Development of late circadian preference – sleep timing from childhood to late adolescence

Liisa Kuula[a], MA, Anu-Katriina Pesonen[a], PhD, Ilona Merikanto[a], PhD, Michael Gradisar[b], PhD, Jari Lahti[a,c], PhD, Kati Heinonen, PhD[a], Eero Kajantie[d,e,f], MD, PhD, Katri Räikkönen[a], PhD

Affiliations: [a]Department of Psychology and Logopedics, University of Helsinki, Helsinki, Finland; [b]School of Psychology, Flinders University, Adelaide, Australia; [c]Helsinki Collegium for Advanced Studies, Helsinki, Finland; [d]National Institute for Health and Welfare, Chronic Disease Prevention Unit, Helsinki, Finland; [e]Children's Hospital, Helsinki University Hospital and University of Helsinki, Helsinki, Finland; [f]PEDEGO Research Unit, MRC Oulu, Oulu University Hospital and University of Oulu, Oulu, Finland

Address correspondence to: Liisa Kuula, Department of Psychology and Logopedics, Faculty of Medicine, P O Box 21, 00014 University of Helsinki, [liisa.kuula-paavola@helsinki.fi], +358 407546308.

Keywords: morningness, eveningness, chronotype, poor sleep, sleep midpoint

Short title: Sleep patterns from childhood to late adolescence

Funding Source: All phases of this study were supported by The Academy of Finland. This work was also supported by Juho Vainio Foundation, Signe and Ane Gyllenberg Foundation, PsyCo Doctoral Programme of Psychology, Sigrid Juselius Foundation, Foundation for Pediatric Research, Novo Nordisk Foundation, Emil Aaltonen Foundation, and the Australian Research Council. No monetary or material compensation was given to anyone to produce the manuscript.

Financial Disclosure: Dr. Gradisar reports he has received partial project funding from Re-Timer Pty Ltd., paid consultancies from the Australian Psychological Society and Little Brown Book company, and is a shareholder in ResMed. The other authors have indicated they have no financial relationships relevant to this article to disclose.

Liisa Kuula wrote the first draft of the manuscript. All the authors have indicated they have no potential conflicts of interest to disclose.

Abbreviations: WASO – Wake After Sleep Onset, SE – Sleep Efficiency, MEQ – Morningness-Eveningness Questionnaire, BMI – Body Mass Index, SES – socio-economic status, PDS – Pubertal Development Scale, MD – Mean Difference, CI – Confidence Interval, T1 – Time point 1, T2 – Time point 2, T3 – Time point 3

ABSTRACT

STUDY OBJECTIVES

To assess differences relating to circadian preference in objectively measured sleep patterns from childhood to adolescence, over a 9 year period. Sleep timing is likely to shift later in adolescence, but it is unclear whether this associates with childhood sleep patterns; we hypothesized there is developmental continuity in sleep timing and duration according to circadian preference.

STUDY DESIGN

Young participants (N=111, 65% girls) from a community-based birth cohort underwent sleep actigraphy at mean ages 8.1 (SD=0.3), 12.3 (SD=0.5), and 16.9 (SD=0.1) years. A short version of Morningness-Eveningness Questionnaire was administered in late adolescence. At each follow-up, sleep midpoint, duration, wake after sleep onset (WASO), sleep efficiency (SE) and weekend catch-up sleep were compared between those reporting morning, intermediate, and evening preferences in late adolescence.

RESULTS

Mixed model analyses indicated that sleep timing was significantly earlier among morning types compared to evening types at all ages (p-values<0.04). The mean differences in sleep midpoint between morning and evening types increased from a mean of 19 minutes (age 8), 36 minutes (age 12), to 89 minutes (age 17). The largest change occurred from age 12 to 17. Sleep duration, WASO, SE, and catch-up sleep did not differ according to circadian preference.

CONCLUSIONS

This study found significant continuity in sleep timing from childhood to adolescence, over 9 years, indicating that late circadian preference reported in late adolescence begins to manifest in middle childhood. Further studies are needed to establish whether sleep timing has its origins at an even earlier age.

Introduction

Circadian preference varies between individuals, and is influenced by genetic factors[1-3] and external cues[4]. This results in differences in activities such as sleep timing. Later circadian preference is associated with several adverse outcomes[5-8].

During childhood, sleep timing is highly dependent on parental guidance. This typically changes during adolescence when more autonomy is gained over schedules[9]. Together with emerging biological pressure towards a later-timed circadian rhythm, adolescence is a particularly vulnerable period for problems in circadian regulation[10, 11]: several reports emphasize that adolescents have a high risk for developing delayed sleep phase disorder[12], as they tend to have the most irregular sleep behavior and a large amount of weekend catch-up sleep compared to other age groups[13].

Previous cross-sectional studies have reported shorter sleep duration and later sleep midpoint among those who report a preference for eveningness[14-16]. In this longitudinal study we investigated how self-reported circadian preference reflects in the developmental trajectories of objectively measured sleep patterns from middle childhood to late adolescence, and hypothesized there is significant variation in the trajectories specifically related to sleep duration and its timing. We expected that compared to adolescents with a morning preference, adolescents with a circadian preference towards eveningness would have a later sleep midpoint from middle childhood onwards, resulting in shorter sleep duration over time.

Methods

Participants

Participants were recruited from an urban community-based cohort composed of 1049 healthy singletons born in 1998 in Helsinki, Finland. Details are described in previous reports[17, 18]. The current study builds on objective sleep measurements from three time points across nine years, from age 8, and 12 to age 17 years. Figure 1 (online only) illustrates the participation in the follow-ups.

In 2006 (Time 1 (T1), at 8 years of age), we invited a subsample of the initial cohort members who had given permission to be included in a follow-up and who were traceable. Due to original research interests, this subsample was weighted on mothers who consumed more glycyrrhizin (which inhibits placental 11β-HSD2 function) in the form of licorice during pregnancy[17].

In 2009-2011 (Time 2 (T2), at 12 years of age), all the initial cohort members (n=1049) who had given permission to be contacted and whose addresses were traceable were invited to a follow-up, of which 692 (75.2%) could be contacted by phone (mothers of the adolescents).

In 2014-2015 (Time 3 (T3), at 17 years of age), we invited all cohort members who participated at T2 and lived within a 30 km radius from Helsinki to participate in a follow-up. At T3, the Morningness-Eveningness Questionnaire (MEQ)[19] was administered resulting in data from 189 adolescents. Due to missing responses to some of the questions in the full MEQ, we used a previously validated short form of MEQ (rMEQ)[20] comprising 6 out of the 19 items in full MEQ.

Complete sleep actigraphy data from all the three measurement points and rMEQ data from T3 were available for 112 adolescents. One participant was excluded from analysis due to sleep midpoint differing over four SDs from the mean at T3. Thus, our analytical sample consisted of 111 (64% females) adolescents who had complete sleep data and information on circadian preference.

The Ethics Committees of the City of Helsinki Health Department and Children's Hospital in Helsinki University Central Hospital approved the study protocols (HUS 400/E7/05 for T1 and T2; 177/13/03/03/2014 for T3). Informed written child and parent consent were obtained at T1 and T2, and only adolescent consent at T3.

The representativeness of the samples at each time point T1[21], T2[22] and T3[16] in relation to the original cohort has been reported previously. The sample in this study (n=111) did not differ from the rest of the participants at T3 (n=86) regarding any of the sleep variables, body mass index (BMI), sex, age, mother's BMI, mother's age at birth, gestational age, maternal alcohol consumption, length at birth, birthweight, pubertal development, or, highest education level of the parents. Those in the sample had mothers reporting lower maternal licorice consumption compared to other T3 participants (p=0.03). With regard to the initial cohort, there were no differences between the current sample (n=111) and the rest of the initial cohort (n=938) in mother's BMI, maternal licorice consumption, maternal alcohol consumption, gestational age, length at birth, and birthweight (p>0.07), but current participants were more likely to be girls (p=0.002) and had older mothers (p=0.003).

Sleep

Actigraphs are watch-like, wrist-worn devices containing motion accelerometers to measure limb movements. Actigraphy is a widely used objective method used to study sleep–wake patterns in pediatric populations[23]. We measured sleep duration, quality, and timing using actigraphs (Actiwatch AW4 at T1 and AW7 at T2 and T3, CamNtech Ltd, Cambridge, United Kingdom). All measurements were completed with medium sensitivity and 1-minute epochs. We used the validated Actiwatch algorithm[23] to detect sleep onset and offset.

Participants were instructed to wear actigraphs for 10 days at T1, T2 and T3 on their non-dominant wrists, and completed sleep diaries during the measurement period. Actigraphy data were handled as described previously[18]. Participants were instructed to document all temporary pauses into the sleep log, and, to report other significant occurrences, such as travel or illness. Nights were excluded from further sleep analyses if: (a) the actigraph was not in use; (b) information on bedtimes was missing; (c) the data on reported bedtime indicated that the person was already asleep (suggesting that the bedtime was incorrectly reported); (d) information on waking time was missing and the activity pattern was unclear; or (e) a change in normal life was reported, such as sleep-overs, daytime napping, illness, or travel.

Sleep duration, onset, offset, and wake after sleep onset (WASO) were extracted from the data by the software (Actiwatch Activity & Sleep Analysis versions 5.42 and 7.0, CamNtech Ltd, Cambridge, United Kingdom). Sleep efficiency (SE) was calculated as the time spent asleep divided by the amount of time in bed, multiplied by 100 (reported as a percentage). Sleep midpoint was defined as the time point when half of assumed sleep (time in bed) had passed since sleep onset. Sleep onset, offset, and midpoints were calculated for both weekdays and weekends separately. Irregular sleep patterns were operationalized as the amount of catch-up sleep during the weekend (calculated as the subtraction of weekday nights' sleep duration from weekend nights' sleep duration), assumed to be an indicator of cumulative sleep debt [12]. Additionally, we calculated differences in mean sleep midpoint, sleep onset, sleep offset, weekend catch-up sleep, sleep duration, WASO, and, SE from T1 to T2, from T1 to T3 and from T2 to T3 in order to study the amount of change in these variables over development.

Circadian preference was assessed at T3 using the six-item short version of the MEQ[19, 20]. MEQ is a questionnaire which evaluates an individual's preference to perform their daily tasks at a certain time. Questions include both direct questions about a person's circadian preference and descriptions of hypothetical situations in which an individual has to select which time frame would result in optimal performance. As described previously[16], we used a rating yielding in a 3-class circadian preference: morning, intermediate, and evening. We used the following cut-off points for the classification of rMEQ types: 5-12 for eveningness, 13-18 for intermediate, and 19-27 for morningness[20].

Covariates and confounders

Information on age and sex were derived from initial cohort records, and these were controlled for in all analyses. Pubertal development was self-reported using the Pubertal Development Scale (PDS)[24] at T2 and T3, as described previously[22]. The PDS is a validated five-item self-report scale for: body hair, growth spurts, skin changes, and menarche and breast development for girls, and facial hair and voice change for boys. At T3 a mean value was calculated based on a scale of no changes yet (1) to changes seem complete (4); at T2 the fourth option was omitted due to the participants' young age. BMI was calculated as kg/m^2 using measurements from clinical visits (T1, T2) or nurse's home visit (T3). Parental education was self-reported at T2 as described previously[25], and was used as a proxy for socioeconomic status (SES). These variables were investigated as potential confounders for differences in sleep between morning, intermediate, and evening types.

Statistical methods

We used SPSS version 24.0 for all statistical analyses (IBM Corp. Released 2016. IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp.). In order to avoid multiple comparisons, we used a linear mixed model approach, where at the first step we examined whether the overall level of sleep pattern across time differed across circadian preference, and second, whether the sleep pattern trajectory developed differently across the time points depending on the circadian preference. Finally, as post-hoc analyses only for the statistically significant outputs from the mixed models, we used ANCOVAs to calculate the mean differences (MD) between circadian preference types. All analyses are reported using 95% confidence intervals (95% CI) and the significance threshold was set at .05. Covariates included sex and age at the time of sleep measurements.

Results

Initial analyses

Table 1 presents basic characteristics of the sample according to circadian preference. There were no significant differences in circadian preference regarding birthweight, SES, age at measurement points, BMI at T1, T2 and T3, or pubertal development at T2 and T3 (all p-values >0.05). There were no significant sex differences in the circadian preference (p=0.88), but girls and boys differed regarding two sleep measures: sleep duration at T1 and T3 was significantly longer in girls compared to boys (MD=0:16 hours (h), 95 % CI [0:00, 0:33], p<0.04 and MD=0:18 h, 95 % CI [0:03, 0:32], p=0.014, respectively).

Table 2 (online only) lists the mean amount of measured nights: only participants with sleep data from all time points and a minimum of three nights (2 participants had only weekday nights at T1, and 5 participants at T3) from at least two time points were included. Regarding differences in sleep timing, weekday and weekend nights were analyzed separately. At T1 sleep data were available for 3-4 nights from 1%, for 5-7 nights from 83%, and for 8-12 nights from 16%. The corresponding percentages were 3%, 24%, and 72% at T2, and 2%, 25%, and, 71% at T3, respectively.

Table 2 (online only) presents the raw sleep values in the entire sample and according to the three circadian preference types at T1, T2, and T3. In line with previously reported normative development[13, 18, 26], weekday and weekend sleep duration decreased over the three measurement points, sleep quality (as indicated by decreasing WASO minutes and increasing SE) improved, the amount of weekend catch-up sleep increased, and both weekday and weekend sleep onset and offset times shifted to later resulting in later sleep midpoints on both weekdays and weekends. In the current study T3 sleep measures correlated with previous time points' measures as follows: sleep duration T1 to T3 (r=0.23, p=0.02), T2 to T3 (r=0.39, p=0.001); WASO T1 to T3 (r=0.29, p=0.002), T2 to T3 (r=0.68, p=0.001); SE T1 to T3 (r=0.32, p=0.001), T2 to T3 (r=0.68, p<0.001). Sleep midpoint and weekend catch-up sleep did not correlate significantly with previous time points' measurements.

Developmental trajectories of sleep patterns according to circadian preference

The mixed model analyses showed that one interval towards morningness changed the overall mean of sleep midpoint on all days, (B=-23.82 minutes, 95% CI [-32.87, -14.77]; p <0.001), weekdays (B=-24.20 minutes, 95% CI [-35.74, -12.66]; p<0.001) and weekends (B=-35.81 minutes, 95% CI [-54.58, -17.04]; p<0.001). This was reflected also in later sleep onset, (B=-20.89 minutes, 95% CI [-29.80, -11.98]; p <0.001; B=-27.61 minutes, 95% CI [-40.79, -14.44]; p<0.001, respectively) and offset (B=-

17.54 minutes, 95% CI [-28.04, -7.04]; p≤0.001; B=-28.87 minutes, 95% CI [-42.83, -14.91]; p<0.001, respectively) on both weekdays and weekends, respectively. Figures 2-4 illustrate the statistically significant trajectories across time. Sleep duration (p=0.71), weekend catch-up sleep (p=0.93), WASO (p=0.53), SE (p =0.70) across T1, T2, and T3, were not significantly associated with circadian preference in all days, weekdays or weekends in the mixed model analyses and were not examined further.

As shown in Figure 2, the post-hoc comparisons at each time point indicated sleep midpoints were 19 (T1), 36 (T2), and 89 (T3) minutes later among the evening types compared to the morning types (p-values<0.04), and this difference was more emphasized during the weekend nights (28, 55, and 140 minutes, at the respective time points; p-values<0.02). During weekday nights, the differences were significant only at T2 and T3 (27 minutes, p<0.02 and 77 minutes p<0.001, respectively; 16 minutes at T1, p= 0.10). In addition, intermediate types had a later sleep midpoint compared to morning types and at weekends at T1 (p=0.01), at T2 (p=0.01), but not at T3 (p=0.15). Later circadian preference was also reflected in significantly later sleep onset (Figure 3) and offset (Figure 4) times both during weekdays and weekends.

We detected significant time by circadian preference interactions for sleep midpoint (weekdays p=0.006; weekends p=0.002), and sleep onset (weekdays p=0.002; weekends p<0.05). Table 3 shows that mean differences in the sleep midpoint from T1 and T2 to T3 were significantly larger in evening types compared to intermediate and morning types in all days, weekdays and weekends (mixed model interactions with time in evening vs. intermediate type p=0.003; p=0.018; p=0.003; evening vs. morning type p=0.008; p=0.026; p=0.055, respectively; p-values>0.59 for morning vs. intermediate type).

Furthermore, these differences occurred as a result of evening types' weekday sleep onset times becoming later (mixed model interactions with time in evening vs. intermediate type p=0.006; evening vs. morning type p=0.008; p-values=0.44 for morning vs. intermediate type) (Table 3).

Discussion

We examined sleep trajectories from childhood to late adolescence, over a period of nine years, with respect to individual circadian preferences in adolescence. Based on objective assessment of sleep timing over three measurement points, the data indicated that sleep timing is established already in childhood and persists over development into late adolescence. While the difference in sleep midpoint between morning and evening types was only 19 minutes at the age of 8 years, it increased over time resulting in a mean difference of 89 minutes at the age of 17 years. The largest change occurred between 12 and 17 years of age.

We did not detect any differences in pubertal status or BMI between the circadian preference types across development. Likewise, sleep duration, quality, or amount of weekend catch-up sleep did not differ between the circadian preference types over the transition from middle childhood to late adolescence. This may suggest that our findings related to sleep timing are not a result of any cumulative sleep debt, but represent an independent feature of sleep. Similarly, when analyzed in cross-section, adolescent circadian preference was not associated with sleep duration or quality, but only with sleep timing[27].

Weekend sleep midpoint is likely to be an accurate indicator of the natural circadian preference [11, 13, 28]. Already at the age of 8 years, weekend sleep midpoint differed between those who reported a morning preference and those reporting either an intermediate or an evening preference at age 17. This would suggest that the morning type is separate from other diurnal preferences already at an early age. However, the developmental changes in sleep timing differed according to circadian preference, with evening types having the greatest changes in sleep midpoint across time points. This may reflect a growing autonomy over sleep schedules[9].

As strengths, our study was performed in a well characterized birth cohort with objectively-defined sleep patterns. The follow-up period of nine years covered the educational and developmental pathway from middle childhood to late adolescence. As limitations, the longitudinal sample with data available from all measurement points was considerably smaller than the cross-sectional samples. However, our longitudinal sample did not differ statistically from the rest of the T3 participants, and only differed in two respects from the initial cohort members (sex and maternal age), somewhat limiting the representativeness of our findings. Second, we had rMEQ information available only for T3 and were thus unable to test temporal stability in the subjective circadian preference.

This longitudinal study is the first to demonstrate how differences in sleep patterns according to circadian preference persist from childhood to late adolescence, and shows that these preferences are distinguishable already in childhood. The results indicate that the type of an individual's circadian preference, as observed on the verge of adulthood, was established in childhood. In particular, the earlier sleep timing of the morning types stood out most clearly at the first assessment time at 8 years. While sleep rhythm shifted later in all participants over time, the trajectory towards later sleep was particularly marked in the evening types. Finally, we disclose that poor or irregular sleep may not be risks for developing a late circadian preference. These implications underline the importance of distinguishing circadian preference and sleep timing from other sleep patterns and problems. While is likely that several processes influence the development of circadian preference[1-4], future replication studies using longitudinal designs will aid in determining the direction of effect.

References

[1] Hu Y, Shmygelska A, Tran D, Eriksson N, Tung JY, Hinds DA. GWAS of 89,283 individuals identifies genetic variants associated with self-reporting of being a morning person. Nat Commun. 2016;7:10448.

[2] Lane JM, Vlasac I, Anderson SG, Kyle SD, Dixon WG, Bechtold DA, et al. Genome-wide association analysis identifies novel loci for chronotype in 100,420 individuals from the UK Biobank. Nat Commun. 2016;7:10889.

[3] Jones SE, Tyrrell J, Wood AR, Beaumont RN, Ruth KS, Tuke MA, et al. Genome-Wide Association Analyses in 128,266 Individuals Identifies New Morningness and Sleep Duration Loci. PLoS Genet. 2016;12:e1006125.

[4] Duffy JF, Dijk DJ. Getting through to circadian oscillators: why use constant routines? J Biol Rhythms. 2002;17:4-13.

[5] Wong PM, Hasler BP, Kamarck TW, Muldoon MF, Manuck SB. Social Jetlag, Chronotype, and Cardiometabolic Risk. J Clin Endocrinol Metab. 2015;100:4612-20.

[6] Wennman H, Kronholm E, Partonen T, Peltonen M, Vasankari T, Borodulin K. Evening typology and morning tiredness associates with low leisure time physical activity and high sitting. Chronobiol Int. 2015;32:1090-100.

[7] Roeser K, Bruckner D, Schwerdtle B, Schlarb AA, Kubler A. Health-related quality of life in adolescent chronotypes--a model for the effects of sleep problems, sleep-related cognitions, and self-efficacy. Chronobiol Int. 2012;29:1358-65.

[8] Zuurbier LA, Luik AI, Hofman A, Franco OH, Van Someren EJ, Tiemeier H. Fragmentation and stability of circadian activity rhythms predict mortality: the Rotterdam study. Am J Epidemiol. 2015;181:54-63.

[9] Short MA, Gradisar M, Wright H, Lack LC, Dohnt H, Carskadon MA. Time for bed: parent-set bedtimes associated with improved sleep and daytime functioning in adolescents. Sleep. 2011;34:797-800.

[10] Hagenauer MH, Lee TM. The neuroendocrine control of the circadian system: adolescent chronotype. Front Neuroendocrinol. 2012;33:211-29.

[11] Roenneberg T, Kuehnle T, Pramstaller PP, Ricken J, Havel M, Guth A, et al. A marker for the end of adolescence. Curr Biol. 2004;14:R1038-9.

[12] Crowley SJ, Acebo C, Carskadon MA. Sleep, circadian rhythms, and delayed phase in adolescence. Sleep Med. 2007;8:602-12.

[13] Gradisar M, Gardner G, Dohnt H. Recent worldwide sleep patterns and problems during adolescence: a review and meta-analysis of age, region, and sleep. Sleep Med. 2011;12:110-8.

[14] Allebrandt KV, Teder-Laving M, Kantermann T, Peters A, Campbell H, Rudan I, et al. Chronotype and sleep duration: the influence of season of assessment. Chronobiol Int. 2014;31:731-40.

[15] Kitamura S, Hida A, Watanabe M, Enomoto M, Aritake-Okada S, Moriguchi Y, et al. Evening preference is related to the incidence of depressive states independent of sleep-wake conditions. Chronobiol Int. 2010;27:1797-812.

[16] Merikanto I, Pesonen AK, Kuula L, Lahti J, Heinonen K, Kajantie E, et al. Eveningness as a risk for behavioral problems in late adolescence. Chronobiol Int. 2017;34:225-34.

[17] Strandberg TE, Jarvenpaa AL, Vanhanen H, McKeigue PM. Birth outcome in relation to licorice consumption during pregnancy. Am J Epidemiol. 2001;153:1085-8.

[18] Pesonen AK, Martikainen S, Heinonen K, Wehkalampi K, Lahti J, Kajantie E, et al. Continuity and change in poor sleep from childhood to early adolescence. Sleep. 2014;37:289-97.

[19] Horne JA, Ostberg O. A self assessment questionnaire to determine Morningness Eveningness in human circadian rhythms. Int J Chronobiol. 1976;4:97-110.

[20] Hatonen T, Forsblom S, Kieseppa T, Lonnqvist J, Partonen T. Circadian phenotype in patients with the co-morbid alcohol use and bipolar disorders. Alcohol Alcohol. 2008;43:564-8.

[21] Pesonen AK, Raikkonen K, Matthews K, Heinonen K, Paavonen JE, Lahti J, et al. Prenatal origins of poor sleep in children. Sleep. 2009;32:1086-92.

[22] Kuula L, Pesonen AK, Martikainen S, Kajantie E, Lahti J, Strandberg T, et al. Poor sleep and neurocognitive function in early adolescence. Sleep Med. 2015;16:1207-12.

[23] Meltzer LJ, Montgomery-Downs HE, Insana SP, Walsh CM. Use of actigraphy for assessment in pediatric sleep research. Sleep Med Rev. 2012;16:463-75.

[24] Petersen AC. A self-report measure of pubertal status: Reliability, validity, and initial norms. J Youth Adolesc. 1988;17:117-33.

[25] Pesonen AK, Martikainen S, Kajantie E, Heinonen K, Wehkalampi K, Lahti J, et al. The associations between adolescent sleep, diurnal cortisol patterns and cortisol reactivity to dexamethasone suppression test. Psychoneuroendocrinology. 2014;49:150-60.

[26] Iglowstein I, Jenni OG, Molinari L, Largo RH. Sleep duration from infancy to adolescence: reference values and generational trends. Pediatrics. 2003;111:302-7.

[27] Tonetti L, Fabbri M, Filardi M, Martoni M, Natale V. Effects of sleep timing, sleep quality and sleep duration on school achievement in adolescents. Sleep Med. 2015;16:936-40.

[28] Roenneberg T, Kuehnle T, Juda M, Kantermann T, Allebrandt K, Gordijn M, et al. Epidemiology of the human circadian clock. Sleep Med Rev. 2007;11:429-38.

Table and Figure legends:

[Table 1 - Basic characteristics of the participants at T1, T2 and T3]

[Table 2 - Sleep characteristics of the participants at T1, T2, and T3] (ONLINE ONLY)

[Table 3 – Change in sleep midpoint and sleep onset]

[Figure 1 - Participation in the follow-ups] (ONLINE ONLY)

[Figure 2 –Sleep midpoint at ages 8 y, 12 y, and 17 y according to circadian preference at 17 y.]

[Figure 3 –Sleep onset at ages 8 y, 12 y, and 17 y according to circadian preference at 17 y.]

[Figure 4 –Sleep offset at ages 8 y, 12 y, and 17 y according to circadian preference at 17 y.]

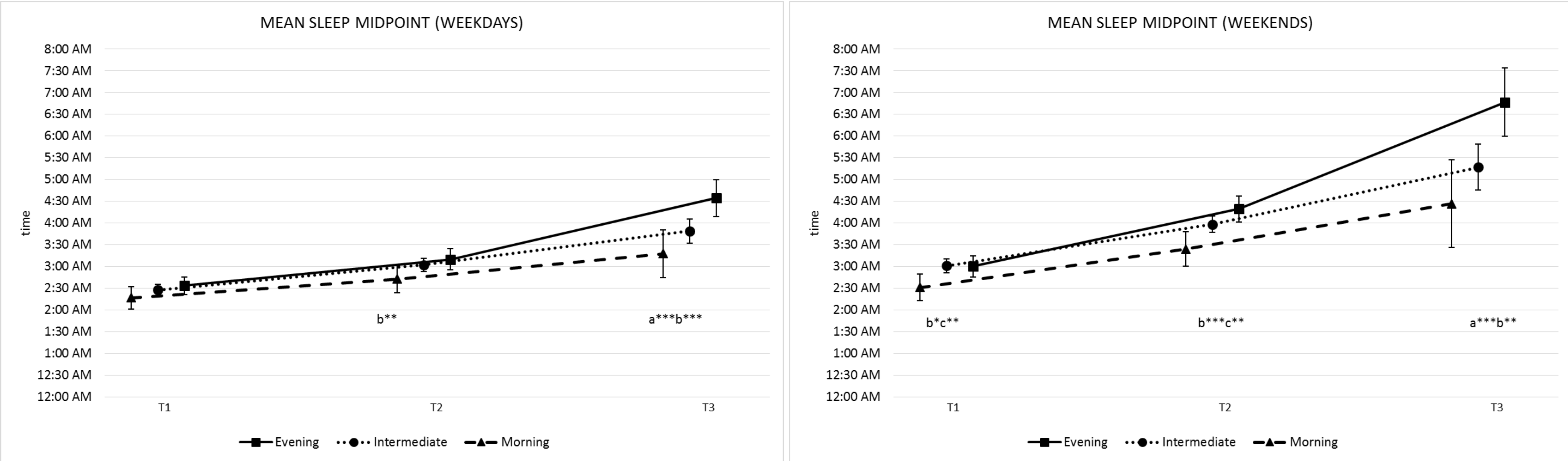


Figure 2–Mean measures of sleep midpoint at Time point 1 (T1), Time point 2 (T2), and Time point 3 (T3) according to circadian preference. Bars represent 95 % confidence intervals. Mean difference significance marked: a=evening vs. intermediate type; b=evening vs. morning type; c=intermediate vs. morning type; *p<.05, **p<.01 ***p<.001.

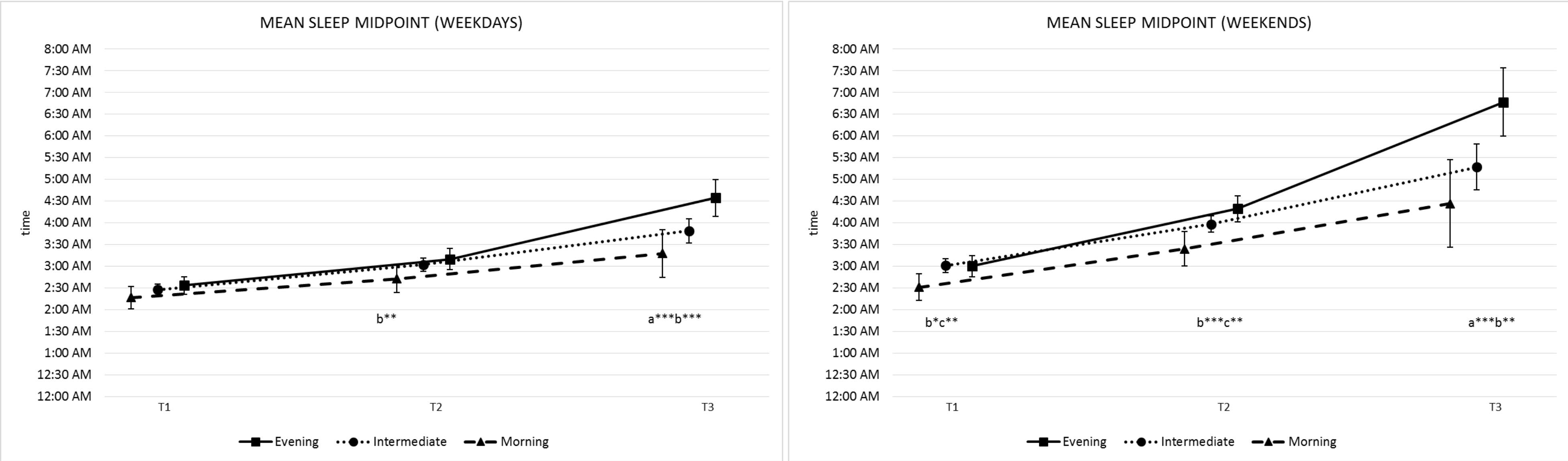


Figure 2–Mean measures of sleep midpoint at Time point 1 (T1), Time point 2 (T2), and Time point 3 (T3) according to circadian preference. Bars represent 95 % confidence intervals. Mean difference significance marked: a=evening vs. intermediate type; b=evening vs. morning type; c=intermediate vs. morning type; *p<.05, **p<.01 ***p<.001.

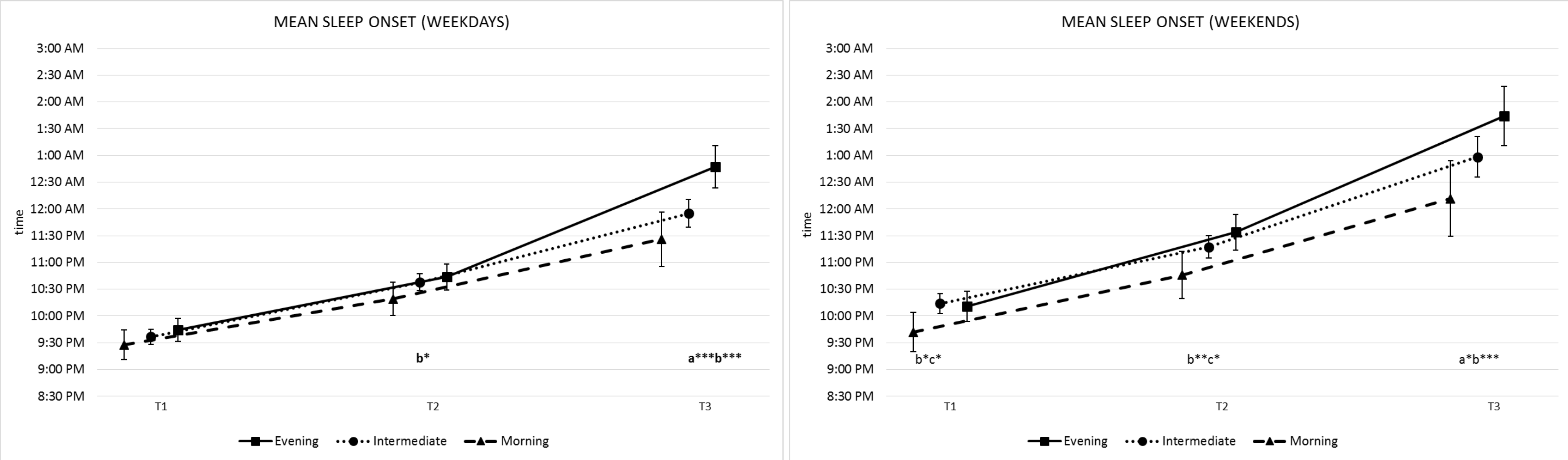
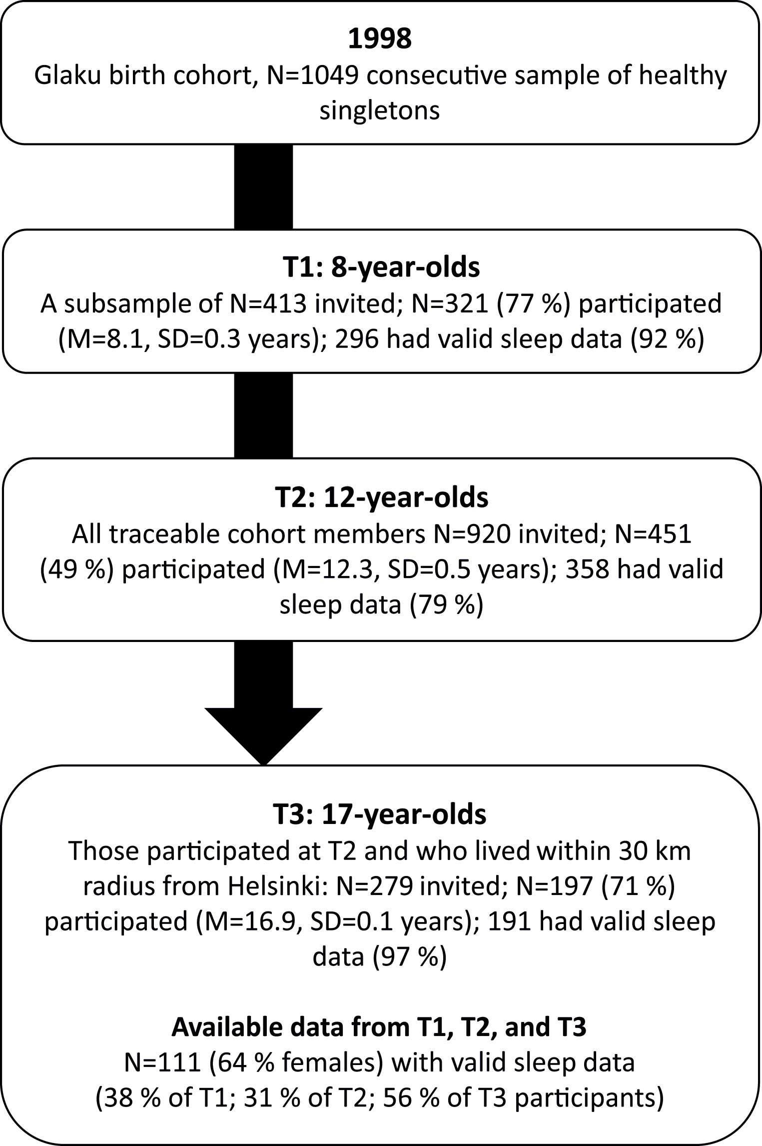


Figure 3–Mean measures of sleep onset at Time point 1 (T1), Time point 2 (T2), and Time point 3 (T3) according to circadian preference. Bars represent 95 % confidence intervals. Mean difference significance marked: a=evening vs. intermediate type; b=evening vs. morning type; c=intermediate vs. morning type; *p<.05, **p<.01 ***p<.001.


1998
Glaku birth cohort, N=1049 consecutive sample of healthy singletons
T1: 8-year-olds
A subsample of N=413 invited; N=321 (77 %) participated (M=8.1, SD=0.3 years); 296 had valid sleep data (92 %)
T2: 12-year-olds
All traceable cohort members N=920 invited; N=451 (49 %) participated (M=12.3, SD=0.5 years); 358 had valid sleep data (79 %)
T3: 17-year-olds
Those participated at T2 and who lived within 30 km radius from Helsinki: N=279 invited; N=197 (71 %) participated (M=16.9, SD=0.1 years); 191 had valid sleep data (97 %)
Available data from T1, T2, and T3
N=111 (64 % females) with valid sleep data (38 % of T1; 31 % of T2; 56 % of T3 participants)

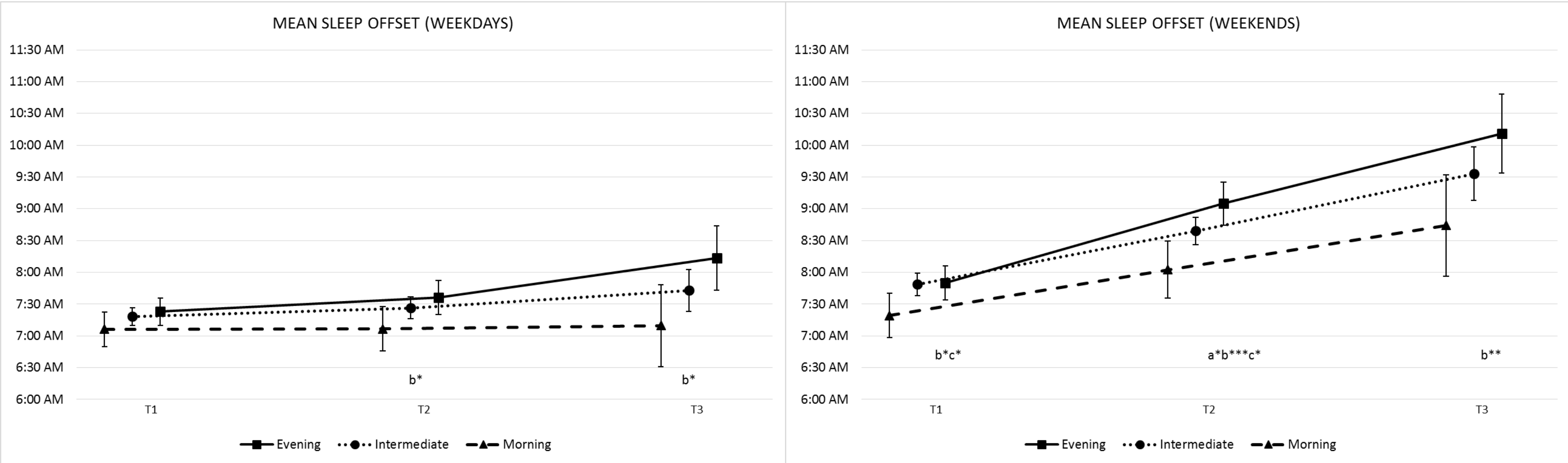


Figure 4 – Mean measures of sleep offset at Time point 1 (T1), Time point 2 (T2), and Time point 3 (T3) according to circadian preference. Bars represent 95 % confidence intervals. Mean difference significance marked: a=evening vs. intermediate type; b=evening vs. morning type; c=intermediate vs. morning type; *p<.05, **p<.01 ***p<.001.

Table 2 Sleep characteristics of the participants at T1, T2, and T3

	All			Evening type			Intermediate type			Morning type		
	T1 Mean (SD)	T2 Mean (SD)	T3 Mean (SD)	T1 Mean (SD)	T2 Mean (SD)	T3 Mean (SD)	T1 Mean (SD)	T2 Mean (SD)	T3 Mean (SD)	T1 Mean (SD)	T2 Mean (SD)	T3 Mean (SD)
Measured nights (n)	6.9 (1.2)	8.1 (1.6)	8.2 (1.8)	7.3 (1.1)	7.8 (2.0)	8.2 (1.6)	6.9 (1.4)	8.1 (1.5)	8.0 (1.9)	7.0 (0.8)	8.7 (1.0)	9.3 (1.2)
Sleep midpoint, all days, time	2:35 (0:32)	3:15 (0:38)	4:21 (1:30)	2:39 (0:30)	3:27 (0:36)	5:01 (1:36)	2:37 (0:23)	3:16 (0:40)	4:16 (1:31)	2:18 (0:31)	2:53 (0:24)	3:34 (0:35)
Sleep midpoint, weekdays, time	2:26 (0:33)	3:00 (0:39)	4:00 (1:29)	2:32 (0:27)	3:10 (0:39)	4:33 (1:36)	2:27 (0:35)	3:01 (0:40)	3:57 (1:30)	2:14 (0:28)	2:43 (0:23)	3:19 (0:40)
Sleep midpoint, weekend, time	2:56 (0:40)	3:58 (0:48)	5:38 (2:25)	2:59 (0:42)	4:19 (0:38)	6:45 (3:30)	3:01 (0:37)	3:57 (0:49)	5:26 (1:54)	2:29 (0:43)	3:24 (0:40)	4:29 (0:58)
Sleep onset, weekday, time	21:37 (0:35)	22:36 (0:39)	0:03 (1:09)	21:43 (0:32)	22:44 (0:40)	0:47 (1:26)	21:37 (0:37)	22:37 (0:41)	23:54 (0:59)	21:25 (0:33)	22:20 (0:26)	23:28 0:38)
Sleep onset, weekend, time	22:08 (0:46)	23:17 (0:52)	1:02 (1:35)	22:10 (0:48)	23:34 (0:45)	1:40 (1:56)	22:14 (0:43)	23:16 (0:56)	0:59 (1:29)	21:40 (0:46)	22:47 (0:37)	0:13 (0:44)
Sleep offset, weekdays, time	7:17 (0:35)	7:25 (0:43)	7:45 (1:22)	7:21 (0:27)	7:36 (0:45)	8:11 (1:55)	7:19 (0:39)	7:26 (0:44)	7:43 (1:09)	7:03 (0:28)	7:07 (0:29)	7:10 (0:49)
Sleep offset, weekend, time	7:44 (0:45)	8:40 (0:56)	9:35 (1:45)	7:48 (0:43)	9:05 (0:40)	10:06 (2:00)	7:49 (0:44)	8:39 (0:57)	9:34 (1:38)	7:16 (0:47)	8:00 (0:53)	8:45 (1:21)
Catch-up sleep at weekend (min)	-0:01 (0:37)	0:29 (0:47)	0:41 (1:12)	0:01 (0:36)	0:36 (0:35)	0:49 (1:30)	-0:03 (0:37)	0:29 (0:52)	0:37 (1:06)	0:03 (0:40)	0:18 (0:44)	0:42 (1:03)
Sleep duration, all days (h)	8:24 (0:41)	7:57 (0:25)	7:05 (0:37)	8:26 (0:43)	8:02 (0:28)	7:00 (0:39)	8:21 (0:41)	7:56 (0:24)	7:09 (0:37)	8:33 (0:41)	7:53 (0:27)	7:01 (0:35)
Sleep duration, weekdays (h)	8:25 (0:42)	7:49 (0:28)	6:55 (0:43)	8:25 (0:43)	7:53 (0:32)	6:46 (0:52)	8:23 (0:41)	7:48 (0:26)	6:59 (0:38)	8:32 (0:47)	7:48 (0:32)	6:52 (0:42)
Sleep duration, weekend (h)	8:23 (0:49)	8:18 (0:45)	7:36 (1:04)	8:27 (0:53)	8:26 (0:32)	7:36 (1:01)	8:19 (0:50)	8:18 (0:49)	7:37 (1:08)	8:35 (0:39)	8:04 (0:43)	7:35 (0:55)
WASO, all days (h)	1:14 (0:32)	1:00 (0:20)	0:50 (0:20)	1:12 (0:35)	0:59 (0:18)	0:47 (0:15)	1:17 (0:30)	1:01 (0:22)	0:50 (0:21)	1:04 (0:35)	1:00 (0:17)	0:51 (0:20)
SE (%), all days	84.0 (6.1)	85.3 (4.3)	86.4 (4.6)	84.1 (6.7)	85.6 (3.9)	86.9 (3.4)	83.4 (5.7)	85.1 (4.6)	86.2 (5.0)	86.3 (6.2)	85.7 (3.8)	86.5 (4.7)

Abbreviations: T1= Time point 1 (at age 8 years); T2=Time point 2 (at age 12 years); T3=Time point 3 (at age 17 years); WASO= wake after sleep onset; SE= Sleep Efficiency; SD=standard deviation, h =hours.

Table 1 Basic characteristics of the participants at T1, T2 and T3

	Evening N=28 (25.2 %)		Intermediate N=66 (59.5 %)		Morning N=17 (15.3 %)				
	Mean (SD) or N (%)		Mean (SD) or N (%)		Mean (SD) or N (%)		p[a]	p[b]	p[c]
Sex (female)	18 (64.3)		43 (65.2)		10 (58.8)		.63	.72	.94
Birth weight, g[d]	3628 (300)		3565 (506)		3612 (471)		.73	.89	.46
Highest parental education[e]							.71	.29	.12
Secondary or less	0 (0.0)		8 (12.1)		1 (5.9)				
Vocational	4 (14.3)		12 (18.2)		4 (23.5)				
University degree	24 (85.7)		46 (69.7)		12 (70.6)				
Age at T1, years	8.0	(0.33)	8.1	(0.29)	8.0	(0.32)	.22	.89	.22
Age at T2, years	12.3	(0.60)	12.3	(0.52)	12.4	(0.54)	.34	.71	.57
Age at T3, years	16.9	(0.14)	16.9	(0.12)	16.9	(0.13)	.79	.63	.29
BMI[f] at T1	16.6	(1.69)	16.8	(2.08)	16.4	(1.50)	.47	.67	.68
BMI[f] at T2	19.5	(2.55)	19.7	(3.11)	19.3	(2.79)	.66	.81	.79
BMI[f] at T3	22.4	(3.00)	21.8	(3.62)	21.1	(2.46)	.45	.15	.47
Pubertal development[g] at T2	1.83	(0.50)	1.92	(0.55)	2.08	(0.56)	.29	.13	.48
Pubertal development[g] at T3	3.28	(0.45)	3.32	(0.35)	3.27	(0.46)	.64	.94	.68

Abbreviations: T1= Time point 1 (at age 8 years); T2=Time point 2 (at age 12 years);
T3=Time point 3 (at age 17 years); BMI Body Mass Index.
P-values are obtained from χ2 tests for categorical variables and T-tests for continuous variables.

p[a] morning vs intermediate
p[b] morning vs evening
p[c] intermediate vs evening
[d] derived from hospital records
[e] parent-reported at T2
[f] calculated as kg/m2
[g] measured using Pubertal Development Scale

Table 3 –Change in sleep midpoint and sleep onset

		Change in minutes from T1 to T2			Change in minutes from T2 to T3		
		MD	95 % CI	p	MD	95 % CI	p
Weekday sleep midpoint							
Evening –	Intermediate	-3.1	(-21.5, 15.2)	0.74	-37.9	(-73.1, 2.8)	0.035
Evening –	Morning	-10.7	(-35.7, 14.3)	0.40	-50.4	(-98.1, -2.7)	0.039
Intermediate –	Morning	-7.5	(-29.8, 14.7)	0.50	-12.5	(-29.7, 54.7)	0.56
Weekday sleep onset							
Evening –	Intermediate	0.4	(-17.7, 18.5)	0.96	-46.4	(-79.4, -13.4)	0.006
Evening –	Morning	-8.3	(-33.0, 16.3)	0.51	-57.9	(-102.8, 13.0)	0.012
Intermediate –	Morning	-8.7	(-30.6, 13.2)	0.43	-11.5	(-51.2, 28.2)	0.57
Weekend sleep midpoint							
Evening –	Intermediate	-28.7	(-51.9, -5.6)	0.015	-75.2	(-138.9, -11.4)	0.021
Evening –	Morning	-33.1	(-65.3, -0.8)	0.044	-97.0	(-184.9, -9.0)	0.031
Intermediate –	Morning	-4.3	(-33.0, 24.4)	0.77	-21.8	(-100.2, 56.6)	0.58
Weekend sleep onset							
Evening –	Intermediate	-24.4	(-51.3, 2.4)	0.07	-32.4	(-76.7, 11.9)	0.15
Evening –	Morning	-27.7	(-65.1,9.7)	0.14	-47.8	(108.9,13.2)	0.12
Intermediate –	Morning	-3.3	(-36.6,30.0)	0.85	-15.4	(-69.8,39.0)	0.58

Abbreviations: MD=Mean difference; CI= confidence interval; T1=Time point 1 (at age 8); T2=Time point 2 (at age 12); T3= Time point 3 (at age 17). P-value represents significance in mean difference between two circadian preference types. Mean values presented in Table 2.