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Original Article

Breakpoints of time in bed, midpoint of sleep, and social jetlag from infancy to early adulthood

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ABSTRACT

Objectives: The present study investigated sleep duration and sleep timing from infancy to early adulthood.
Methods: A cross-sectional survey study of $N = 18{,}323$ participants (9004 female) from 0 to 25 years ($M = 12.36$; $SD = 5.76$) from kindergartens, schools and universities in SW Germany. Participants reported their usual bedtimes and rise times on weekdays/weekends. Time in bed (TIB), the midpoint of sleep, and social jetlag were calculated from these four clock times.
Results: Weekday rise times were progressively earlier until the age of 17 years, while weekend rise times contrarily were later. As a consequence, TIB during the week was progressively shorter until the age of 16 years. The midpoint of sleep (MSFsc) was increasingly later until it reached a plateau at 17 years. Social jetlag increased until 16 years to 3:18 h. Gender differences were small for sleep duration/chronotype with males sleeping less and later than girls and non-significant for social jetlag. A regression with two breakpoints explained variability in sleep duration and sleep timing by age (45–61% explained variance) better than a regression with one breakpoint (44–59%), linear regression (25–54%) or polynomial regression (43–60%).
Conclusions: The age around 16–17 years can be considered a remarkable breakpoint when sleep behavior significantly changes back towards slightly longer sleep, less socially jetlagged behavior, and the increase in eveningness is then stopped but not reversed. A somewhat softer breakpoint is identified around 5–7 years when the rapid changes in sleep behavior initiate.

1. Introduction

There are individual differences in the amplitude and phase of the circadian sleep-wake rhythm. Infants, children, adolescents, and young adults share typical characteristics in their preferred circadian rhythmicity, and the passage from childhood to adulthood is a stormy one. The present study aims to portray the changes from a young age (newborns) to early adulthood in a large cross-sectional sample mainly from southwest Germany.

1.1. Time in bed

From childhood to adolescence to adulthood, the timing of sleep drifts from morningness to eveningness and then back again to morningness, while individual sleep duration or time in bed (TIB) remains relatively stable longitudinally and correlates highly ($r = 0.73$ within individual correlation) over a period of 10 years [1]. However, on average, sleep duration declines with increasing age [2]. Sleep duration decreases from 14 h at six months of age to 8 h in 16-year-olds [3] and, especially between 14 and 17 years, sleep duration is insufficient, when girls sleep longer than boys [4]. During young adulthood, sleep duration becomes longer again [5], mainly because of earlier bedtimes on weekends. In many studies, sleep duration is approximately measured by questions that deal with time in bed (TIB), namely by assessing bedtimes and rise times. Therefore, sleep duration differs somewhat from TIB. In addition, TIB is longer than sleep duration. Nevertheless, parallel to sleep duration, TIB decreases with increasing age [6,7].

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1.2. Midpoint of sleep

The midpoint of sleep (MSF) is the clock time between sleep onset and waking up. It is correlated with dim light melatonin onset ($r = 0.7$) and seems a reliable marker of chronotype [8]. From infancy to early and middle childhood, individuals attach to the daily rhythm set by parents or other caregivers. Starting in late childhood with puberty, adolescents experience powerful sexual, emotional and cultural changes and as a consequence, they prefer to go to bed much later than pre-adolescents [9]. MSF gender differences are strongest during puberty and early adolescence where boys experience a later MSF than girls [5,10]. The end of adolescence coincides with an abrupt change where sleep timing reverts to morningness orientation [10]. In a large U.S. sample [11], the peak in lateness was at ~19 years (18.4 years for females and 19.2 years for males). This turn back to morningness is one year earlier in females than in males [10]. An earlier reverse to morning orientation has been found by Tonetti et al., [4]. In a U.S. sample, the gender differences in MSF were greatest for 15–25-year-olds with males being the later chronotypes [11].

1.3. Social jetlag

There is a discrepancy between weekdays and weekend sleep timing which has been called social jetlag [12]. Social jetlag (SJ) is already present in infants aged 0–6 years; the difference becomes greater with increasing age – more than 30 min at age six [13,14]. Early weekday school schedules induce more sleep loss and daytime sleepiness on weekdays [15–17]. Beginning at nine years, children sleep significantly longer on the weekend than on weekdays [1]. Sleep is curtailed by the early school schedules and this weekday sleep deprivation is partly compensated for by longer sleep duration (1 h 20 min) on weekends [18]. The misalignment of adolescents' weekday-weekend sleep pattern [11] has implications for physiological [19,20] and psychological functioning [21–23], health [24] and academic achievement [25,26]. For example, the late sleep pattern on weekdays is correlated with the consumption of alcohol, caffeine, and tobacco [19]; obesity [20]; depression [21,22]; (hypo)mania [23]; increased blood pressure [24]; lower attention in class [25]; and worse grades [25,26]. SJ is most extreme in adolescents, and particularly in boys [27]. SJ is still found in early adulthood [28] but then is softened by a weakened endogenous pacemaker [29] or by internalized worldly responsibilities like establishing a career or a family [30].

1.4. The present study

Sleep duration and timing differ with age [1,10,17] and a shift of chronotype at 19–20 years was coined as a marker for the end of adolescence [10]. However, to our best knowledge, these authors did not calculate a mathematically derived breakpoint for this shift. The present study aims at portraying differences of time in bed (TIB), midpoint of sleep (MSF), and social jetlag (SJ) from young age (newborns) to early adulthood and suggests that there are different sleep patterns: long TIB and early MSF in the pre-adolescent stage, short TIB, late MSF, and SJ in the adolescent stage, and short TIB and a turn back to early MSF in the post-adolescent stage. Regarding gender differences, longer TIB for girls than for boys, an earlier turn towards later sleep times in girls than in boys, and stronger social jetlag in boys than in girls are hypothesized. Mathematically derived breakpoints by age for the changes in TIB, MSF, and SJ are suggested.

2. Participants and methods

2.1. Participants and data collection

This study included 18,323 participants (9319 male, 9004 female) between 0 and 25 years ($M = 12.36$, $SD = 5.76$). Participants were recruited in SW Germany. We used clock time data projects that aimed at investigating the effects of chronotype on sleep problems [18], on the effectiveness of lessons at specific times of day [31], and primary school grades [32]. Data from three extensive projects are based on $N = 3337$ [18], $N = 1474$ [31], and $N = 1085$ [32]. $N = 12{,}427$ additional data were collected from more than 70 research students who participated in data collection for this study. Data collection was from 2006 to 2016. All protocols were approved and follow the guidelines of the university's research committee. The methods were carried out following the relevant guidelines and regulations. We received informed consent of all participants as well as written informed consent of all participants' parents when below 18 years. The methods were chosen in accordance with the age group. A parent-report online questionnaire was used to gather infants' sleep data, classroom-based pencil and paper questionnaires were used for the school students enrolled in fourth grade or higher and a combination of different data collection methods (online/paper and pencil) was used for the university students.

2.2. Measures

Participants reported their usual bedtimes and rise times on weekdays and weekends. Five variables were calculated from these four clock times: average TIB, TIB on weekdays, TIB on weekends, SJ, and MSF. Since the data is not based on actual sleep data (eg, actigraphy or polysomnography), we used TIB as an approximation for sleep duration. There are two conceptualizations of chronotype, one as a preference measure [33] and the other one as a clock-based measure [9]. We here based our study on the clock times and thus refer to chronotype as MSF. The MSF was adjusted for individual sleep debt on weekdays (MSFsc) [10] and was not based on actual sleep data (sleep onset/awakening) but on self-report measures on bedtimes and rise times. SJ is considered as the absolute difference between mid-sleep on weekdays and mid-sleep on weekends [12]. Here, we used an approximation for SJ, because it also calculated from the self-reported bedtimes and rise times on weekdays and weekends.

2.3. Statistical analyses

SPSS [34] was used to perform descriptive analyses (Figs. 1 and 2). We calculated a MANOVA in SPSS to assess the general influence of age (continuous variable) and gender on the dependent sleep variables (Table 1). We performed linear regression, segmented (or broken-line/breakpoint) regression using the R-package "segmented" [35], and polynomial regression in R [36] to analyze the relationships between age and the dependent variables (Figs. 3–5) and, additionally, separately for males and females (Appendices A–C). The R-package "segmented" was used to analyze linear models that show one or more segmented relationships in their linear predictor (in our case, age) and provide breakpoints of those relationships. Hence, we used this analysis to define the age at which males and females show a change in their sleeping behavior. A model fit comparison was also made in R. The clock times were linearized (eg, clock times after 23:59 were transformed into values of 24:00, 24:01… and higher). Figures were created in SPSS and R and then annotated in Adobe Illustrator [37]. We analyzed full data sets where participants responded to all questions. See Appendix D for the code used to generate Figs. 3–5 and the figures in Appendix (A–C).

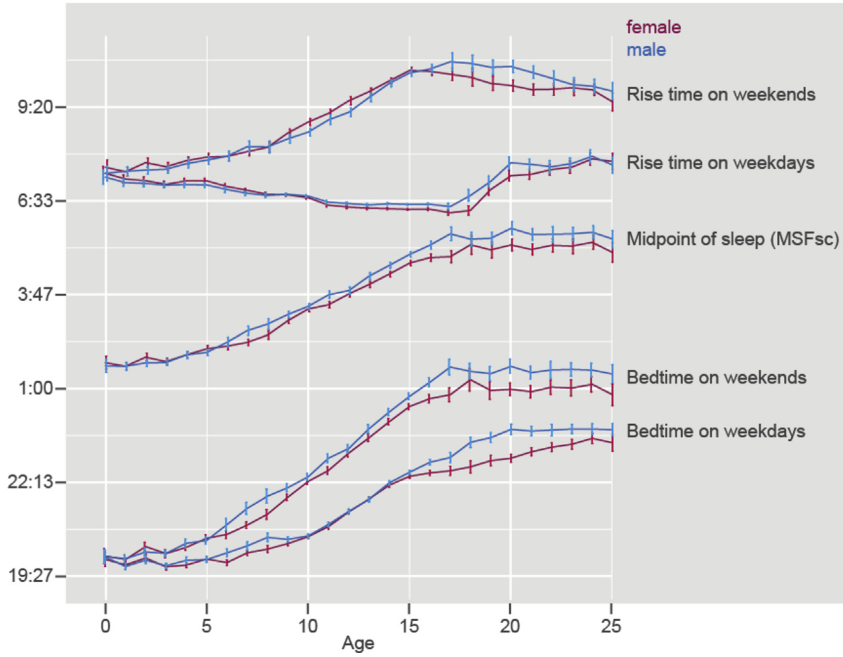

Fig. 1. Rise and bedtimes on weekdays and weekend, and midpoint of sleep by age and gender. *Note:* Age in years on the x-axis, the y-axis shows clock times; Error bars are 95% CI.

3. Results

3.1. Descriptives

Fig. 1 shows differences in rise times, bedtimes and MSFsc by age and gender with respect to weekdays and weekend; Fig. 2 shows these differences for TIB and SJ (see also Appendices E and F for the results when not separated by gender and Appendix G for the descriptives of each sample). Rise times on weekdays get progressively earlier until the age of 17 while rise times on weekends contrarily get later with increasing age until the age of 18. Thus, the difference in rise times between weekdays and weekend is largest

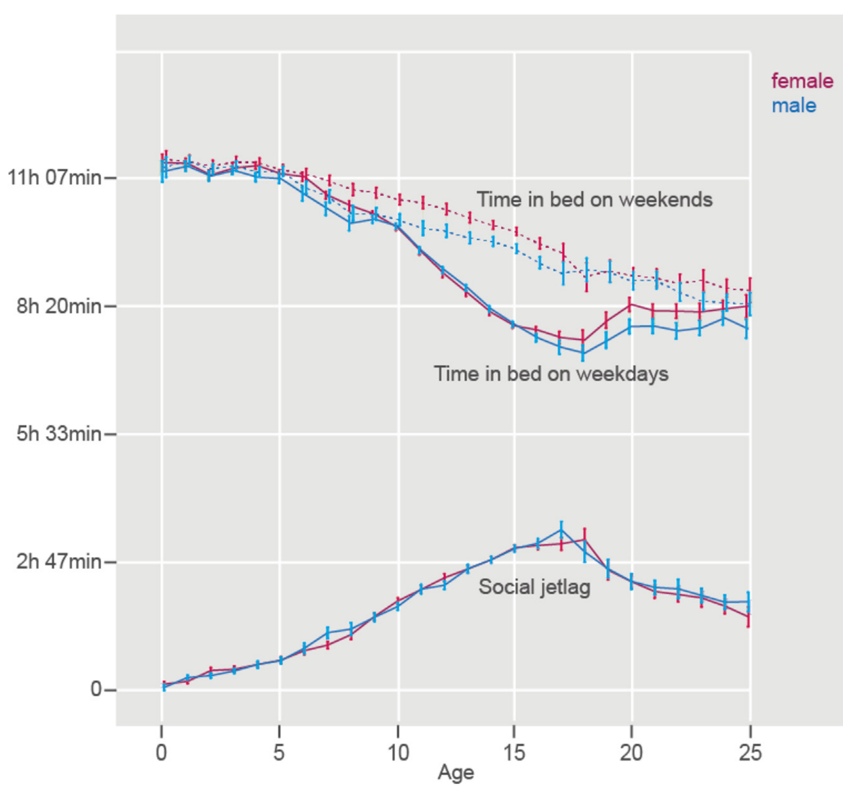

Fig. 2. Time in bed on weekdays and weekend, and social jetlag by age and gender. *Note:* Age in years on the x-axis, the y-axis depicts time in bed; Error bars are 95% CI.

Table 1
Analysis of variance.

Dependent variable	F	p	η^2_p
Age			
Rise time on weekdays	13.2	<0.001	0.001
Rise time on weekends	6793.9	<0.001	0.271
Bedtime on weekdays	29,397.9	<0.001	0.616
Bedtime on weekends	23,841.5	<0.001	0.565
Time in bed (TIB) on weekdays	20,372.6	<0.001	0.527
Time in bed (TIB) on weekends	5643.5	<0.001	0.236
Time in bed (TIB)	21,265.2	<0.001	0.537
Midpoint of sleep (MSFsc)	16,123.0	<0.001	0.468
Social jetlag (SJ)	6049.5	<0.001	0.248
Gender			
Rise time on weekdays	77.5	<0.001	0.004
Rise time on weekends	8.5	0.003	<0.001
Bedtime on weekdays	141.1	<0.001	0.008
Bedtime on weekends	147.9	<0.001	0.008
Time in bed (TIB) on weekdays	13.8	<0.001	0.001
Time in bed (TIB) on weekends	248.7	<0.001	0.013
Time in bed (TIB)	90.2	<0.001	0.005
Midpoint of sleep (MSFsc)	116.4	<0.001	0.006
Social jetlag (SJ)	3.4	0.064	<0.001

Note: Corrected R^2, rise time on weekdays = 0.005, rise time on weekends = 0.271, bedtime on weekdays = 0.617, bedtime on weekends = 0.567, TIB on weekdays = 0.527, TIB on weekends = 0.243, TIB = 0.538, MSFsc = 0.470, SJ = 0.248.

near the end of adolescence. After the age of 18, rise times on weekdays (getting later) and on weekends (getting earlier) re-approach each other to some extent but the gap does not close.

Bedtimes on weekdays were early for ages 0–6 (well before 20:00) and got increasingly later from the six years to 20 years and then stay on a level of late bedtime at around 23:30. Bedtimes on weekends show a similar but steeper progression in lateness and this progression went from 20:00 to 20:30 at the age of five, with a steep increase until the age of 17 when the bedtimes on the weekend remain late at around 1:15. MSFsc is early during infancy (1:39 am in 1-year-olds) and becomes increasingly later until the end of adolescence where it reaches a plateau at ~5:20 am for 18–25-year-olds. Regarding gender differences, males generally were later than girls, except pre-pubertal rise times.

TIB is longest (11:24 h) in one-year-olds and differences in rise times between weekdays and weekend are relatively small (17 min in one-year-olds, 29 min in three-year-olds, 56 min in six-year-olds; Fig. 1). TIB on weekdays was progressively shorter until 18 years (7:53 h) and then increased again, mainly because of the later rise times during the week. TIB on the weekend gets continuously shorter with increasing age. Regarding gender, girls spent more time in bed – in pre-adolescence this difference is visible for weekends while in early adolescence, the longer TIB for girls is more pronounced on weekdays. SJ is nearly absent during the toddler age, increases from 6 to 18 years where it reaches about 3:18 h, and then decreases again to 1:47 h at 25 years. There are no gender differences in social jetlag (Fig. 2).

3.2. Analysis of variance

In general, there were significant and substantial age effects (η^2_p) on rise and bedtimes, sleep duration and sleep timing as shown by a multivariate analysis of variance (Table 1) except rise times on weekdays ($\eta^2_p = 0.001$). Concerning gender, all effects were small ($\eta^2_p < 0.010$) with the exception of sleep duration on weekends ($\eta^2_p = 0.013$) and non-significant concerning SJ.

3.3. Linear, segmented, and polynomial regression models

Linear regressions, linear regressions with one and two breakpoints, and polynomial regressions were performed (see Figs. 3–5 and Appendix H) to analyze the effects of age on TIB, MSFsc, and SJ. Consistent with these three dependent variables and also in analyses separated by gender (see Appendices A–C and I), the

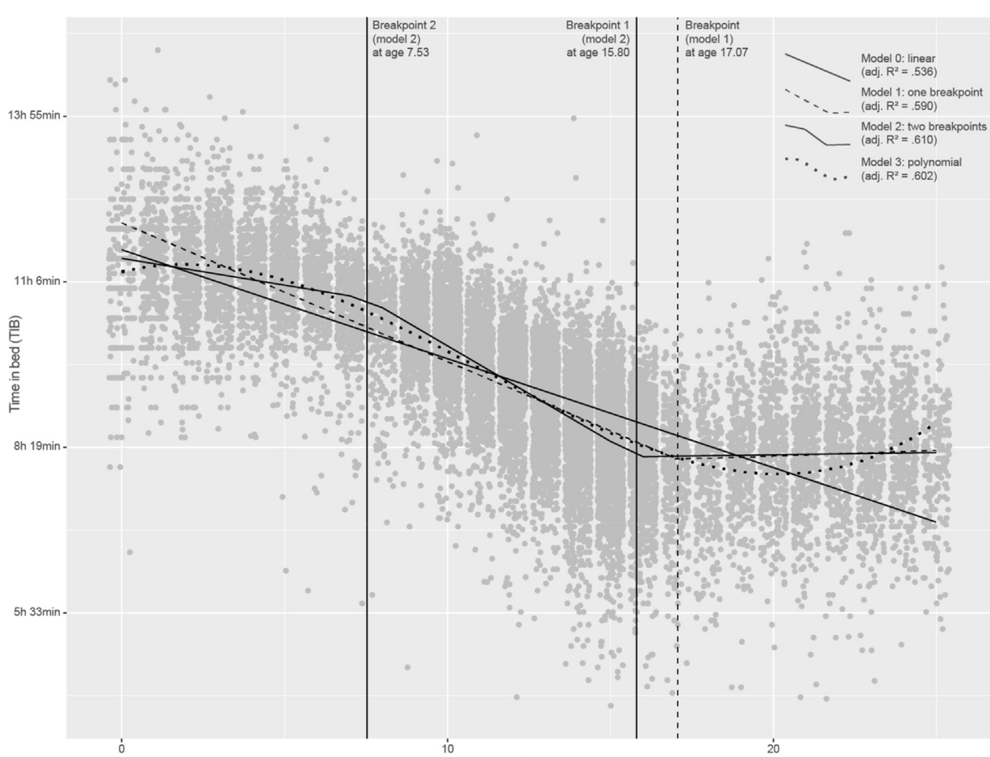

Fig. 3. Regression models, time in bed (TIB) by age.

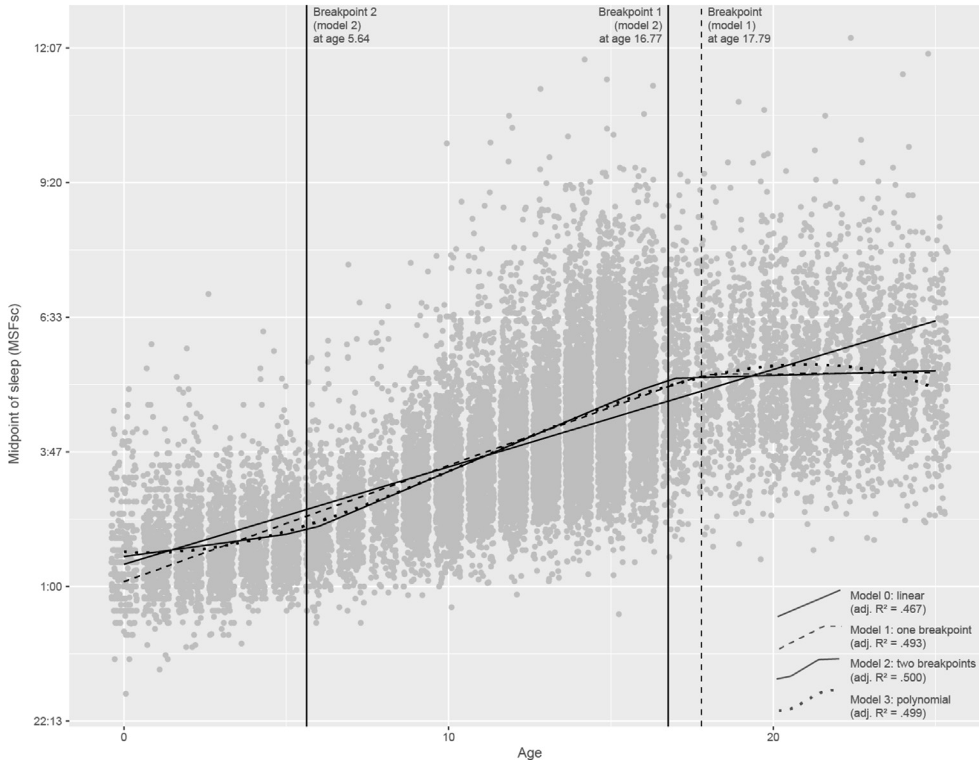

Fig. 4. Regression models, the midpoint of sleep (MSFsc) by age.

regressions with two breakpoints explained significantly higher amounts of variance (with significantly reduced residual variance) than the polynomial regressions, the regressions with one breakpoint, and the linear regressions (Appendix J).

The two breakpoints in sleep behavior from model 2 occur at different ages for TIB, MSFsc, and SJ. TIB and SJ had a breakpoint at ~16 years (15.80 years, Fig. 3/15.71 years, Fig. 5), which is the approximate time when students complete their secondary

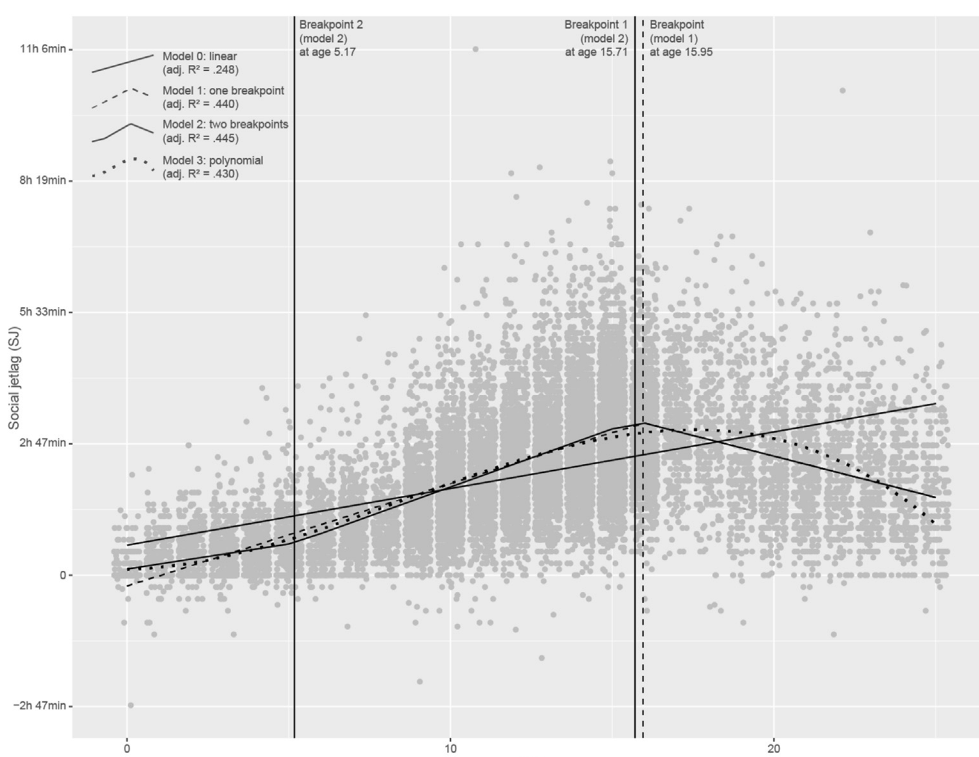

Fig. 5. Regression models, social jetlag (SJ) by age.

education and apprenticeship or higher education starts. The increase in MSFsc stopped one year later at ~17 years (16.77 years, Fig. 4). There was an early breakpoint for SJ at 5.17 years which was earlier than the breakpoints in MSFsc (5.64 years) and TIB (7.53 years).

Boys had a much later breakpoint (at 9.41 years) than girls (at 6.59 years) in TIB (Appendix A) which implies that the girls' TIB starts to decline earlier than boys'. However, at this stage, girls' TIB was longer than boys'. Thus, they catch up with the boys for a similar TIB during adolescence but then again have an earlier breakpoint than boys at 15.57 years which implies that girls again have more TIB than boys in early adulthood. Males had a later MSFsc than females, and this difference increased with increasing age (Appendix B). SJ was equally distributed across the genders (Appendix C).

4. Discussion

Within this sample of German children and adolescents, the respondents seem to have sufficient sleep based on the TIB measure as compared with the National Sleep Foundation's recommendation [38]; only the 14–17 years old adolescents' time spent in bed are near the lower level of the recommended sleep duration. Yet, this value refers to average TIB on weekdays and weekend, which takes into account the weekend recovery sleep. Given the schooldays/workdays, adolescents from 14 to 19 years sleep shorter than the suggested 8–10 h [38]. Weekday rise times became progressively earlier until 17 years while weekend rise times contrarily became later. The discrepancy is induced by early school schedules/late bedtimes and has several bad outcomes for adolescent development and general health [39]. The misalignment between the internal biological clock and the social schedule is largest towards the end of adolescence. However, the delay of bedtimes stops at around 20 years. In consequence, TIB became shorter until the 18 years and then slowly increased again, which is line with previous studies [3,5,40]. Here, we show that in young adults, there is a turn towards longer TIB, which is a new mosaic compared to existing studies. In agreement with most previous studies [10,41,11], the present study showed that women had longer TIB and earlier MSFsc. On the other hand, gender effects are generally much smaller than age effects.

SJ is nearly absent during the toddler age but then increases until 17 years where it reaches 3:18 h. Of course, toddlers usually conform to their own rhythms and are not influenced too much by social schedules in Germany (at least during the first years of life). Thus, the internal rhythm and the “social” rhythm are more or less similar. On the contrary, young children influence the social rhythm and sleep of their parents, rather than vice versa [30]. Due to the discrepancy between early school start times and the dramatic changes in sleep behavior on the weekend, SJ increases until the end of adolescence. The early breakpoint for SJ at 5.17 years suggests that the shift of circadian rhythm with its peak in adolescence starts with the misalignment of weekday and weekend sleep timing in early childhood, and thus we propose that this misalignment should be studied further as one causal factor which triggers late chronotype in adolescence, along with other factors (eg, sexual hormones).

Breakpoints of the segmented regressions and inspection of the graphs show that, near the end of adolescence, breakpoints in TIB, MSFsc, and SJ occur. MSFsc's breakpoint was 16.30 years for girls and 17.02 years for boys. These breakpoints were earlier than the values presented by Fischer et al., [11] and Roenneberg et al., [10] who reported a peak at 18.4/19.5 years in women and of 19.2/20.9 years in men. Note that these data are not completely identical but complementary, although Fischer et al., [11] did not use schooldays/workdays data, and our model with only one breakpoint also yielded a later breakpoint than our model with two breakpoints. However, our model was still much earlier when compared to Fischer et al., [11] and Roenneberg et al., [10]. Roenneberg et al., [10] used data from 10 years until retirement and Fischer et al., [11] from 15 years or older; our sample ranged from 0 to 25 years. Thus, the different turning points suggested by previous studies may be related to the different age ranges of the samples. The other point to consider is that we, similar to Fischer et al. [11], used a proxy for MSFsc which is slightly different from the more precise measure of sleep onset time and wake time. Finally, the turning point may depend on the analysis model. The segmented regression with breakpoints suggested earlier turning points (around 16–17 years instead of around 18–20 years) than, for example, a polynomial model. The polynomial regressions suggested similar turning points as suggested by Roenneberg et al., [10]. Alternately, the segmented model with breakpoints described our data better than the polynomial model, and therefore we suggest further investigation of segmented models.

4.1. Limitations

The strengths of this study are the large data set and the novel statistics. However, the data used in this study stem from different projects using different data collection methods (parent-report, self-report; online survey or paper and pencil in class).

As another limitation, this study reports data from cross-sectional designs. The interpretation relies on correlations and any causal interpretations of age and sleep variables should be treated with caution. Thus, developmental changes are suggested, but longitudinal studies are needed to validate the results of this study. Alternately, the developmental changes can be attributed to the population. We had 50.9% male subjects in our database, which is close to a representative sample – for example, in Germany, 51.3% of the general population below 20 years are males, and between 20 and 29 years 50.9% are males.

In the same vein, a methodological limitation is the use of self-administered questionnaires that calls for cautious interpretation of the sleep measures. On the other hand, the collection of objective data on sleep variables (eg, via actigraphy or polysomnography) was not feasible for such a large sample. Self-reported and actual sleep are moderately correlated ($r = 0.43$) and the self-reported time spent asleep is about 1 h longer than the actual time spent asleep [42].

The location of breakpoints may be dependent on the educational background of the sample. The transition from school to university or apprenticeship occurs at different ages. The intermediate track (Realschule) graduates at around 16 years, and the upper track (Gymnasium) graduates at 18 years, and therefore, the breakpoints may occur earlier or later depending on the educational background of the sample. Future studies, therefore, should control for the educational background when calculating the breakpoints.

4.2. Conclusions

The present study investigated breakpoints of sleep duration and timing using TIB, MSFsc, and SJ as markers in 0–25-year-olds. A comparison of linear, segmented and polynomial regressions identified the segmented regression with two breakpoints as the better way of explaining age differences in sleep duration and timing among this age range. Therefore, the breakpoints at 5–7 and 16–17 years suggest significant developmental changes in human sleep duration and timing. The age of 16–17 years is a remarkable breakpoint where sleep behavior significantly changes back towards a more morning-oriented and less jetlagged behavior.

Author contributorship

C.R. designed the study; C.R., H.I.G., and C.V. collected most of the data. C.R., C.V., and N.K. made the analyses, C.R., C.V., H.I.G., and N.K. wrote the manuscript. All authors reviewed the manuscript.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sleep.2019.01.023.

Conflict of interest

All authors declare no financial conflict of interest. The study complies with German Law. All authors declare no potential conflicts of interest concerning the research, authorship and/or publication of this article.

The ICMJE Uniform Disclosure Form for Potential Conflicts of Interest associated with this article can be viewed by clicking on the following link: doi.org/10.1016/j.sleep.2019.01.023.

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