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The effect of pubertal development on the sleep-wake cycle

Jorge Borrani *
Gonzalo Guerra
Aída García
Candelaria Ramírez
Pablo Valdez

Universidad Autónoma de Nuevo León, Laboratory of Psychophysiology. Monterrey, Nuevo León, México.

ABSTRACT

Objective: To analyze if the delay of the sleep-wake cycle is the effect of pubertal development, independently of age or school grade. **Methods:** Girls and boys between 4th and 6th grade were divided into a low pubertal stage and a high pubertal stage group. Age and school grade were controlled to isolate the effect of puberty by pairing the groups on these variables. The regular bedtime, waking time, sleep duration and daytime sleepiness were obtained through questionnaires. A Pubertal Developmental Scale with questions about bodily changes was used to determine pubertal stage. **Results:** Girls in high pubertal stages reported weekend bedtimes an hour later than girls in low puberty stages (low pubertal stage: 22:36±2:11 h, high pubertal stage: 23:37±1:27 h, $U=215$, $p<0.05$); there were no differences on waking time or sleep duration. Boys of different pubertal development did not have differences on any sleep parameter. Girls had a longer sleep duration compared to boys on weekends, but not on weekdays. **Discussion:** The bedtime delay in girls is the effect of pubertal development, not of age or school grade. There was no effect on boys due to their lower pubertal development at this age. Variability in pubertal development creates disparities in the sleep patterns of pubescent girls, even of the same age and school grade. Acknowledging this delay can help to create school and sports schedules in which young people are fully awake and alert. In research, it is crucial to consider pubertal development while studying sleep in children and adolescents.

Keywords: Adolescent; Puberty; Sleep

Corresponding author:
Jorge Borrani
E-mail: jorgeborrani@gmail.com
jorgeborrani@yahoo.com.mx

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INTRODUCTION

The phase and period of the sleep-wake cycle change considerably during the human lifespan, one notable change is that young people tend to stay up later during the night and wake up later in the day[1,2].

Even though this change in the sleep-wake cycle is usually related to adolescence, the physiological phenomenon driving the delay of the sleep phase is puberty. Other mammalian species also experience these changes in sleep habits[3], which implies that they are not just a consequence of an increase in the use of technology, or a reduction in parental control[4].

Puberty is a period of massive physiological and psychological changes, caused by the activation of the hypothalamic-pituitary-adrenal axis and the hypothalamic-pituitary-gonadal axis, which increases the production of androgens, estrogens and progesterones, among other hormones. These hormones are usually related to sexual maturation and their most evident effects are the appearance of secondary sex characteristics, but they also have important effects on the nervous system and sleep[5,6].

Sleep is produced and maintained by brain structures that are thought to be susceptible to pubertal hormones, for example, a characteristic that defines the sleep state in the brain is the appearance of EEG slow-wave activity, which starts declining when pubertal hormones initiate a synaptic pruning of the brain[7]. Similarly, there is also a reduction of nighttime melatonin release that negatively relates with the pubertal increase in luteinizing hormone[8]. The increase in hormone production during puberty is thought to delay the sleep-wake cycle in adolescents through one, or a combination of the following mechanisms: by changing the period of the circadian clock, by changing the sensitivity of the system to light, or by reducing homeostatic sleep pressure[9].

Although the delay of the sleep-wake cycle in adolescents is attributed to the effect of pubertal hormones[10], there is scarce behavioral evidence showing that adolescents, in fact, delay their sleep as their puberty advances. This lack of evidence is because most studies document this delay by comparing age groups of younger and older adolescents, which proves the effect of age but not the effect of puberty[9]. To analyze the effect of puberty it is necessary to determine the advance of this developmental process, one way to do this is to measure the amount of pubertal hormones in the body, and the other is to measure the effects of such hormones.

The Tanner Scale is the most common evaluation system to determine the advance of pubertal development, without using blood or saliva samples. This scale is completed by a professional via visual inspection, it classifies growth of axillary and pubic hair and the development of breast and testes in five stages, from prepubertal to post-puberal[11]. Medical inspection of secondary sexual characteristics is difficult to implement in school settings, therefore self-report scales have been developed to assess a great number of participants in a non-invasive fashion[12]. Self-report scales of pubertal development also classify body, skin and voice changes in similar stages, ranging from a moment of no pubertal change to when changes are complete[13].

Although puberty and age correlate, that is, older children tend to be more advanced in their pubertal development than younger ones, puberty onset in humans has a normal window of appearance of around six years, even in children under similar environmental factors[14]. For example, in Mexico the mean age for menarche is 12.5 years of age, but it may appear from 9.5 until 15.5 years of age, and still be considered a normal pubertal onset[15]. Boys have a similar variability in pubertal onset, but it is delayed approximately one year in comparison to girls. In consequence, if the delay and extension of the sleep-wake cycle is due to puberty, there is no fixed age for these changes to begin.

This means that even among children of the same age and school grade, children with a more advanced puberty could have a more delayed sleep phase, making it harder for them to comply with early morning activities. It is well documented that school schedules interfere with adolescent sleep schedules[16], and that there is a marked delay from weekdays to weekends in high school and college students, which is thought to be a recovery of the weekday sleep restriction[17]. Again, this restriction and recovery has been studied through age groups and not through pubertal development.

To analyze these changes on the sleep-wake cycle of adolescents, it is crucial to dissociate puberty from other factors that may influence sleep habits. For example, age drives many other developmental processes that happen independently of puberty, therefore it is always important to control this factor in adolescents. Also, as children advance in school grade there is a documented reduction of sleep time, probably due to an increase in academic workload[18]. The advance from one grade to the next may also change school schedules and social activity, which are important influences on the sleep-wake cycle of adolescents. Therefore, it is important to control age and school grade when analyzing changes in the adolescent sleep-wake cycle.

Only a few of the studies that analyze the adolescent sleep-wake cycle take into account pubertal development and of those that do, not all control age or school grade. In a longitudinal study by Andrade, Benedito-Silva, Domenice, Arnhold and Menna-Barreto[1] participants advanced Tanner stages every semester that was surveyed, similar to their delay in sleep onset. Although this suggests a relationship between pubertal development and sleep habits, there were no analysis to link these variables.

In a classic study by Carskadon, Vieira and Acebo[4] five hundred and fifty 6th graders were recruited. This sample criteria partially controlled age, since it left a relatively small range of 11 to 12 years of age, and it effectively controlled school grade. Pubertal development was classified in two pubertal stages for boys ("no changes yet" and "incomplete changes"), and three stages for girls ("no changes", "incomplete changes" and "marked complete changes"); bedtimes were divided into early and late bedtimes. A relationship was found between later bedtimes and a higher stage of puberty. Nevertheless, it is not clear if this relation is independent of age. During puberty, a difference of one year can cause great changes, so it could have happened that participants with earlier bedtimes were all 11 years old and those with later bedtimes were all 12 years old.

It is not clear how much later were the bedtimes of participants in higher puberty stages, from the bedtimes of participants with lower pubertal development. It was also not clear how much more advanced in pubertal development were the participants with late bedtimes, compared to the participants with early bedtimes.

Another longitudinal study showed, through actigraphy, that participants with more pubertal advance between two moments of the study, were the ones that delayed their sleep onset the most. This study also found a decrease in sleep duration, which could happen if bedtime is delayed and waking time is not delayed as well. Age in this study was also in a tight range from 9.9 to 11.2 years of age, and it was further controlled statistically by partialling age out of the correlation model, nevertheless, school grade was not controlled[19].

Even though there is evidence to support the hypothesis that the delay of the sleep-wake cycle in adolescents is the effect of pubertal development, there are no studies that isolate the effect of puberty by directly controlling age or school grade. Therefore, the objective of this study is to analyze if the delay of the sleep-wake cycle is the effect of pubertal development, independently of age or school grade.

MATERIAL AND METHODS

Participants

For this study, eighty-two children between 9 and 12 years of age were recruited from fourth, fifth and sixth grade of elementary school (age: 10.32 ± 0.9 years; school grade: 5.0 ± 0.8 years; mean ± standard deviation). This sample was divided into a group of 52 girls (age: 10.52 ± 0.8 years; school grade: 4.7 ± 0.7 years) and a group of 30 boys (age: 11.26 ± 0.9 years; education: 5.4 ± 0.7 school years). Participants attended school from 8:30 h to 12:30 h.

Girls were divided into two groups of different pubertal development (low pubertal stage 1.5 ± 0.46; high pubertal stage: 3.6 ± 0.57; $U = 7.0$, $p<0.001$), as well as boys (low pubertal stage: 1.6 ± 0.24; high pubertal stage: 2.2 ± 0.45; $U = 23$, $p<0.001$). In order to isolate the effect of puberty from age and school grade, the low and high pubertal stage groups were paired by age (Girls: low pubertal stage 10.39 ± 0.79 years old, high pubertal stage 10.65 ± 0.81 years old; $U = 316.50$, NS; Boys: low pubertal stage 11.25 ± 1.05 years old, high pubertal stage 11.27 ± 0.83 years old; $U = 112.50$, NS) and school grade (Girls: low pubertal stage 4.65 ± 0.74 school years, high pubertal stage 4.92 ± 0.79 school years; $U = 274.50$, NS; Boys: low pubertal stage 5.4 ± 0.73 school years, high pubertal stage 5.4 ± 0.73 school years; $U = 112.50$, NS).

Participants were paired case by case, for example, a 10-year-old girl in the 5th grade, with a puberty stage score of 2, was paired with another 10-year-old girl that is also in the 5th grade, but that had the highest possible puberty stage, in this case a score of 4. The average difference in puberty stage between pairs of girls was 2.0 ± 0.69, but for pairs of boys the average difference was 0.6 ± 0.55. This difference is very small, so pubertal stage differences were not expected in boys.

Participants slept 8:56 ± 1:33 h on weekdays and 10:19 ± 2:25 h on weekends, they had no sleep disorders or other sleep complaints at the moment of the application. All were without risk of having suffered brain damage, and were not using medications that could affect sleep or the nervous system in general.

Instruments and procedures

A general data questionnaire was used to collect information about health, brain damage risk, gender and age. The Sleep Timing Questionnaire[20] was used to collect the usual bedtime and waking time of the children, during weekdays and weekends. The Epworth Sleepiness Scale[21] is a questionnaire about the probability of falling asleep in different situations during the day, it was used to measure sleepiness that may occur because of sleep deprivation.

The Pubertal Development Scale (PDS)[12] is a Likert-type questionnaire that is answered by the participant, it assesses the physical development of participants in the areas of height, changes in skin (appearance of acne vulgaris), pubic hair growth and axillary hair growth. Male participants were also asked about changes in their voice and facial hair growth; female participants were also asked about breast growth and the appearance of their menstrual period. Through these questions each characteristic is scored as follows, 1: no change yet, 2: change has barely begun, 3: change is definitely underway, and 4: change is completed; menarche is scored 1: menarche has not appeared or 4: menarche has already appeared. These scores were then averaged to obtain a final score of pubertal development.

All tasks and questionnaires were administered as an interview and were applied individually at the school the participants attended, during their regular schedule.

Data Analysis

A Mann-Whitney U test was used to compare daily sleepiness and sleep parameters such as bedtime, waking time and sleep duration, between low and high pubertal stage groups and also between girls and boys. A Wilcoxon T test was used to compare the same sleep parameters between weekdays and weekends.

RESULTS

The girls in the high pubertal stage group went to sleep an hour later on weekends than the girls in the low pubertal stage group (low pubertal stage: 22:36 ± 2:11 h, high pubertal stage: 23:37 ± 1:27 h, $U = 215$, $p<0.05$). Waking time and sleep duration did not show significant differences during weekends. During weekdays, girls showed no pubertal stage differences on sleep parameters (Figure 1). Among boys there were no differences between low and high pubertal stage groups on any sleep parameter, either on weekdays or on weekends (Figure 2).

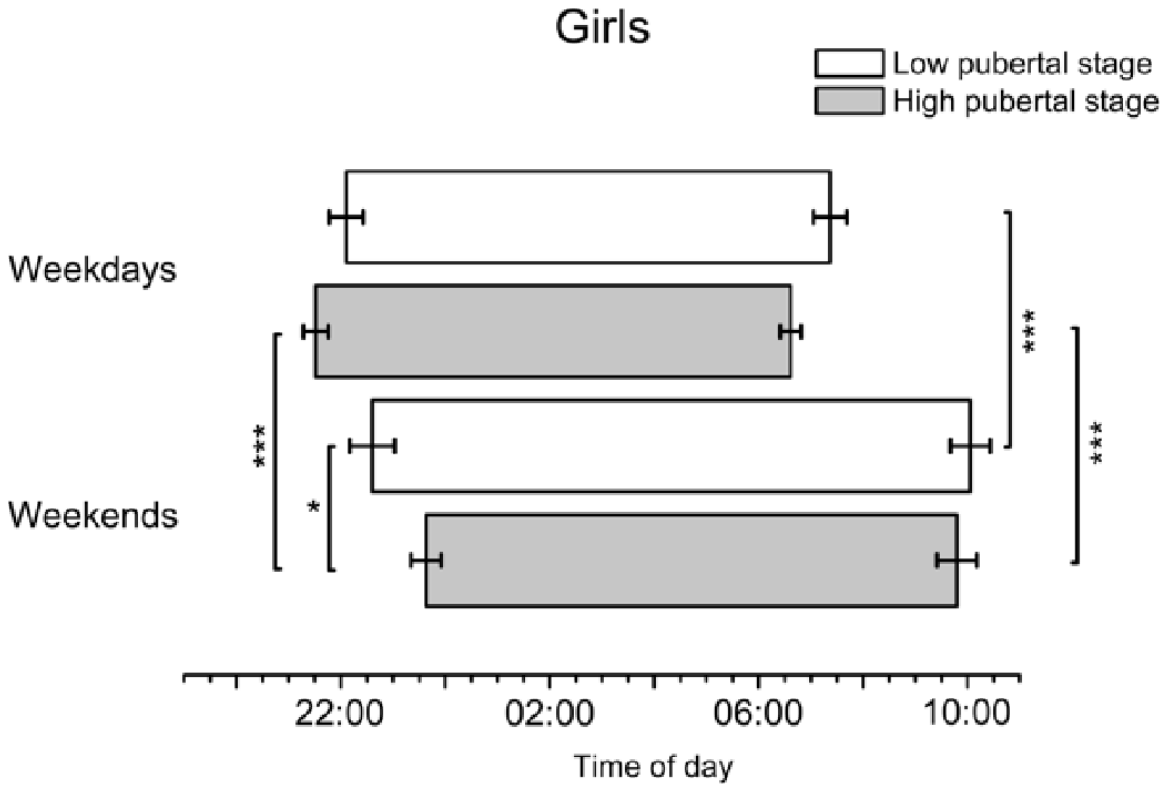

Figure 1. Comparison of the sleep-wake cycle parameters in girls between the low pubertal stage group and the high pubertal stage group, during weekdays and weekends. *p<0.05 ***p<0.001

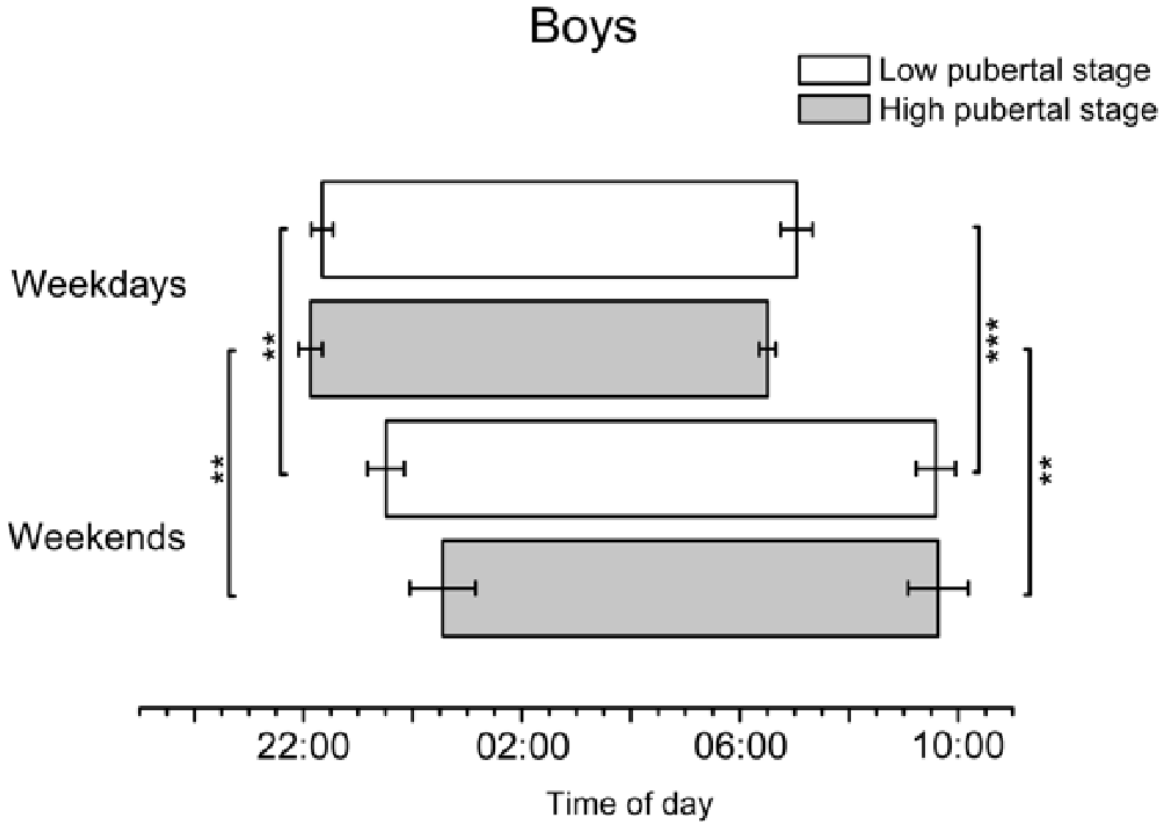

Figure 2. Comparison of the sleep-wake cycle parameters in boys between the low pubertal stage group and the high pubertal stage group, during weekdays and weekends. **p<0.01 ***p<0.001

Comparing weekdays (WD) to weekends (WE), girls in the low pubertal stage group delayed their waking time (WD: 7:21 ± 1:64 h, WE: 10:03 ± 1:56 h, T = 6.0, p<0.001) and had a longer sleep duration on the weekends (WD: 9:15 ± 2:00 h, WE: 11:27± 2:16 h, T = 13.5, p<0.001), without differences in bedtime. Girls in the high pubertal stage group delayed their bedtime (WD: 21:30 ± 1:12 h, WE: 23:37 ± 1:27 h, T = 0.0, p<0.001) and their waking time (WD: 6:36 ± 1:01 h, WE: 9:47 ± 1:56 h, T = 0.0, p<0.001) during weekends, and had no differences in sleep duration (Figure 1).

In boys, these same comparisons showed that low pubertal stage boys delayed their bedtime (WD: 22:20 ± 0:46 h, WE: 23:30 ± 1:18 h, T = 0.0, p<0.01), their waking time (WD: 7:01 ± 1:07 h, WE: 9:35 ± 1:23 h, T = 1.0, p<0.001), and had longer sleep durations on the weekend (WD: 8:41 ± 0:57 h, WE: 10:02 ± 1:40 h, T= 9.0, p<0.05). High pubertal stage boys also delayed their bedtime (WD: 22:07 ± 0:50 h, WE: 00:33± 2:19 h, T = 0.0, p<0.001) and waking time (WD: 6:30 ± 0:34 h, WE: 9:37 ± 2:08 h, T = 0.0, p<0.001), but had no change in sleep duration (Figure 2).

When comparing participants by gender, regardless of pubertal stage, there were no differences in bedtime or waking time between boys and girls. Nevertheless, girls had a longer sleep duration on weekends in comparison to boys (girls: 10:45 ± 2:18 h, boys: 9:31 ± 2:25 h, U = 541, p<0.05); this difference disappears when comparing sleep parameters on weekdays. Also, there were no differences when gender comparisons were made between girls and boys of low pubertal stage, and the same happened when comparing girls and boys of high pubertal stage.

The average score for the whole sample in daily sleepiness was 9.03 ± 3.93, which is three points above the normal limit of six[21]. Nevertheless, there were no differences when comparing sleepiness by pubertal development or by gender.

DISCUSSION

The results show that, at least in girls, the delay in bedtime that is characteristic of adolescence is the effect of pubertal development, independently of age and school year. This bedtime delay means that girls in the same age and in the same school grade can be two pubertal stages apart, and thus have a difference of about one hour in their bedtime, which is a considerable delay[22]. Girls, regardless of pubertal stage, also sleep longer on the weekend compared to boys, this could be interpreted as a greater need for sleep in the gender that is typically more advanced in pubertal development, but it could also reflect other gender differences that increase their sleep on weekends.

The effect of pubertal development was not strong enough to be evident on waking time. Other studies report changes in waking time when analyzing high school or college students[23], but in this study participants are barely entering puberty, therefore the effect on waking time is probably not yet manifested. The lack of differences on sleep duration is expected, since other studies[24,17] have already established that, although there is a delay in the sleep-wake cycle of adolescents, there is no overall change in sleep duration when weekdays and weekends are considered.

These results support what other reports had suggested, that the delay of the sleep phase is due to puberty. Nevertheless, the improved control of age and school year in this study further confirms that this delay in the sleep-wake cycle of pubescent girls is independent of other age-related changes, and also independent of changes related to school grade advance, such as an increased academic workload.

On boys, there was no significant effect of pubertal development on their sleep-wake cycle, probably due to the fact that boys start puberty later, and therefore show a smaller range of pubertal stages during these ages, which is a common issue in these studies[25,26]. The effect of this small range of pubertal stages was that comparisons were made between participants in very similar stages of puberty. To obtain a wider range of pubertal stages in boys it is necessary to recruit participants in middle school. Also, boys have been found to be less accurate when reporting their pubertal status[12], which could also confound the pubertal stage comparisons made here. The present results should be replicated taking into account other variables, such as body mass index, sibling order, the presence of siblings in the same room, and the use of light-emitting screens[27].

In sum, these results indicate that the bedtime delay of pubescent girls is the effect of puberty, and not of age or school grade. Therefore, girls that are more advanced in their pubertal development delay their bedtime sleep schedule, compared to other girls of the same age and in the same school year. This effect was observed only during weekends, days when they can choose their bedtime without the constraint of school schedules.

In this study, all participants had a delay in bedtime from weekdays to weekends, similar to that reported in the literature[1,28]. Low puberty girls and boys showed an increase in sleep duration from weekdays to weekends, while the other groups did not show a sleep extension. This suggests that there is no pubertal effect on the weekend extension of sleep. The index for sleep deprivation of this study was daytime sleepiness, but no differences were found with pubertal development, probably related to the absence of differences in sleep duration.

It is crucial that everyone in touch with children and adolescents (educators, coaches, parents and public policy makers) acknowledges that there are individual differences in pubertal development, and thus, different sleep patterns even within the same age group and school grade. Through this understanding, better decisions can be taken about school and sport training schedules, in order to ensure young people are awake and alert during their activities. Educating children and adolescents about the changes in their sleep-wake cycle has been related to the development of healthy sleep habits, which can help them to better cope with the conflict between their sleep pattern and socially imposed schedules for school and entertainment[29]. Similarly, it is crucial that researchers consider puberty as a central factor in sleep-wake cycle changes, and hence take it into consideration when investigating sleep in children and adolescents. The measurement of puberty is a complex subject in itself, and innovative approaches need to be made to fully integrate it into sleep research.

CONCLUSION

The delay of bedtime in pubescent girls is the effect of pubertal development, independently of age and school year.

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