Title: An epidemiological study of sleep-wake timings in school children from 4 to 11 years old: insights on the sleep phase shift and implications for the school starting times' debate

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Highlights:

- The shift of bed and wake-times for later hours on free-days starts at an early age

- Insufficient sleep length and circadian misalignment are present since kindergarten

ABSTRACT

Objective: It has been assumed that during adolescence there is a strong shift towards eveningness, while children's sleep is relatively stable. Several studies have focused on the conflict between school start-times and adolescents' circadian rhythms; however, fewer studies have been conducted on younger children. The aim of this study was to examine sleep durations, schedules and sleep phase shift in preschool and school age children.

Methods: Data for sleep patterns on school and free-days was obtained by means of questionnaires (Children ChronoType Questionnaire) for 3155 Portuguese children aged 4-to-11 years old.

Results: As children grow older and school-grade level increases, we found later bedtimes and sleep onsets on both school and free-days; and later wake-times only on free-days. By contrast, wake-times were progressively earlier, imposed by school start-times. There was a progressive reduction in the amount of sleep on school-nights as grade level increased. Greater social jetlag, later midpoint of sleep and higher restriction-extension patterns were found across development.

Conclusion: The displacement of bed and wake-times for later hours on free-days starts at an early age. Changing early school start-times could adjust social demands to the biological rhythm of children.

Keywords: Sleep schedules and durations; Sleep phase delay; pre and primary school children; pubertal transition; School start-times

1. Introduction

It has been assumed that during puberty and adolescence circadian rhythms, or sleep-wake cycles, shift towards a preference for late-morning wake times and late-onset sleep times (e.g., 1, 2), with previous research suggesting this transition occurs around the ages of 12-14 years (3, 4, 5, 6, 7). Contrastingly, before adolescence or during preschool and school-age years sleep is thought to be relatively stable, and recent guidelines (e.g., 8, 9) refer to children of school-age years as a single homogenous group in terms of their sleep needs and patterns (6-13 years). However, findings suggest that circadian changes to sleep occur prior to the physical changes of puberty (10) and rapid changes in sleep behavior appear to initiate around 5-7 years of age (11). Recently, a study using actigraphy to assess school-age children's sleep concluded that sleep of children in third and fourth grades is already delayed in comparison to their younger counterparts (12). Zimmermann (13) reported that in preschool children between the ages of 2 and 4 there is already a slight shift towards eveningness. Similarly, Randler, Faßl and Kalb (14) found that a slight turn towards eveningness already occurs during toddler age, even though the greatest change happens during pre-puberty around the age of 9-10 years. Collectively, the findings suggest that changes previously assumed to occur drastically around adolescence or with the onset of puberty might nonetheless start earlier, changing gradually as children develop.

Even though the delay in sleep-wake patterns and its conflict with school start-times are vastly studied on adolescents (3, 6, 15), there are fewer studies in children focused on SST. However, a displacement of wake-times during the weekend to later hours is already observed in ages as early as 4-6 years (16, 17) and the differences between sleep-wake patterns during weekdays and weekends completely disappear during holidays, indicating that school children are somewhat sleep deprived (18). Randler, Vollmer, Kalb and Itzek-Greulichc (11) reported an early breakpoint for social jetlag (SJL) at 5.17 years, suggesting the circadian rhythm shift towards eveningness that peaks in adolescence starts nevertheless in early childhood with the

misalignment of sleep timing between scheduled and free-days and thus proposing that this misalignment should be considered one contributing factor to a later chronotype during adolescence, along with other factors, such as sexual hormones. Social jetlag (SJL) is already present in infants 0-6 years of age and becomes greater as age increases (13, 14). Sleep is shortened by early school start-times thus sleep deprivation is partly compensated for by longer sleep durations on free-days (17). Hence, it is possible that there is already a misalignment between intrinsic biological sleep mechanisms and early school start-times in younger children.

Given the assumption that circadian rhythms shift with puberty or adolescence, most studies have focused essentially on youngsters in the years of pubertal development and adolescents. In one of the very few studies with primary school children, Arbabi, Vollmer, Dörfler and Randler (19) found an association between evening orientation/chronotype and academic achievement at the age of 10. The authors reported that an earlier chronotype was associated with earlier midpoint of sleep and less social jetlag, showing that individual circadian preferences are manifested, and, thus late chronotype can be detrimental to early school schedules in pre-adolescent children. Since the sleep habits of preschool and school-age children have not been investigated as exhaustively as other groups, current understanding of the status of sleep duration and sleep schedules among children between 4 and 11 years old is relatively limited. The first aim of this study was to characterize school-grade level and age-related differences in sleep duration, schedules, and school-versus-free-days discrepancies following the sleep variables extracted by Werner et al. (20) in the original study with Children's Chronotype Questionnaire (night sleep duration, sleep restriction-extension pattern, sleep need, bedtime, sleep onset, lights-off, sleep latency, sleep inertia, wake-time, get-up and fully alert time, social jetlag and midpoint of sleep). The second aim of this study was to investigate whether there is already a sleep-wake pattern delay on preschool and school-aged years by examining specifically sleep restriction-extension pattern, midpoint of sleep, social jetlag, wake-times and sleep onset and nigh sleep duration. We hypothesize that changes in sleep which have been

assumed to occur principally with the transition to puberty are already taking place since preschool years, and therefore there is a steadily increasing mismatch between school schedules and children's circadian patterns across preschool and school-aged years. Thus, we predict that sleep onset and wake-times shall already be delayed on free-days, that sleep duration will be shorter on school-days and longer on free-days to compensate sleep deficits and that schedule discrepancies on free-days versus school-days (social jetlag) and sleep restriction-extension patterns shall already be present in younger children. Furthermore, we mainly expect these patterns to be gradually and consistently greater from 4 to 11 years as age increases.

2. Methods

2.1. Design

The present cross-sectional study, in which we evaluated sleep schedules and sleep duration among children 4-to-11-years of age, was part of a large-scale, school-based survey that recruited participants from both kindergarten and primary schools in Portugal. Ethical approval was provided by the General Direction of Education – Portuguese Ministry of Education.

2.2. Procedures and participants

This investigation was conducted in Continental Portugal, which is divided into 5 educational regions (Alentejo [DREA], Algarve [DREALG], Center [DREC], Lisbon and Tagus Valley [DREL], North [DREN]). For the purpose of the study, the expression "school clusters" will be used to refer to a group of schools in the same parish, under the same Direction, that offer all levels of education ranging from kindergarten up to 12th grade of high school ("agrupamentos de escola" in Portuguese). Based on the list of public-school clusters available at the Ministry of Education's public network for the academic year of 2012/2013, a cluster sample was planned to cover all educational regions. Participants were recruited through the "school clusters": for each educational region, a specific number of school clusters were randomly sampled, based on the calculation of the approximate proportion of school clusters (and, thus, the country's population distribution) in each region. A total of 11 school clusters were sampled randomly, and invitations were sent to their principals. In case of refusal, which happened twice, another "school cluster" was randomly selected. 84.6% (11/13) of the approached "school clusters" agreed to participate in this study. The target study population included all preschool to 6th grade students between 4 and 11 years of age from each one of these school clusters, who were invited, along with their parents, to participate in the survey. Based on the voluntary principle and the guarantee of anonymity, informed consent was obtained from the respondents, who were free to discontinue the participation in the study at any time. Questionnaires and

informed consents were provided and retrieved through the children's teachers. Children between 4 and 11 years of age whose parents provided data to calculate at least one of the chronotype measures were included in the study. 11 subjects were excluded, leaving a final sample for the current study of 3155 children.

2.3. Measures

Portuguese version of Children's Choronotype Questionnaire (QCTC).

All children were assessed through QCTC (21), the Portuguese version of the Children's Chronotype Questionnaire (CCTQ; 20), a parent-report 27-item questionnaire, in which tutors respond to a short demographics sections and questions about sleep/wake parameters for both scheduled and free days, regarding 4- to 11-year-old children. (The scale also provides three individual measures of chronotype which were not the focus of the present study). Reliability results for the QCTQ (Cronbach's α=.728; 22) were similar to those obtained through the original questionnaire, CCTQ, for the M/E scale (Cronbach's α =.81; 20). Scheduled days (SC) were defined as those when the children's sleep-wake patterns are directly influenced by individual or family activities (e.g., school, scouts or athletics) and free days (FR) as those when the children's sleep/wake patterns are "free" from any influence of individual or family activities (20). As in the original study by Werner et al. (20), sleep onset (SO) was defined as sleep latency added to time of lights-off; night sleep duration (NSD) as the difference between sleep onset in the evening and wake-up time in the morning; and sleep inertia as the difference between wake-up time and time being fully alert. Sleep need was calculated through the weighted average: ([weekday sleep duration × 5] + [weekend sleep duration × 2])/7. Midpoint of sleep was calculated (SO + NSP/2) for both school (MSC) and free-days (MSF). Corrected midpoint of sleep (MSFsc) was calculated using the formula suggested by Roenneberg et al. (23): MSF − [0.5 × (NSP on FR − Sleep Need)]. Social jetlag was calculated according to Roenneberg's (SJL_R; was operationalized as the absolute difference between MSF and MSC;

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23) and Jankowski's formulas (SJLsc; 24). Sleep restriction-extension pattern was defined as the difference between sleep duration on school and free-days.

Portuguese version of Self-rating scale for pubertal development (EAP).

Children from the age of 9 attending 4th grade or above were assessed through EAP (25), the Portuguese version of the Self-Rating Scale for Pubertal Development (SSPD), a self-report measure of pubertal status adapted by Carskadon and Acebo (26) from the interview-based Pubertal Development Scale (PDS; 27). EAP includes 5 items which rate physical development and the results of those are combined to classify the adolescents' pubertal development, 3 of which are common to both boys and girls and 2 are specific questions by gender. This brief self-rating scale is intended for children from the age of 9 and it is a 4-point Likert Scale – except for item 5 of the female version, which is a "yes-or-no" question (if the answer is affirmative, it is asked for girls to report in which age they had the menarche) – rating an overall maturation measure (global mean) and a categorical maturation measure (total punctuation of puberty, the sum of the answers 2, 4 and 5), that can be converted in the Tanner pubertal development stage, through the algorithm developed by Peterson et al. (27).

2.4. *Statistical collection and analysis*

All analyses were performed using version 22.0 of IBM SPSS Statistics for Windows (IBM Corpo., Armonk, NY). Results for continuous variables with normal distributions were presented as mean ± standard deviation (SD). Skewness and Kurtosis were used to judge distribution (if under 2 and 7, respectively, variables were considered close to normally distributed; 28). Initially we performed univariate analysis to explore the associations between variables. Comparisons of sleep parameters across different age and school-grade groups were conducted using one-way ANOVAS and between boys and girls using Student's t-tests. Homogeneity of variance was tested by Levene method. One-way ANOVAS were followed by Tukey post hoc tests or Games-Howell post hoc tests when homogeneity assumptions were

violated. For the parameters that were not normally distributed, Kruskall-Wallis Tests were performed as non-parametric techniques instead of one-way ANOVAS and Mann-Whitney U Tests instead of t-tests. Comparisons on sleep parameters between school and free-days were conducted through Paired-Samples T-Test (or Wilcoxon Signed Rank Tests when assumptions were violated). Due to the multiple testing, Bonferroni correction was used to counteract the significance level p=.05. Thus, statistical significance was set at $p < .003$ in the sex, age and school-grade level analysis (.05/16 variables; Tables I, III and IV) and at $p < .005$ (.05/10) in the comparison between school and free-days (Table II). We then performed a series of multifactorial ANCOVAs / General Linear Model (GLM) entering sex and age as fixed factors and school cluster as the random factor (data of 1 school cluster was excluded because it only had 22 participants), while controlling for the school entry time of each participant (introduced as covariate), in order to determine the main effects and detect possible interactions between age and other factors on the variables of interest (i.e., sleep restriction-extension pattern, social jetlag and corrected midpoint of sleep). Considering the aims of the present work, special attention will be given to the effects of age. Partial eta squares were computed as effect size measures to appreciate the impact of each factor on the variables of interest (using Cohen criteria to interpret the values found). It was not possible to test the impact of age and pubertal stage in the same model, since these variables were largely correlated ($r > 0.7$). Thus, in order to avoid multicollinearity, age was chosen for GLM analysis, as it is more discriminative for prepubertal participants in the current sample. Still, we conducted preliminary ANCOVAs to detect possible interaction effects between pubertal developmental stage, age and sex, on the variables of interest, and no significant interactions were found between the pubertal stage and age or sex, over the relevant variables (neither when considering the 9-11 years old subset of the sample, neither when considering all age groups, nor when considering a dichotomized pubertal versus non pubertal categorization).

2.5. Sample characteristics

Overall, the survey was answered by the children's mother (85.1%, N=2675), father (10.1%, N=319), both mother and father (1.8%, N=57) or others (3%, N=94). Tutors age was 37.25±6.30. Most tutors had completed high school education (28.3%, N=784), 26.3% (N=729) completed basic education, 23.7% (N=655) did not complete basic education, and 21.7% (N=599) had completed or were completing higher education.

The final analysis included 3155 children attending one of 11 public school clusters across five educational regions of continental Portugal (DREN [3 schools]; DREL [3 schools]; DREC [2 schools]; DREA [2 schools]; DREALG [1 school]), 51% boys (N=1601) and 49% girls (N = 1544), with ages ranging from 4 to 11 years old, 7.92±2.054. Albeit there was no gender difference in age (t(3143)=-1.030, p=0.303), there was a gender difference in pubertal stage, with slightly more girls reaching midpubertal/late pubertal stage (9-11 years old girls vs boys: 66.13% vs 18.22%, [t(1073.331)=-16.240, p<.001]).

3. Results

3.1. Overview of the sleep-wake patterns

On school-days, children woke-up, on average, at 7:37±32m and got-up at 7:43±33m. They woke-up with the help of a relative (76.1%, N=2277), on their own (19.1%, N=571) or with an alarm clock (4.8%, N=145), and were fully awake at 7:49±34m. On school-days, bedtime was, on average, at 21:35±36m, lights-off at 21:49±38m, sleep latency 11m±9m and sleep onset 21:59±39m. Period of sleep was, on average, 9h37m±44m, MS 2:48±28m.

On free-days, children woke-up, on average, at 9:05±1h03m. Most did not return to sleep (84.4%, N=2556) and the ones who did (15.6%, N=474), returned to sleep 16m±16m after waking up. On free-days, children got-up at 9:24±1h0m3 and were fully awake at 9:24±1h06m. Most children did not take regular naps (91.5%, N=2760), and the ones who did (8.5%, N=258),

napped once a week (28.2%, N=68), twice (52.3%, N=126), three times (5.8%, N=14), four (0.8%, N=2), five (5.4%, N=13), six (0.4%, N=1) or seven times a week (7.1%, N=17), on average, for 1h36m±44m a day. Bedtime was 22:14±47m, lights-off 22:27±48m, sleep latency 11m±9m and sleep onset 22:38±49m. Period of sleep on free-days was, on average, 10h27m±1h01m, and MSF 3:52±47m. Sleep need was, on average, 9h51m±40m. MSFsc was 3:34±41m.

Most sleep-wake parameters did not differ significantly between boys and girls (Table I), except wake-up, get-up and fully alert time on free-days, which were later in girls. MSF was also later in girls. Girls also exhibited a greater sleep restriction-extension pattern and social jetlag (according to Roenneberg's formula).

3.2. Differences between school-days and free-days

Table II shows the parents' reports of their child's sleep-wake parameters on school-days and free-days for the whole sample. Most parameters were statically different between school and free-days; timing was delayed and sleep durations were lengthened from school to free-days. For example, children in our sample go to bed and start sleeping, on average, 39 minutes later on free-days in comparison to school-days, and extend their sleep by waking up, on average, 1 hour and 28 minutes, and by getting up, on average, 1 hour and 41 minutes later on weekend mornings. Their MSF is delayed, on average, by 1 hour and 4 minutes when compared to their MSC. Night sleep duration averages about 50 minutes more on free-days than school-days. There was no statistical significance in the differences in sleep latency.

3.3. Differences by age

Our results (Table III) show that, on free-days, wake-times and sleep onsets are already delayed compared to school-days in children as young as 4 years of age, and that this delay increases progressively with age. Figure 1b shows that children have later sleep onsets as they get older, both on school and free-days. However, wake-times (Figure 1a) on school-days get earlier

across these age groups since they are mostly dictated by school start-times. Social jetlag (Figure 1c) increases gradually as children grow older and is already present in younger children (SJL_R is 45 minutes and SJLsc 24 minutes for children at the age of 4, and go up to 1 hour and 21 minutes and 42 minutes in children at the age of 11, respectively). MSFsc (Figure 1d) too increases progressively from 4 to 8 years of age, when it reaches its maximum, and then it remains stable around ages 9-11. A sleep restriction-extension pattern (Figure 1e) is already present in children as young as 4 years of age (30 minutes), and it increases gradually as children grow older, reaching 1 hour and 16 minutes at the age of 11. Night sleep duration (Figure 1f) decreases significantly on school-days as children grow older, while on free-days they remain relatively consistent across age-groups (there are no significant differences). The effect size of age was small on sleep restriction-extension patterns, school entry times, corrected midpoint of sleep and social jetlag operationalized by Jankowski and medium on social jetlag operationalized by Roenneberg.

3.4. Differences by school-grade level

Sleep parameters vary greatly across school-grade level (Table IV). As shown above with age, wake-times (Figure 2a) and sleep onsets (Figure 2b) are already delayed in children attending kindergarten (k) on free-days compared to school-days. On school-days, wake-times are increasingly earlier across school-grade level, most probably dictated by school entry (Figure 2e) due to earlier school start-times since on free-days wake-times are increasingly later. Sleep onsets are progressively later as school-grade level goes up on both school and free-days. SJL_R is already 47 minutes in kindergarten and it increases until 6th grade, reaching, at the latter school-age level, 1 hour and 22 minutes (Figure 2c). SJLsc increases from 26 minutes in kindergarteners to 44 minutes in 6th graders. MSFsc also increases from kindergarten through 6th grade, although at a lower rate (Figure 2d). Kindergarteners already present a sleep restriction-extension pattern of 31 minutes, and this pattern increases as school-grade level goes up, reaching a maximum of 1 hour and 16 minutes at 5th grade (Figure 2f). As expectable, there is a

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pronounced overlap of results by school-grade level and results by years of age. On school-days, night sleep duration (Figure 2g) decreases gradually as school-grade level increases, whereas on free-days, although there is a decreasing tendency, they remain middling constant. The effect size of school-grade level was small on sleep restriction-extension patterns, midpoint of sleep corrected and social jetlag operationalized by Jankowski and medium on social jetlag operationalized by Roenneberg and school entry times.

3.5. *Multifactorial analyses – main effects and interaction effects*

The interactions effects (Table V) between age and sex and between age and school cluster were not significant for sleep restriction-extension pattern, social jetlag as operationalized by Jankowski or corrected midpoint of sleep. For social jetlag operationalized by Roenneberg significant interaction effects were found between sex and age. Therefore, in this case we further analyzed the main effect of age for boys and girls separately. Post hoc analysis showed this interaction does not invalidate the main effects, as the general tendency for social jetlag operationalized by Roenneberg across age, a middling linear increase, is the same for boys and girls. However, girls exhibited a more pronounced increase of social jetlag between the ages of 10 and 11 than boys.

There were statistically significant main effects of age, school entry time and school cluster on sleep restriction-extension patterns and midpoint of sleep and statistically significant main effects of age, sex and school entry times on social jetlag operationalized by Jankowski. There were statistically main effects for age, sex, school cluster and school entry times on social jetlag operationalized by Roenneberg. The effect size of age and school cluster was large for each one of the variables of interest, while the effect size of school entry time was small for every variable.

These analyses confirm our results are not moderated by age-sex or age-school cluster interactions.

4. Discussion

The present large-scale school-based study on the sleep habits of Portuguese children suggests that the delay of the sleep-wake pattern in relation to school schedules is already apparent in preschool children, and that it increases gradually year after year, from preschool to the 6th grade. Albeit without studying preschool children, Spruyt and colleagues (29) also observed this tendency. Hence, our results suggest that changes assumed to occur with the onset of puberty or during adolescence start much earlier and change gradually as children develop. Research on middle and high school teens found a delayed sleep-wake time by an average of 1-3h from school to free-days as a function of age (3, 6, 15) which has been interpreted as a result of puberty (23, 30, 31). Our findings indicate that similar patterns, albeit softly, already occur in preschool children as follows: 39 min later for sleep onset, 1h 28 min later for wake-up time and 50 min longer for sleep period on free-days than on school-days. According to Touchette et al. (16), this may occur due to the fact that the endogenous circadian period in children is already longer than 24 hours.

Younger children in our sample already exhibit statistically significant sleep restriction-extension patterns and a behavioral sleep rebound on free-days, as well as social jetlag, suggesting that their late sleep-wake patterns lead to the accumulation of sleep debt during the week, for which they try to compensate on free-days by extending their sleep duration. On free-days, all children sleep more than they do on school-days, including the younger ones, and there is a progressive and significant reduction in the amount of sleep time on school-days as school-grade level and age increased. These phenomena, consistently found in adolescents (e.g., 32), suggest a gradual delay in sleep-wake patterns of children in preschool and school-age years. Our findings are in line with the ones presented by Gruber (12), indicating that free-days versus school-days discrepancies start at a much younger age than what is assumed. The reduction in the amount of sleep time occurs due to a progressive delay in sleep onset as age and school-grade level increase, while wake-times demanded by school start-times remain constant or even

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advanced. Although the sleep restriction-extension pattern and social jetlag increased as children grew older, they already seem to be a reason for concern in younger children, especially because previous studies (12, 33) found that, whilst the majority of children spend the recommended amount of hours in bed, only a small percentage obtain the recommended amount of sleep following the National Sleep Foundation recommendations (34). This is a cause for concern since sleep deprivation during the first years of life may result in long-lasting consequences (35), as sleep is considered crucial for learning and academic function in children given its role in brain maturation (36). Insufficient sleep duration in children has social, academic, health and behavioral consequences (37), may result in excessive daytime sleepiness (38), it interferes with the memorization process (30, 39, 40) and increases the risk of cognitive impairments (41). Prolonged sleep deprivation can result in serious physical symptoms, such as increased heart rate and blood pressure (42), insulin resistance and changes in hormones which may lead to obesity (16, 43, 44) and is associated with poorer overall health and body's natural defense mechanisms (45). Furthermore, social jetlag has also been recognized as detrimental for psychological (46), physiological (47) and cognitive functioning (48, 49) and health (50).

During the past decade, the growing amount of scientific evidence demonstrating that an adequate sleep duration and timing is crucial for the teens' health, well-being and academic performance, as well as the encouragement of the American Academy of Pediatrics and The American Medical Association for later school start-times that allow students to get sufficient sleep and align school schedules to their biological sleep rhythms, have led to the delay of school start-times in some middle and high schools (51). Studies show teens in schools with later start-times have less daytime sleepiness, fatigue and sleep restriction, exhibit a better behavior, attention and concentration during class (52, 53, 54, 55, 56) and show improved sleep quality (57). Furthermore, previous studies indicate not only that early school start-times for both middle and high school students are associated with diverse and serious adverse sleep, health, safety, and education consequences, but also that delaying them may mitigate the impact

of negative consequences (58, 59, 60). Our results suggest it is possible that early school start-times likewise contribute to insufficient sleep duration and circadian misalignment in younger children, albeit to a much lesser degree than their older peers. Despite not being the focus of our analysis, our findings dispute the predominant supposition that sleep-wake habits are unaltered across the school age period, as several previous studies (e.g., 12) have shown. Even though night sleep duration's means were within the recommended sleep range, particularly amongst preschool children they were closer to the lower limit. A great percentage of Portuguese school-children sleep less than the recommended number of hours on school-days due to late bedtimes, thus accumulating a sleep debt for which they try to compensate by sleeping longer on free-days.

Though there is an obvious overlap of children's sleep-wake patterns across age and school-grade level, school entry varies importantly across school cycles in Portugal. Hence, an analysis by school-grade level was performed in order to underline the circadian misalignment of school start-times and children's biological sleep rhythms. Our results suggest that the advance of school start-times across school-grade level, from preschool to the 2nd study cycle, in the Portuguese school system is clearly inappropriate, as it follows an inverse tendency from the sleep-wake schedules exhibited by our participants. In other words, there seems to be an increasing divergence between school schedule's progression and sleep-wake patterns exhibited by children in our sample. Delaying school start-times could adjust social demands to the biological rhythm of children. Albeit school-age children's schedules are largely influenced by their tutor's schedules and Portugal has one of the longest working schedules amongst European countries, which might explain the late schedules at bedtimes in this study, tutors' schedules are not the only factor contributing to their sleep-wake patterns' delay since the delay is progressive from 4 to 11 years of age. Furthermore, though it may seem Portuguese children already have later school start-times than many children in other countries, it is important to take into account that Portugal follows Greenwich Mean Time, even though Portugal's time zone is slightly to the

west of the Prime Meridian. A large portion of continental Portugal is on -1 Time Zone during winter. This means that there is a mismatch (of approximately 37 minutes in "winter time", plus one more hour mismatch in summer) between clock time and solar time. Thus, for instance, when Portuguese preschool children start kindergarten at 9:30 clock time, they are entering at 8:53 solar time (winter hour). And when 5th and 6th grade students (10-11 years old) start classes at 8:30, they are in reality starting at 7:53 solar time (winter).

A gender difference in sleep-wake patterns was also observed. In line with our results, previous studies (3, 6, 12, 61) found a tendency for girls to wake up later and sleep longer on free-days, suggesting later chronotypes in the analyzed age range. A possible explanation for these results is the early changes in homeostasis and chronotype for preadolescent girls.

Contrary to what was expected, interaction effects between pubertal development stage and age and between pubertal development stage and sex were not found on the variables of interest. This may be due to the fact that our sample largely consists of prepubertal children and not exactly adolescents, including children until the age of 11. Therefore, there is a limited range of represented pubertal development stages (early pubertal and midpubertal stages are represented, but there is an insufficient number of cases for the late pubertal analysis and none for postpubertal stage).

As to the effect of school "cluster", albeit it was not the focus of the present work, it seems to deserve further research given its magnitude and statistical significance. It is important to notice that since no significant interaction was found between age and school cluster, one may conclude that the main effects by age are applicable to the variety of school clusters considered.

Our results should be considered in light of some limitations. First, the study was cross-sectional, which restricts the possibility to draw longitudinal inferences. Second, subjective measures were used, and parent-report surveys are exposed to social desirability bias and inadvertent error. Besides, parents can only report the sleep period, as they aren't able to know how much of that time in bed is spent sleeping. Studies found that sleep periods are longer in

parental reports than actigraphy records (62). Nonetheless, survey designs are considered the best method to collected information from large groups and to determine community trends (63). The major strengths of the present study are the large and representative sample size that includes children from all regions of continental Portugal and the amplitude of age groups covered. As potential implications of the present study, we believe there is a need for families, educational authorities and health professionals to be alert to children's circadian biology, since they need to receive an adequate quantity and quality of sleep in order to achieve peak daily performance. Hence, society should promote adequate sleep habits and practices among developing children and adapt school organization to meet their sleep-wake cycle.

5. *Conclusion*

Our results show that the displacement of sleep-wake patterns to later hours is already apparent in preschool children and that it increases gradually with age, from preschool to the 6th grade. Albeit there is a progressive delay in sleep onset across school-grade level and age groups, wake-times on school-days advance as age and school-grade level increase due to an advance in school start-times to earlier hours. Thus, there is an increasing divergence between sleep-wake patterns exhibited by children in our sample and school schedules progression. The changes of school starting times in Portugal, from kindergarten (9:30) to 5-6th school grades of basic education (8:30), seem in clear contradiction with the progression in sleep-wake patterns from 4 to 11 years old.

6. *Acknowledgments*

8. References

1. Crowley, S. J., Tarokh, L., & Carskadon, M. A. (2014). Sleep during adolescence. In S. H. Sheldon, R. Ferber, M. H. Kryger, & D. Gozal (Eds.), *Principles and practice of pediatric sleep medicine* (2nd ed., pp. 45-51). Elsevier.

2. Foley, J. E., Ram, N., Susman, E. J., & Weinraub, M. (2018). Changes to sleep-wake behaviors are associated with trajectories of pubertal timing and tempo of secondary sex characteristics. *Journal of Adolescence*, *68*, 171-186. doi:10.1016/j.adolescence.2018.07.017

3. Collado, M. J., Díaz-Morales, J. F., Escribano, C., Delgado, P. & Randler, C. (2012). Morningness-Eveningness and sleep habits among adolescents: age and gender effects. *Psicothema*, *24*(3), 410–415.

4. Díaz-Morales, J. F., & Gutiérrez, M. (2008). Morningness-Eveningness in adolescence. *Spanish Journal of Psychology*. *11*(1), 201–206.

5. Gau, S., & Soong, W. (2003). The transition of sleep-wake patterns in early adolescence. *Sleep*, *26*(4), 449-454. doi:10.1093/sleep/26.4.449

6. Laberge, L., Petit, D., Simard, C., Vitaro, F., Tremblay, R. E., & Montplaisir, J. (2001). Development of sleep patterns in early adolescence. *Journal of Sleep Research*, *10*, 59–67.

7. Randler, C. (2007). Gender differences in morningness–eveningness assessed by self-report questionnaires: A meta-analysis. *Personality and Individual Differences*, *43*(7), 1667-1675. doi:10.1016/j.paid.2007.05.004

8. Hirshkowitz, M., Whiton, K., Albert, S. M., Alessi, C., Bruni, O., DonCarlos, L., … Ware, J. C. (2015). National Sleep Foundation's updated sleep duration recommendations: final report. *Sleep Health*, *1*(4), 233-243. doi:10.1016/j.sleh.2015.10.004

9. Paruthi, S., Brooks, L. J., D'Ambrosio, C., Hall, W. A., Kotagal, S., Lloyd, R. M., … Wise, M. S. (2016). Consensus statement of the american academy of sleep medicine on the recommended amount of sleep for healthy children: Methodology and discussion. *Journal of Clinical Sleep Medicine*, *12*(11), 1549-1561. doi:10.5664/jcsm.6288

10. Sadeh, A., Dahl, R. E., Shahar, G., & Rosenblat-Stein, S. (2009). Sleep and the Transition to Adolescence: A Longitudinal Study. *Sleep*, *32*(12), 1602-1609. doi:10.1093/sleep/32.12.1602

11. Randler, C., Vollmer, C., Kalb, N., & Itzek-Greulich, H. (2019). Breakpoints of time in bed, midpoint of sleep, and social jetlag from infancy to early adulthood. *Sleep Medicine*, *57*, 80-86. doi:10.1016/j.sleep.2019.01.023

12. Gruber, R., Somerville, G., Wells, S., Keskinel, D., & Santisteban, J. A. (2018). An actigraphic study of the sleep patterns of younger and older school-age children. *Sleep Medicine*, 47, 117-125. doi:10.1016/j.sleep.2018.03.023

13. Zimmermann, L. K. (2016). The influence of chronotype in the daily lives of young children. *Chronobiology International*, *33*(3), 268-279. doi:10.3109/07420528.2016.1138120

14. Randler, C., Faßl, C., & Kalb, N. (2017). From Lark to Owl: developmental changes in morningness-eveningness from new-borns to early adulthood. *Scientific Reports*, *7*(1). doi:10.1038/srep45874

15. Russo, P. M., Bruni, O., Lucidi, F., Ferri, R., & Violani, C. (2007). Sleep habits and circadian preference in Italian children and adolescents. *Journal of Sleep Research*, *16*(2), 163-169. doi:10.1111/j.1365-2869.2007.00584.x

16. Touchette, É., Mongrain, V., Petit, D., Tremblay, R. E., & Montplaisir, J. Y. (2008). Development of sleep-wake schedules during childhood and relationship with sleep duration. *Archives of Pediatrics & Adolescent Medicine*, *162*(4), 343-349. doi:10.1001/archpedi.162.4.343

17. Doi, Y., Ishihara, K., & Uchiyama, M. (2013). Sleep/wake patterns and circadian typology in preschool children based on standardized parental self-reports. *Chronobiology International*, *31*(3), 328-336. doi:10.3109/07420528.2013.852103

18. Mishra, A., Pandey, R. K., Minz, A., & Arora, V. (2017). Sleeping habits among school children and their effects on sleep pattern. *Journal of Caring Sciences*, *6*(4), 315-323. doi:10.15171/jcs.2017.030

19. Arbabi, T., Vollmer, C., Dörfler, T., & Randler, C. (2014). The influence of chronotype and intelligence on academic achievement in primary school is mediated by conscientiousness, midpoint of sleep and motivation. *Chronobiology International*, *32*(3), 349-357. doi:10.3109/07420528.2014.980508

20. Werner, H., LeBourgeois, M. K., Geiger, A., & Jenni, O. G. (2009). Assessment of chronotype in four- to eleven-year-old children: Reliability and validity of the children's chronotype questionnaire (CCTQ). *Chronobiology International*, *26*(5), 992-1014. doi:10.1080/07420520903044505

21. Couto, D., Allen Gomes, A., Pinto de Azevedo, M.H., Bos, S.M.C., Leitão, J. A. & Silva, C.F. (2014). The European Portuguese version of the Children ChronoType Questionnaire (CCTQ): reliability and raw scores in a large continental sample [P532]. *Journal of Sleep Research, 23* (s1), 160.doi:

http://onlinelibrary.wiley.com/doi/10.1111/jsr.12213/abstract

22. Couto, D., Gomes, A., Azevedo, H., Leitão, J., & Silva, C. (n.d.). The European Portuguese version of the Children ChronoType Questionnaire (CCTQ): reliability and raw scores in a large continental sample [P532]. [Abstract]. *Journal of Sleep Research*, *23*, 160. doi:10.1111/jsr.12213/abstract

23. Roenneberg, T., Kuehnle, T., Pramstaller, P. P., Ricken, J., Havel, M., Guth, A., & Merrow, M. (2004). A marker for the end of adolescence. *Current Biology*, *14*(24), 1038-1039. doi:10.1016/j.cub.2004.11.039

24. Jankowski, K. S. (2017). Social jet lag: Sleep-corrected formula. *Chronobiology International*, *34*(4), 531-535. doi:10.1080/07420528.2017.1299162

25. Crisóstomo, A., Couto, D., Marques, D. & Gomes A. A. (2012). *Escala de Autoavaliação da Puberdade - EAP [Adapt. portuguesa da versão original de Carskadon & Acebo, 1993]*. Departamento de Educação, Universidade de Aveiro

26. Carskadon, M., & Acebo, C. (1993). A self-administered rating scale for pubertal development. *Journal of Adolescent Health, 14*, 190-195.

27. Petersen, A. C., Crockett, L., Richards, M., & Boxer, A. (1988). A self-report measure of pubertal status: Reliability, validity, and initial norms. *Journal of Youth and Adolescence*, *17*(2), 117-133. doi:10.1007/bf01537962

28. Kim, H. (2013). Statistical notes for clinical researchers: assessing normal distribution (2) using skewness and kurtosis. *Restorative Dentistry & Endodontics*, *38*(1), 52. doi:10.5395/rde.2013.38.1.52

29. Spruyt, K., O'Brien, L. M., Cluydts, R., Verleye, G. B., & Ferri, R. (2005). Odds, prevalence and predictors of sleep problems in school-age normal children. *Journal of Sleep Research*, *14*(2), 163-176. doi:10.1111/j.1365-2869.2005.00458.x

30. Carskadon, M. A. (2011). Sleep in adolescents: The perfect storm. *Pediatric Clinics of North America*, *58*(3), 637-647. doi:10.1016/j.pcl.2011.03.003

31. Carskadon, M. A., Vieira, C., & Acebo, C. (1993). Association between puberty and delayed phase preference. *Sleep*, *16*(3), 258-262. doi:10.1093/sleep/16.3.258

32. Carskadon, M. A., Wolfson, A. R., Acebo, C., Tzischinsky, O., & Seifer, R. (1998). Adolescent sleep patterns, circadian timing, and sleepiness at a transition to early school days. *Sleep*, *21*(8), 871-881. doi:10.1093/sleep/21.8.871

33. Goodwin, J. L., Silva, G. E., Kaemingk, K. L., Sherrill, D. L., Morgan, W. J., & Quan, S. F. (2006). Comparison between reported and recorded total sleep time and sleep latency in 6- to 11-year-old children: the Tucson Children's Assessment of Sleep Apnea Study (TuCASA). *Sleep and Breathing*, *11*(2), 85-92. doi:10.1007/s11325-006-0086-6

34. National Sleep Foundation. (2013). How much sleep do we really need? Retrieved from https://www.sleepfoundation.org/how-sleep-works/how-much-sleep-do-we-really-need

35. Touchette, É., Petit, D., Séguin, J. R., Boivin, M., Tremblay, R. E., & Montplaisir, J. Y. (2007). Associations between sleep duration patterns and behavioral/cognitive functioning at school entry. *Sleep*, *30*(9), 1213-1219. doi:10.1093/sleep/30.9.1213

36. Dahl, R. E. (2005). Sleep, learning, and the developing brain: Early-to-bed as a healthy and wise choice for school aged children. *Sleep*, *28*(12), 1498-1499. doi:10.1093/sleep/28.12.1498

37. Aronen, E. T., Paavonen, E. J., Fjällberg, M., Soininen, M., & Törrönen, J. (2000). Sleep and psychiatric symptoms in school-age children. *Journal of the American Academy of Child and Adolescent Psychiatry*, *39*(4), 502-508. doi:10.1097/00004583-200004000-00020

38. Gaina, A., Sekine, M., Hamanishi, S., Cheng, X., Wang, H., Yamagami, T., & Kagamimori, S. (2007). Daytime sleepiness and associated factors in Japanese school children. *The Journal of Pediatrics*, *151*(5), 518-522. doi:10.1016/j.jpeds.2007.04.036

39. Holz, J., Piosczyk, H., Landmann, N., Feige, B., Spiegelhalder, K., Riemann, D., … Voderholzer, U. (2012). The timing of learning before night-time sleep differentially affects declarative and procedural long-term memory consolidation in adolescents. *PLoS ONE*, *7*(7), e40963. doi:10.1371/journal.pone.0040963

40. Kopasz, M., Loessl, B., Hornyak, M., Riemann, D., Nissen, C., Piosczyk, H., & Voderholzer, U. (2010). Sleep and memory in healthy children and adolescents – A critical review. *Sleep Medicine Reviews*, *14*(3), 167-177. doi:10.1016/j.smrv.2009.10.006

41. Gringras, P., Green, D., Wright, B., Rush, C., Sparrowhawk, M., & Pratt, K. (2014). Weighted blankets and sleep in autistic children: A randomized controlled trial. *Pediatrics*, *134*(2), 298-306. doi:10.1542/ peds.2013-4285

42. Shochat, T., Cohen-Zion, M., & Tzischinsky, O. (2014). Functional consequences of inadequate sleep in adolescents: A systematic review. *Sleep Medicine Reviews*, *18*(1), 75-87. doi:10.1016/j.smrv.2013.03.005

43. Agras, W., Hammer, L. D., McNicholas, F., & Kraemer, H. C. (2004). Risk factors for childhood overweight: A prospective study from birth to 9.5 years. *The Journal of Pediatrics*, *145*(1), 20-25. doi:10.1016/j.jpeds.2004.03.023

44. Garaulet, M., Ortega, F. B., Ruiz, J. R., Rey-López, J. P., Béghin, L., Manios, Y., … Moreno, L. A. (2011). Short sleep duration is associated with increased obesity markers in European adolescents: effect of physical activity and dietary habits. The HELENA study. *International Journal of Obesity*, *35*(10), 1308-1317. doi:10.1038/ijo.2011.149

45. Sekine, M., Chandola, T., Martikainen, P., Marmot, M., & Kagamimori, S. (2006). Work and family characteristics as determinants of socioeconomic and sex inequalities in sleep: The Japanese civil servants study. *Sleep*, *29*(2), 206-216. doi:10.1093/sleep/29.2.206

46. Levandovski, R., Dantas, G., Fernandes, L. C., Caumo, W., Torres, I., Roenneberg, T., … Allebrandt, K. V. (2011). Depression scores associate with chronotype and social jetlag in a rural population. *Chronobiology International*, *28*(9), 771-778. doi:10.3109/07420528.2011.602445

47. Roenneberg, T., Allebrandt, K., Merrow, M., & Vetter, C. (2012). Social jetlag and obesity. *Current Biology*, *22*(10), 939-943. doi:10.1016/j.cub.2013.04.011

48. Vollmer, C., Pötsch, F., & Randler, C. (2013). Morningness is associated with better gradings and higher attention in class. *Learning and Individual Differences*, *27*, 167-173. doi:10.1016/j.lindif.2013.09.001

49. Kolomeichuk, S. N., Randler, C., Shabalina, I., Fradkova, L., & Borisenkov, M. (2016). The influence of chronotype on the academic achievement of children and adolescents – evidence from Russian Karelia. *Biological Rhythm Research*, *47*(6), 873-883. doi:10.1080/09291016.2016.1207352

50. Abbott, S., Weng, J., Reid, K., Daviglus, M., Gallo, L., Loredo, J., … Zee, P. (2017). Sleep-wake timing and stability are associated with increased blood pressure in the Sueno ancillary study of the Hispanic community health study/study of Latinos (HCHS/SOL). *Sleep*, *40*, A378-A378. doi:10.1093/sleepj/zsx050.1015

51. Wahlstrom, K. L. (2016). Later start time for teens improves grades, mood, and safety. *Phi Delta Kappan*, *98*(4), 8-14. doi:10.1177/0031721716681770

52. Bowers, J. M., & Moyer, A. (2017). Effects of school start time on students' sleep duration, daytime sleepiness, and attendance: a meta-analysis. *Sleep Health*, *3*(6), 423-431. doi:10.1016/j.sleh.2017.08.004

53. Epstein, R., Chillag, N., & Lavie, P. (1998). Starting times of school: Effects on daytime functioning of fifth-grade children in Israel. *Sleep*, *21*(3), 250-257. doi:10.1093/sleep/21.3.250

54. Owens, J. A., Dearth-Wesley, T., Herman, A. N., Oakes, J. M., & Whitaker, R. C. (2017). A quasi-experimental study of the impact of school start time changes on adolescent sleep. *Sleep Health*, *3*(6), 437-443. doi:10.1016/j.sleh.2017.09.001

55. Perkinson-Gloor, N., Lemola, S., & Grob, A. (2013). Sleep duration, positive attitude toward life, and academic achievement: The role of daytime tiredness, behavioral persistence, and school start times. *Journal of Adolescence*, *36*(2), 311-318. doi:10.1016/j.adolescence.2012.11.008

56. Rhie, S., & Chae, K. Y. (2018). Effects of school time on sleep duration and sleepiness in adolescents. *PLOS ONE*, *13*(9), e0203318. doi:10.1371/journal.pone.0203318

57. Guérin, N., Reinberg, A., Testu, F., Boulenguiez, S., Mechkouri, M., & Touitou, Y. (2001). Role of school schedule, age, and parental socioeconomic status on sleep duration and sleepiness of Parisian children. *Chronobiology International*, *18*(6), 1005-1017. doi:10.1081/cbi-100107974

58. Boergers, J., Gable, C. J., & Owens, J. A. (2014). Later school start time is associated with improved sleep and daytime functioning in adolescents. *Journal of Developmental & Behavioral Pediatrics*, *35*(1), 11-17. doi:10.1097/dbp.0000000000000018

59. Minges, K. E., & Redeker, N. S. (2016). Delayed school start times and adolescent sleep: A systematic review of the experimental evidence. *Sleep Medicine Reviews*, *28*, 86-95. doi:10.1016/j.smrv.2015.06.002

60. Owens, J. A., Belon, K., & Moss, P. (2010). Impact of delaying school start time on adolescent sleep, mood, and behavior. Archives of Pediatrics & Adolescent Medicine, *164*(7). doi:10.1001/archpediatrics.2010.96

61. Randler, C., Vollmer, C., Beşoluk, Ş., Önder, İ., & Horzum, M. B. (2014). Age and gender differences in morningness–eveningness in Turkish adolescents and young adults. *Biological Rhythm Research*, *45*(2), 277-284. doi:10.1080/09291016.2013.805915

62. Iwasaki, M., Iwata, S., Iemura, A., Yamashita, N., Tomino, Y., Anme, T., … Matsuishi, T. (2010). Utility of subjective sleep assessment tools for healthy preschool children: A comparative study between sleep logs, questionnaires, and actigraphy. *Journal of Epidemiology*, *20*(2), 143-149. doi:10.2188/jea.je20090054

63. Biggs, S. N., Lushington, K., Van den Heuvel, C. J., Martin, A. J., & Kennedy, J. D. (2011). Inconsistent sleep schedules and daytime behavioral difficulties in school-aged children. *Sleep Medicine*, *12*(8), 780-786. doi:10.1016/j.sleep.2011.03.017

Tables

Table I: Differences in sleep variables between boys and girls

Sleep variable		Sex		*t*-test	*p*
		Boys	Girls		
Wake-time	SC	7:38am±32m	7:36am±32m	*t*(3094)=1.574	.116
	FR	8:59am±1h03m	9:12am±1h02m	*t*(3109)=-5,839	<.001*
Get-up	SC	7:44am±33m	7:43am±33m	*t*(3093)=1,195	.232
	FR	9:17am±1h03m	9:32am±1h02m	*t*(2839)=-6.550	<.001*
Fully alert	SC	7:50am±35m	7:49am±33m	*t*(3003)=.609	.543
	FR	9:15am±1h06m	9:33am±1h05m	*t*(2794)=-7,108	<.001*
Sleep inertia	SC	11m±17m	13m±14m	*Z*=-3.398	.001*
	FR	16m±29m	20m±32m	*Z*=-3.545	<.001*
Bedtime	SC	9:36pm±36m	9:35pm±36m	*t*(3094)=1.034	.301
	FR	10:14pm±46m	10:14pm±46m	*t*(3059)=-.234	.815
Lights-off	SC	9:49pm±37m	9:49pm±39m	*t*(3007)=.114	.909
	FR	10:27pm±47m	10:28pm±48m	*t*(2941)=-.688	.491
Sleep latency	SC	11m±9m	11m±9m	*Z*=-.897	.370
	FR	11m±9m	11m±10m	*Z*=-.639	.523
Sleep onset	SC	10:00pm±38m	9:59pm±39m	*t*(2858)=.673	.501
	FR	10:38pm±48m	10:39pm±50m	*t*(2808)=-.532	.595
Night sleep duration	SC	9h38m±43m	9h37m±45m	*t*(2797.407)=.548	.584
	FR	10h21m±1h01m	10h33m±1h01m	*t*(2793)=-5.171	<.001*
MS (MSF and MSC)	SC	2:49am±28m	2:47am±28m	*t*(2828)=1,431	.153
	FR	3:48am±46m	3:56am±47m	*t*(2793)=-4,004	<.001*
Sleep need		9h50m±39m	9h53m±40m	*t*(2710)=-1,816	.069
Sleep restriction-extension pattern		43m±1h03m	55m±1h05m	*t*(2710)=-5.103	<.001*
MSFsc		3:33am±41m	3:36am±42m	*t*(2710)=-1.588	.112
SJL_R		59m±38m	1h08m±40m	*t*(2675.297)=-5.583	<.001*
SJLsc		34m±30m	37m±32m	*t*(2490)=-2.712	.007
School entry		8:49am±47m	8:51am±51m	**t**(3055)=-1.162	.245

Table II: Sleep variables on school-days and free-days

Sleep variable	SC	FR	Paired *t*-Test	*p*
Wake-time	7:37am±32m	9:05am±1h03m	*t*=.255	<.001*
Get-up	7:43 am±33m	9:24am±1h03m	*t*=.226	<.001*
Fully alert	7:50 am±34m	9:24am±1h06m	*t*=.272	<.001*
Sleep inertia	12m±16m	18m±30m	*Z*= -9.871	<.001*
Bedtime	9:35 pm±36m	10:14pm ± 47m	*t*=.695	<.001*
Lights-off	9:49 pm±38	10:27pm±48m	*t*=.683	<.001*
Sleep latency	11m±9m	11m±9m	*Z*=-.281	.779
Sleep onset	9:59 pm±39m	10:38pm±49m	*t*=.691	<.001*
Night sleep duration	9h37m±44m	10h27m±1h01m	*t*=.288	<.001*
MS (MSC and MSF)	2:48±28m	3:52 ± 47m	*t*=.540	<.001*

	7:37am±32m	9:05am±1h03m	*t*=.255	<.001*

Table III: Sleep variables across age

Sleep variable	Age					
	SC			**FR**		
	F	p	η^2	F	p	η^2
Wake-time	$F(7, 3097)=37.306$	<.001*	.078	$F(7, 3111)=8.887$	<.001*	.020
Get-up	$F(7, 3097)=40.332$	<.001*	.084	$F(7, 2842)=8.042$	<.001*	.019
Fully alert	$F(7, 3006)=38.401$	<.001*	.082	$F(7, 2796)=8.480$	<.001*	.021
Sleep inertia	$\chi^2(7)= 6.286$	.507		$\chi^2(7)= 17.035$	.017*	.017
Bedtime	$F(7, 3098)=19.197$	<.001*	.039	$F(7, 3062)=27.743$	<.001*	.060
Lights-off	$F(7, 3011)=19.197$	<.001*	.043	$F(7, 2944)=29.401$	<.001*	.065
Sleep latency	$\chi^2(7)= 11.881$	.105		$\chi^2(7)=9.045$	.249	
Sleep onset	$F(7, 2860)=19.739$	<.001*	.046	$F(7, 2810)=27.723$	<.001*	.065
Night sleep duration	$F(7, 2830)=69.414$	<.001*	.147	$F(7, 2794)=1.571$	.139	.004
MS (MSF and MSC)	$F(7, 2830)=2.521$	.014	.006	$F(7, 2794)=21.363$	<.001*	.051
	F	p	η^2			
Sleep need	$F(7, 2710)=42.827$	<.001*	.100			
Sleep restriction-extension pattern	$F(7, 2710)=20.153$	<.001*	.049			
MSFsc	$F(7, 2710)=10.027$	<.001*	.025			
SJL_R	$F(7, 2710)=29.884$	<.001*	.072			
SJLsc	$F(7, 2490)=10.625$	<.001*	.029			
School entry	$F(7, 3058)=22.414$	<.001*	.049			

Table IV: Sleep variables across school-grade level

Sleep variable	School-grade level					
	SC			FR		
	F	p	η^2	F	p	η^2
Wake-up	$F(6, 3091)=54.622$	<.001*	.096	$F(6, 3104)=11.276$	<.001*	.021
Get-up	$F(6, 3090)=60.711$	<.001*	.105	$F(6, 2836)=9.448$	<.001*	.020
Fully alert	$F(6, 3001)=55.169$	<001*	.099	$F(6, 2792)=10.278$	<.001*	.022
Sleep inertia	$\chi^2(6)=7.790$	.254		$\chi^2(6)=19.068$	.004	
Bedtime	$F(6, 3091)=25.076$	<.001*	.046	$F(6, 3057)=36.464$	<.001*	.067
Lights-off	$F(6, 3005)=25.420$	<.001*	.048	$F(6, 2940)=38.165$	<.001*	.072
Sleep latency	$\chi^2(6)=14.429$	.025		$\chi^2(6)=11.330$	. 079	
Sleep onset	$F(6, 2855)=25.025$	<.001*	.050	$F(6, 2806)=34.944$	<.001*	.070
Night sleep duration	$F(6, 2826)=94.438$	<.001*	.167	$F(6, 2790)=2.462$	.022	.005
MS (MSF and MSC)	$F(6, 2826)=4.915$	<.001*	.010	$F(6, 2790)=26.477$	<.001*	.054
	F		p		η^2	
Sleep need	$F(6, 2707)=59.363$		<.001*		.116	
Sleep restriction-extension pattern	$F(6, 2707)=25.494$		<.001*		.053	
MSFsc	$F(6, 2707)=12.251$		<.001*		.026	
SJL_R	$F(6, 2707)=38.133$		<.001*		.078	
SJLsc	$F(6, 2487)=12.744$		<.001*		.030	
School entry	$F(6, 3057)=35.961$		<.001*		.066	

Table V: Main effects and interaction effects

Sleep variable	Factor	F	p	η²
Sleep restriction-extension pattern	Age	$F(7, 84.194)=7.391$	<.001*	.381
	Sex	$F(1, 2535)=.965$	.326	.000
	School cluster	$F(9, 73.185)=6.130$	<.001*	.430
	School entry (covariate)	$F(1, 2535)=51.023$	<.001*	.020
	Age*sex	$F(7, 2535)=1.180$	.311	.003
	Age*school cluster	$F(60, 2535)=1.287$	.070	.030
SJL_R	Age	$F(7, 89.223)=17.382$	<.001*	.577
	Sex	$F(1, 2535)=26.415$	<.001*	.010
	School cluster	$F(9, 75.827)=5.203$	<.001*	.382
	School entry (covariate)	$F(1, 2535)=31.989$	<.001*	.012
	Age*sex	$F(7, 2535)=2.392$	.019*	.007
	Age*school cluster	$F(60, 2535)=1.082$	.312	.025
SJLsc	Age	$F(7, 90.799=8.047$	<.001*	.383
	Sex	$F(1, 2323)=8.218$	.004*	.004
	School cluster	$F(9, 76.832)=1.402$	.202	.141
	School entry (covariate)	$F(1, 2323)=19.731$	<.001*	.008
	Age*sex	$F(7, 2323)1.473$	.172	.004
	Age*school cluster	$F(60, 2323)=1.035$	.402	.026
MSFsc	Age	$F(7, 84.194)=7.391$	<.001*	.381
	Sex	$F(1, 2535)=.965$	.326	.000
	School cluster	$F(9, 73.185)=6.130$	<.001*	.430
	School entry (covariate)	$F(1, 2535)=51.023$	<.001*	.020
	Age*sex	$F(7, 2535)=1.180$	.311	.003
	Age*school cluster	$F(60, 2535)=1.287$	.070	.030

Figures

1a. Wake-time

1b. Sleep onset

1c. Social Jetlag

1d. Midpoint of sleep (corrected)

1e. Sleep restriction-extension

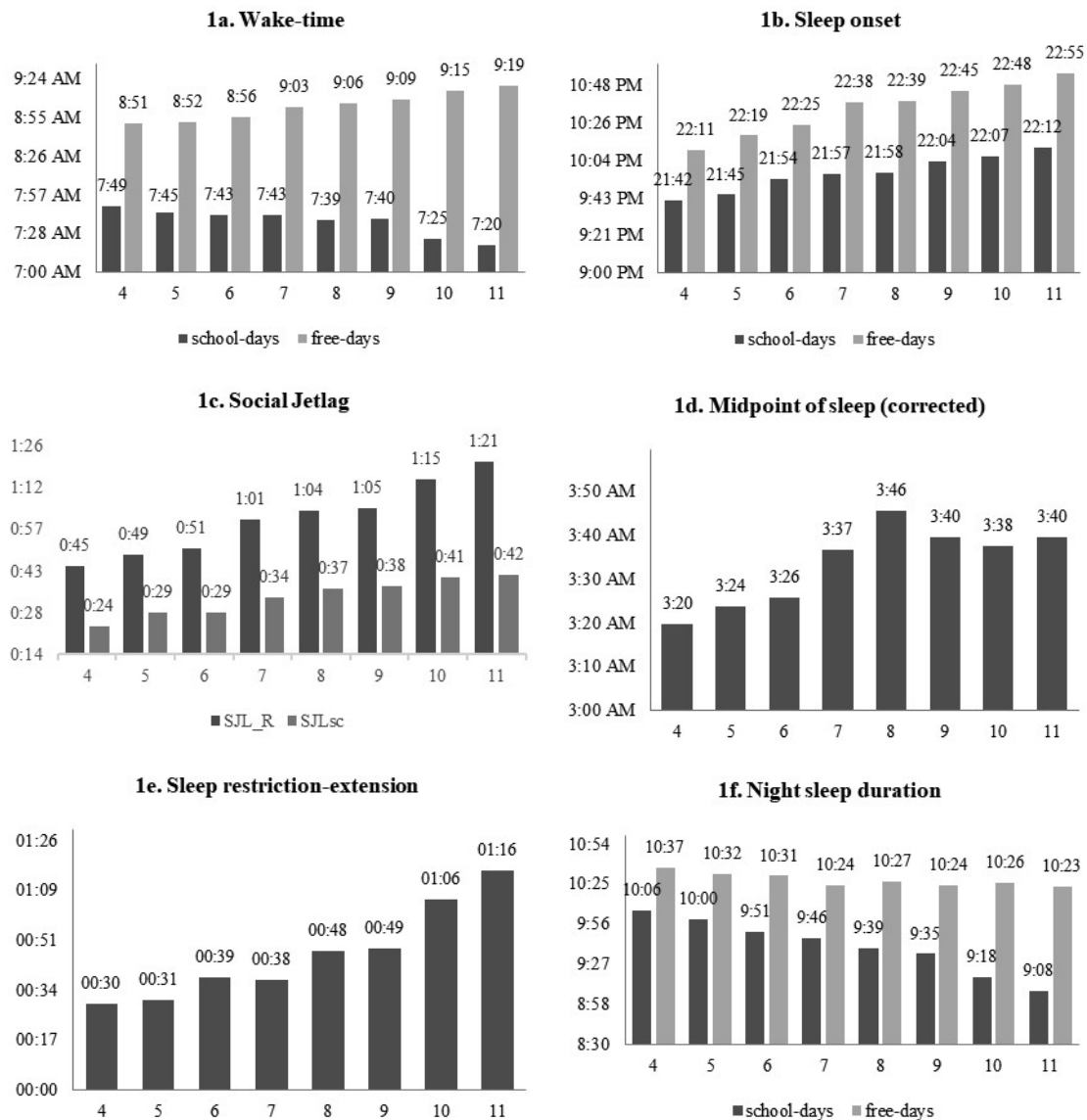**1f. Night sleep duration**

Figure 1. Differences in sleep variables by age. **Figure 1a** shows wake-time progression by age [on SC, post hoc: 4>8, 9, 10, 11; 5, 6, 7>10, 11; 4>8, 9>10, 11; 10, 11<4, 5, 6, 7, 8, 9; on FR: 4<8, 9, 10, 11; 5, 6<9, 10, 11; 10>4, 5, 6; 11>4, 5, 6, 7]. **Figure 1b** shows sleep onset progression by age [on SC, post hoc: 4<6, 7, 8, 9, 10, 11; 5<7, 8, 9, 10, 11; 4<6<9, 10, 11; 4, 5<7<10, 11; 4, 5<8<11; 4, 5, 6<9; 10>4, 5, 6, 7; 11>4, 5, 6, 7, 8; on FR, post hoc: 4<6, 7, 8, 9, 10, 11; 5<7, 8, 9, 10, 11; 4<6<7, 8, 9, 10, 11; 4, 5, 6<7, 8<11; 9, 10, >4, 5, 6; 11>4, 5, 6, 7, 8]. **Figure 1c** shows social jetlag operationalized according to Roenneberg's (23; SJL_R – darker graph), and to Jankowski's (24; SJLsc – lighter graph) formulas [SJL_R post hoc: 4, 5,

6<7, 8, 9<10, 11 and SJLsc post hoc:4<7, 8, 9, 10, 11; 5<9, 10, 11; 6<8, 9, 10, 11; 7<11].

Figure 1d shows the progression of midpoint of sleep operationalized as Roenneberg et al. (23) by age [post hoc: 4, 5, 6<7, 8, 9, 10, 11]. **Figure 1e** shows sleep restriction-extension pattern's [post hoc: 4, 5<8, 9<10, 11; 10, 11>4, 5, 6, 7, 8, 9] and **Figure 1f** shows night sleep duration's progression by age [on SC, post hoc: 4>6, 7, 8, 9, 10, 11; 5>7, 8, 9, 10, 11; 4>6>8, 9, 10, 11; 4, 5>7>9, 10, 11; 4, 5, 6>8>10, 11; 4, 5, 6, 7>9>10, 11; 4, 5, 6, 7, 8, 9>10>11; 11<4, 5, 6, 7, 8, 9, 10; on FR there are no significant differences].

2a. Wake-time

2b. Sleep onset

2c. Social Jetlag

2d. Midpoint of sleep (corrected)

2e. School entry

2f. Sleep restriction-extension

2g. Night sleep duration
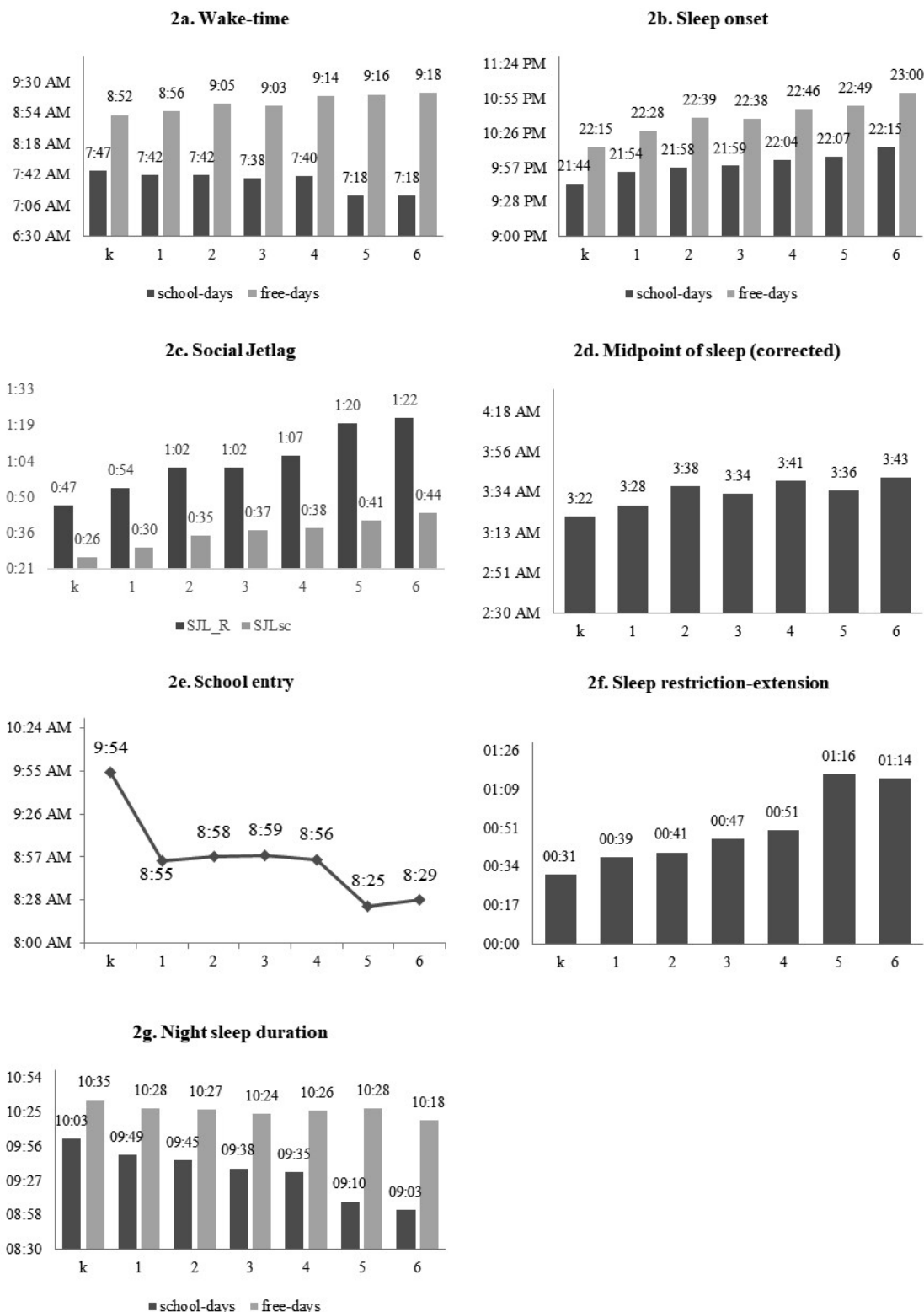
Figure 2. Differences in sleep schedule variables by school-grade level. **Figure 2a** shows wake-times' progression by school-grade level [on school-days, post hoc: k>3rd, 4th, 5th, 6th; 1st, 2nd>5th, 6th; k>3rd, 4th>5th, 6th; 5th, 6th<k, 1st, 2nd, 3rd, 4th; on free-days, post hoc: k<2nd, 3rd, 4th, 5th, 6th; 1st<4th, 5th, 6th; k<3rd<4th, 5th, 6th; 4th>k, 1st, 3rd; 5th>k, 1st, 3rd; 6th>k, 1st]. **Figure 2b** shows sleep onset [on SC, post hoc: k<1st<4th, 5th, 6th; k<2nd<5th, 6th; k<3rd<6th; k, 1st<4th<6th; 5th>k, 1st, 2nd; 6th>k, 1st, 2nd, 3rd, 4th; on FR: k<1st<2nd, 3rd, 4th, 5th, 6th; k, 1st<2nd, 3rd<5th, 6th; k, 1st<4th<6th; 5th>k, 1st, 2nd, 3rd; 6th>k, 1st, 2nd, 3rd, 4th]. **Figure 2c** shows social jetlag operationalized by Roenneberg's (23; SJL_R) and Jankowski's formulas (24; SJLsc) [SJL_R post hoc: k, 1st<2nd, 3rd, 4th, 5th, 6th; k, 1st<2nd, 3rd, 4th<5th, 6th; 5th, 6th>k, 1st, 2nd, 3rd, 4th; SJLsc post hoc: k<2nd, 3rd, 4th, 5th, 6th; 1st<3rd, 4th, 5th, 6th; 2nd<6th**]. Figure 2d** shows corrected midpoint of sleep, operationalized by Roenneberg (23) [post hoc: k<2nd, 3rd, 4th, 5th, 6th; 1st<2nd, 4th, 6th; k, 1st<2nd, 4th, 6th]. **Figure 2e** shows school entry times' progression by school-grade level [post hoc: 5th, 6th <k, 1st, 2nd, 3rd, 4th]. **Figure 2f** shows sleep restriction-extension pattern's [on SC, post hoc: k>4th, 6th; on FR there are no significant differences] and **Figure 2g** shows night sleep duration's progression by school-grade level [on SC, post hoc: k>1st>3rd, 4th, 5th, 6th; k>2nd>4th, 5th, 6th; k, 1st>3rd>5th, 6th; k, 1st, 2nd>4th>5th, 6th; 5th, 6th<k, 1st, 2nd, 3rd, 4th; on FR: k>6th].