters for girls.

Parameter	1	2	3	4	5	6	7	8
1. Pubertal $Status_{int}$	-							
2. Pubertal $Status_{slope}$	-0.380***	-						
3. Emotional $Difficulties_{int}$	0.186***	-0.049***	-					
4. Emotional $Difficulties_{slope}$	0.010	0.002	-0.079***	-				
5. Sleep $Problems_{int}$	0.095**	-0.018	0.212***	-0.019*	-			
6. Sleep $Problems_{slope}$	0.079***	-0.019**	-0.035***	0.019***	-0.045**	-		
7. Age	1.768***	-0.409***	0.148**	0.028	0.128**	0.101***	-	
8. Parental Education	-0.024	0.000	-0.087***	0.015	-0.101***	0.014	-0.019	-

Note. Parameters are unstandardized estimates. *p < .05. **p < .01. ***p < .001. Abbreviations are int = Intercept.

Table 9
Correlations among latent growth curve parameters for girls.

Parameter	1	2	3	4	5	6	7	8
1. Pubertal $Status_{int}$	-							
2. Pubertal $Status_{slope}$	-0.696***	-						
3. Emotional $Difficulties_{int}$	0.245***	-0.166***	-					
4. Emotional $Difficulties_{slope}$	0.036	0.016	-0.553***	-				
5. Sleep $Problems_{int}$	0.140**	-0.069	0.580***	-0.146*	-			
6. Sleep $Problems_{slope}$	0.296***	-0.187**	-0.240**	0.366***	-0.350***	-		
7. Age	0.837***	-0.501***	0.130**	0.071	0.126**	0.252***	-	
8. Parental Education	-0.030	0.000	-0.201***	0.101	-0.264***	0.091	-0.016	-

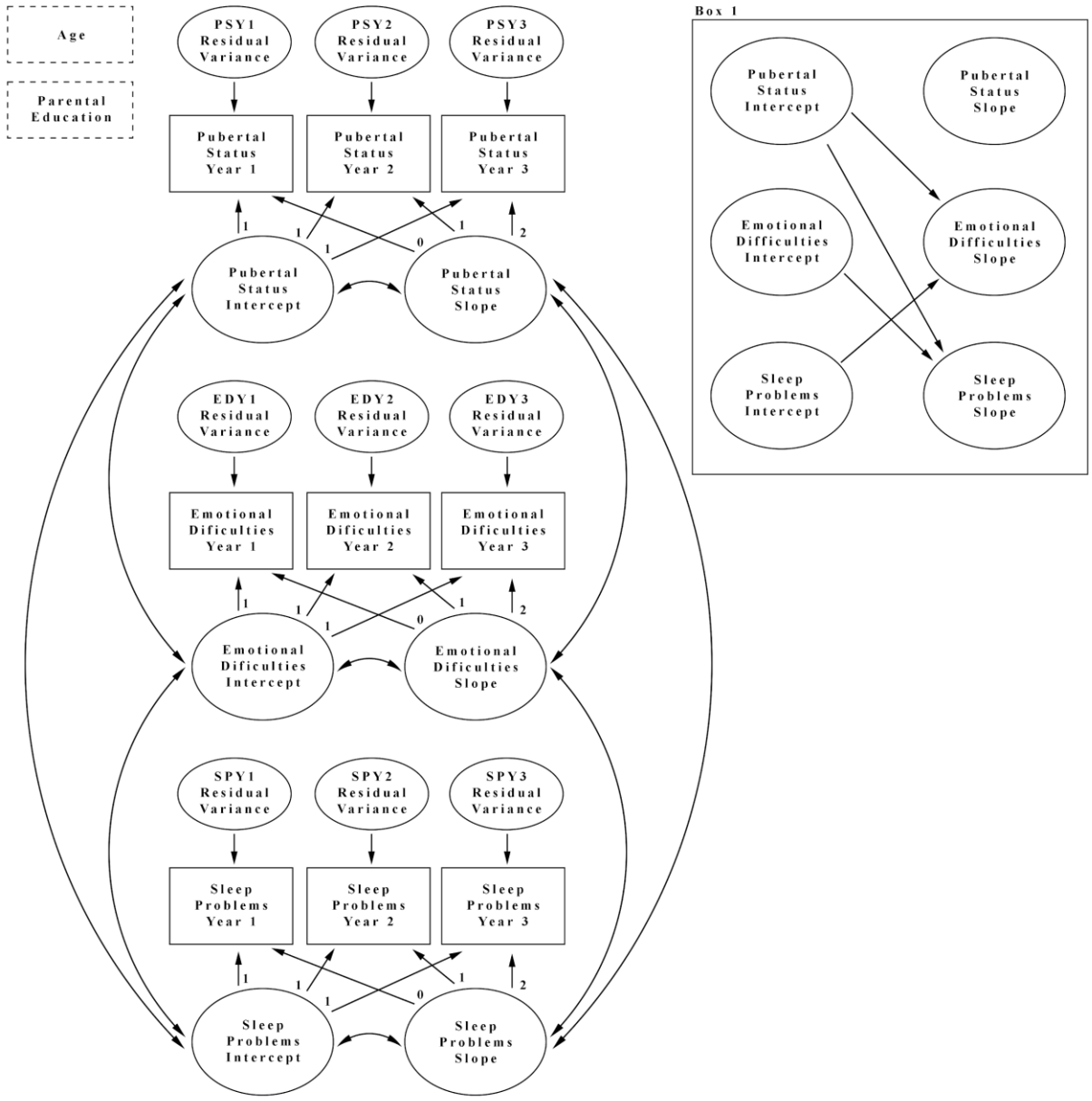
Note. Parameters are unstandardized estimates. *$p < .05$. **$p < .01$. ***$p < .001$. Abbreviations are int = Intercept.

Table 10
Associations between latent growth curve parameters for girls.

	Slope of Emotional Difficulties				Slope of Sleep Problems			
	B [95% CI]	SE	*β* [95% CI]	*p*	*B* [95% CI]	SE	*β* [95% CI]	*p*
Pubertal $Status_{int}$	-0.011 [-0.054, 0.033]	0.022	-0.057 [-0.287, 0.173]	.627	0.083 [0.035, 0.130]	0.024	0.436 [0.172, 0.699]	.001
Emotional $Difficulties_{int}$	-	-	-	-	-0.117 [-0.167, -0.066]	0.026	-0.330 [-0.484, -0.176]	.000
Sleep $Problems_{int}$	-0.054 [-0.111, 0.003]	0.029	-0.138 [-0.284, 0.009]	.065	-	-	-	-
Age	0.017 [-0.011, 0.045]	0.014	0.137 [-0.087, 0.361]	.230	-0.009 [-0.039, 0.021]	0.015	-0.070 [-0.306, 0.166]	.561
Parental Education	0.022 [-0.018, 0.062]	0.020	0.066 [-0.055, 0.187]	.286	0.012 [-0.028, 0.052]	0.020	0.037 [-0.083, 0.157]	.549

Note. Abbreviations are SE = Standard error; int = Intercept.

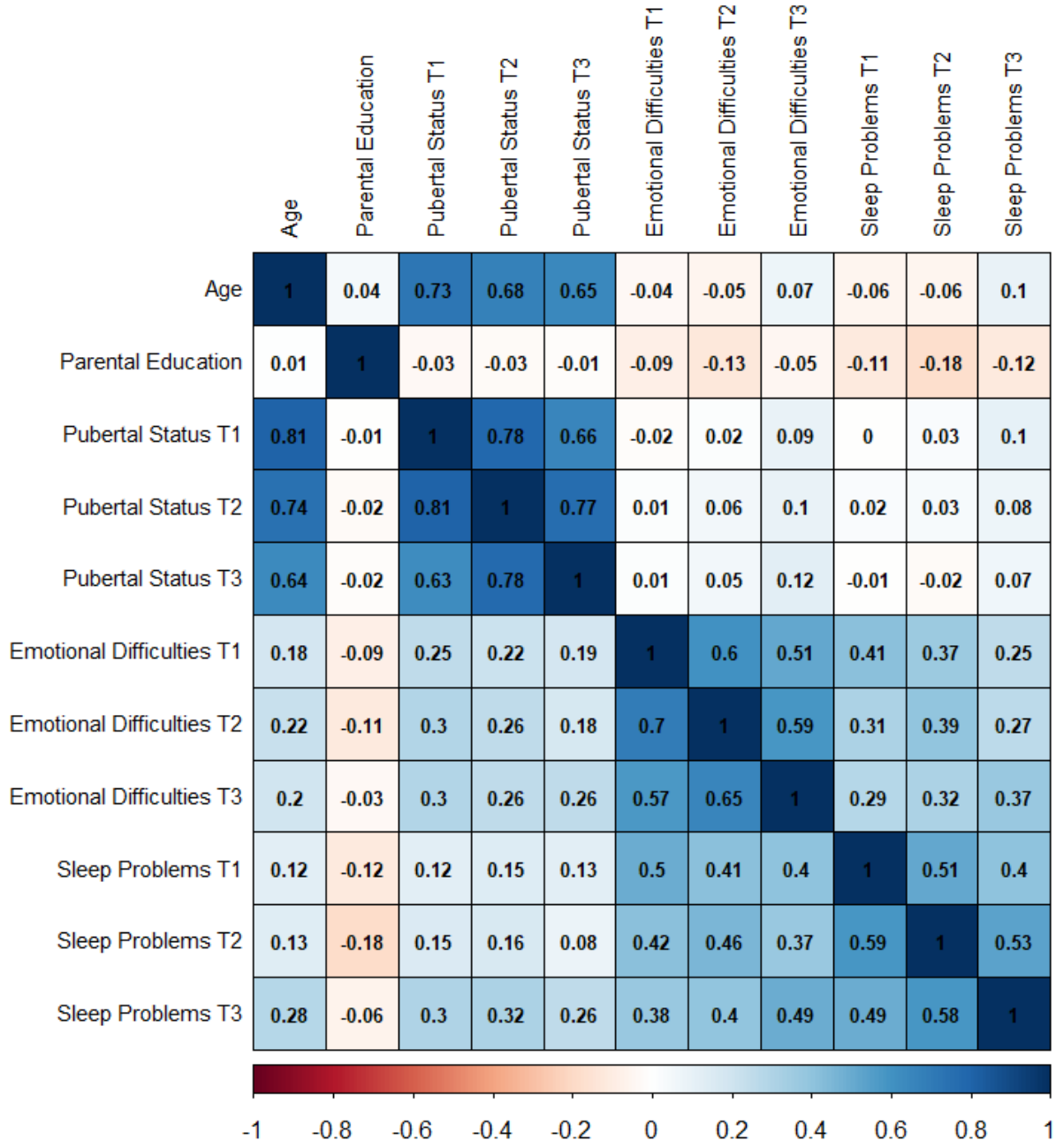
Figure 1
Growth curve assessment model per sex.



Note. Covariates are indicated with dashed lines. Not shown are paths from the covariates to the study variables. For ease of interpretation, Box 1 presents paths not present in the larger figure, but included in the analysis.

Figure 2

Bivariate correlations of study variables.



Note. Correlations for boys are above the midline, while correlations for girls are below. Correlations of |.080| and greater are significant. Abbreviations are T = Time.

Figure 3

Growth curve model for boys.

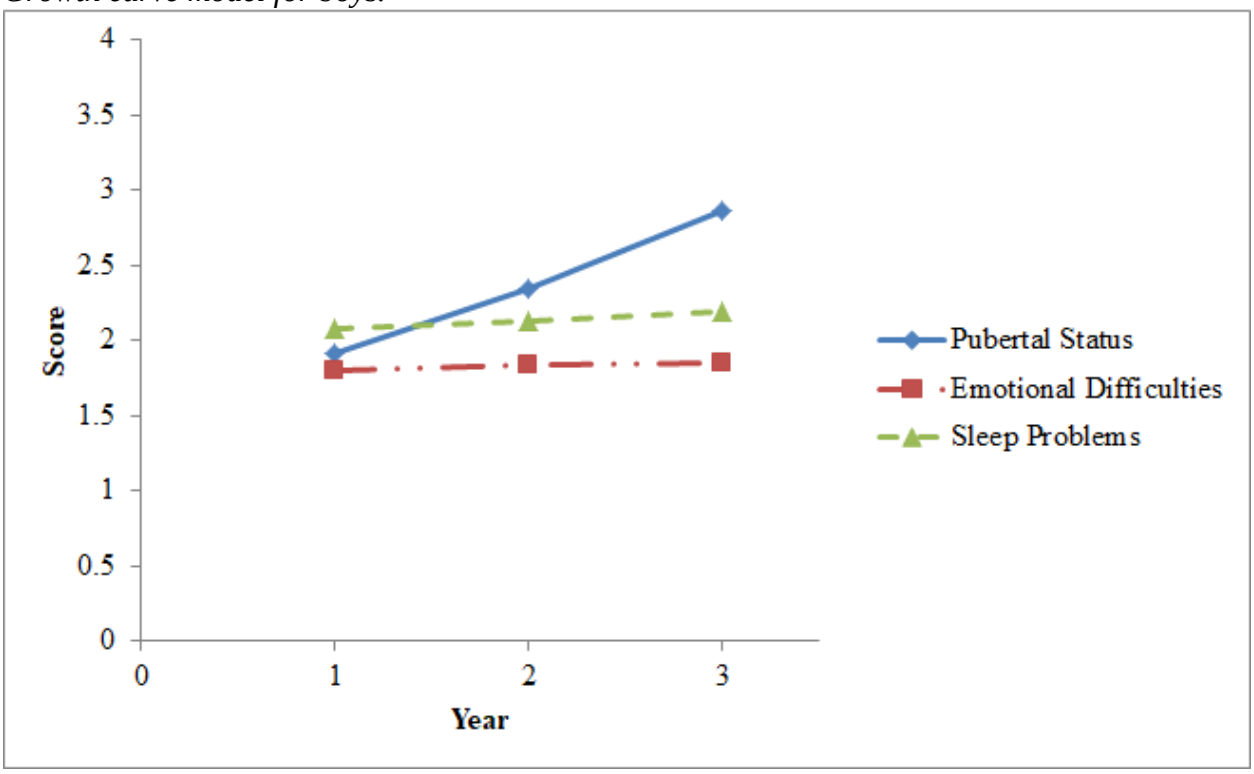


Figure 4

Growth curve model for girls.