

Chronotype is associated with the timing of the circadian clock and sleep in toddlers

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Keywords

children, chronotype, circadian phase, dim light melatonin onset, morningness/eveningness, sleep

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Accepted in revised form 23 January 2014;
received 22 August 2013

DOI: 10.1111/jsr.12142

SUMMARY

Chronotype is a construct reflecting individual differences in diurnal preference. Although chronotype has been studied extensively in school-age children, adolescents and adults, data on young children are scarce. This study describes chronotype and its relationship to the timing of the circadian clock and sleep in 48 healthy children aged 30–36 months (33.4 ± 2.1 months; 24 males). Parents completed the Children's Chronotype Questionnaire (CCTQ) ~2 weeks before the start of the study. The CCTQ provides three measures of chronotype: midsleep time on free days, a multi-item morningness/eveningness score and a single item chronotype score. After 5 days of sleeping on their habitual schedule (assessed with actigraphy and sleep diaries), children participated in an in-home salivary dim light melatonin onset assessment. Average midsleep time on free days was $1:47 \pm 0:35$, and the average morningness/eveningness score was 26.8 ± 4.3 . Most toddlers (58.4%) were rated as 'definitely a morning type' or 'rather morning than evening type', while none (0%) were rated as 'definitely evening type'. More morning types (midsleep time on free days and morningness/eveningness score, respectively) had earlier melatonin onset times ($r = 0.45$, $r = 0.26$), earlier habitual bedtimes ($r = 0.78$, $r = 0.54$), sleep onset times ($r = 0.80$, $r = 0.52$), sleep midpoint times ($r = 0.90$, $r = 0.53$) and wake times ($r = 0.74$, $r = 0.34$). Parent ratings using the single-item chronotype score were associated with melatonin onset ($r = 0.32$) and habitual bedtimes ($r = 0.27$), sleep onset times ($r = 0.33$) and sleep midpoint times ($r = 0.27$). Morningness may best characterize circadian preference in early childhood. Associations between chronotype and circadian physiology and sleep timing suggest adequate validity for the CCTQ in this age group. These findings have important implications for understanding the marked variability in sleep timing during the early years of life.

INTRODUCTION

Chronotype is a construct reflecting individual differences in diurnal preference. In adolescents and adults, evening chronotype is associated with negative social and health consequences (Gelbmann *et al.*, 2012; Roenneberg *et al.*,

2012). Results from an established literature also indicate an inverted U-shaped distribution of chronotype across age, with a shift towards eveningness from school age to adolescence and a subsequent shift back to morningness from adulthood into older age (Carskadon *et al.*, 1993; Roenneberg *et al.*, 2004; Werner *et al.*, 2009; Wolfson *et al.*, 2003). Published

data on chronotype in early childhood are scarce; however, existing studies suggest young children show a relatively strong preference for morningness (Nakade *et al.*, 2012; Wickersham, 2006).

Chronotype is assessed with questionnaires asking individuals about their 'feeling-best rhythms' (Carskadon *et al.*, 1993; Horne and Ostberg, 1976; Wolfson *et al.*, 2003) or sleep timing on 'free' days (Roenneberg *et al.*, 2003). Similar constructs were adapted in the Children's Chronotype Questionnaire (CCTQ) (Werner *et al.*, 2009), a parent-report scale for use with 4–11-year-olds. The CCTQ provides three measures of chronotype: midsleep time on free days (MSF), a multi-item morningness/eveningness (ME) score and a single-item chronotype (CT) score. Although chronotype in adults is related to salivary dim light melatonin onset (DLMO) time (Duffy *et al.*, 2001; Lberge *et al.*, 2000; Wright *et al.*, 2013), the association between toddlers' chronotype and circadian physiology remains an unexplored area of research.

Results from numerous studies suggest that chronotype, in addition to genetics, light exposure and accumulated sleep debt, interact to influence variability in sleep behaviour (Katzenberg *et al.*, 1998; Lazar *et al.*, 2012). Indeed, adults self-reporting a preference for morningness are more likely to have earlier bedtimes, sleep midpoints and wake times (Duffy *et al.*, 2001; Lberge *et al.*, 2000; Wright *et al.*, 2013). Chronotype may also play an important role in determining sleep duration and perceived sleep need, although results are mixed (Roepke and Duffy, 2010). Examining chronotype-sleep links are of particular importance in early childhood because it is a stage marked by substantial interindividual differences in the timing and duration of sleep (Iglowstein *et al.*, 2003). Sleep problems are also prevalent during this developmental stage, affecting ~25% of young children (Owens, 2008).

In this study, parents of 30–36-month-olds ($n = 48$) completed the CCTQ ~2 weeks before starting the study. During the 6-day protocol, children slept on their habitual schedule verified with actigraphy and a daily sleep diary. Children then participated in a 6-h salivary DLMO assessment performed in family's homes. We used these data to (i) describe parent-reported chronotype in toddlers, (ii) test whether chronotype is positively correlated with children's circadian physiology (DLMO), (iii) assess the concordance between reported chronotype and objective actigraphic measures of sleep timing and (iv) explore associations between circadian preference and 24-h sleep duration.

MATERIALS AND METHODS

Participants

Participants were 48 healthy 30–36-month-old children (33.4 ± 2.1 months; 24 females; 83% Caucasian, 17% mixed-race) from two cohorts: Providence, RI ($n = 19$) and Boulder, CO ($n = 29$). The majority of children ($n = 43$) took

regular daytime naps (3.7 ± 1.6 days week⁻¹; nappers). Five children slept only at night (non-nappers). Families were recruited at community events and via flyers and laboratory website advertisements. Parents completed a telephone screening and then questionnaires to evaluate study criteria. Children were included if they were 30–36 months of age at the time of assessment and were excluded if they (i) participated in co-sleeping (i.e. sharing a bed all or part of the night with another individual more than two times per month); (ii) had a bedtime/wake time sleep schedule that differed by >2 h between weekdays and weekends; (iii) travelled beyond two time zones within 3 months of the study; (iv) regularly used medications affecting sleep, alertness or the circadian system; (v) had reported/diagnosed sleep problems; (vi) had developmental disabilities, neurological/metabolic disorders, chronic medical conditions, lead poisoning or head injury involving loss of consciousness; (vii) had a conceptual age <38 weeks or >42 weeks; (viii) were low birth weight (<5.5 lb); or (ix) had a family history (first degree) of diagnosed narcolepsy, psychosis or bipolar disorder.

All parents signed an informed consent approved by the institutional review board (IRB). Families were compensated with \$50 cash, and children received a \$50 United States savings bond after completing the study.

Protocol

About 2 weeks before the start of the study, parents completed the CCTQ. During the first five study days, children slept on their habitual schedule, and researchers made several in-home visits to train children in providing saliva samples. The DLMO assessment occurred on study day 6. During the entire protocol, caffeine or medications affecting sleep and/or circadian rhythms were proscribed. Parents provided daily reports of their child's sleep patterns and protocol compliance via telephone or e-mail. Children were studied neither during summer months (June–August) nor during the 1 week following daylight-saving time changes.

Measures

Children's chronotype questionnaire

The children's chronotype questionnaire (CCTQ) is a 27-item, parent-report questionnaire that provides three measures of chronotype in children: (i) midsleep time on free days (MSF); (ii) a multi-item morningness/eveningness (ME) score; and (iii) a single item chronotype (CT) score. The MSF requires parents to report on several sleep parameters (i.e. bedtime, lights-off time, sleep latency, wake time, get out of bed time and time to be fully alert). 'Scheduled' days are those when the child's sleep patterns are influenced by their own or their family's structured activities (e.g. school, day care, work, athletics, church). 'Free' days are those when the

child's sleep patterns are not influenced by individual or family activities; thus, representing a time when the child would be more likely to sleep at his/her circadian preference. MSF was computed as (sleep onset time + sleep period)/2 on free days. The ME score is calculated using a series of 10 questions asking about the child's 'feeling-best' rhythm for various activities. Based upon findings from 4 to 11-year-old Swiss children, scores range from 10 (extreme morningness) to 49 (extreme eveningness), with scores ≤ 23 corresponding to morning types, 24–32 to intermediate types and ≥ 33 to evening types (Werner *et al.*, 2009). The CT score was a single-item measure in which parents reported their child's chronotype on a five-point scale (1 = 'definitely a morning type', 2 = 'rather a morning type', 3 = 'neither a morning type nor an evening type', 4 = 'rather an evening type than a morning type' or 5 = 'definitely an evening type'). The validity (concordance with actigraphic sleep parameters) and test-retest reliability of the CCTQ with 4–11-year-olds have been established as adequate for research instruments (Werner *et al.*, 2009).

Sleep diary

Parents completed a daily 26-item sleep diary throughout the study. Diary questions asked about bedtime, lights-out time, sleep onset latency, wake time, get out of bed time, nap start time, nap end time and intervals the actigraph was not worn by the child. Diary data were used to ensure compliance with the study protocol and to facilitate scoring of actigraphy data (Acebo *et al.*, 2005).

Actigraphy

Actigraphy is non-invasive tool for objectively assessing sleep patterns in field settings. Children wore model AW64 (Minimitter, Bend, OR, USA) or AW Spectrum (Philips/Respironics, Pittsburg, PA, USA) actigraphs on their non-dominant wrist throughout the duration of the study to obtain uninterrupted recordings of sleep/wakefulness states via measurements of motor activity. Actiware-Sleep version 5.59 software was used to estimate 1-min epochs of sleep or wakefulness from activity levels produced in the surrounding ± 2 -min interval. This algorithm was applied to portions of the record identified as sleep through a combination of diary reports and event markers pressed at 'lights-out' and 'lights-on'. In comparison to videosomnography in young children, this algorithm shows high overall epoch-by-epoch agreement (94%) and is excellent in detecting sleep (sensitivity = 97%); however, it overestimates wake during the sleep period (specificity = 24%) (Sitnick *et al.*, 2008). Standard scoring rules were applied to each sleep episode—sleep start was the first of three epochs of sleep after lights-out, and sleep end was the last of five epochs of sleep before lights-on (Acebo *et al.*, 2005). Sleep episodes were excluded when (i) the actigraph was off for all/part of the sleep period, (ii) concurrent diary report was not available or (iii) the episode

included external motion (e.g. sleeping in a car or stroller). Actigraphic estimates of sleep parameters aggregated across study days 1–5 included the following: lights-out time (bedtime), sleep start (onset) time, sleep midpoint, sleep end time (wake time) and 24-h sleep duration (number of minutes between sleep start time to sleep end time for naps and nighttime sleep). Actigraphy data were not available due to non-compliance ($n = 1$) and technical failure ($n = 3$); in these cases, we used daily diary reports to compute sleep variables. Of the 44 children with actigraphy data, variables were aggregated across 5 days/nights in 85% of children, 4 days/nights in 12% of children and 3 days/nights in 3% of children.

Salivary dim light melatonin assessment

Dim light melatonin onset was assessed with an in-home protocol on the final day of the study. Participants entered dim light conditions (0.01–10.90 lux at angle of gaze) at least 1 h before the first saliva sample, where they remained throughout the data collection interval. Children provided saliva samples (~2 mL) every 30 min for 6 h ending 1 h past their average bedtime (12 samples total) from parent reports during study days 1–5. With help from a researcher, children rinsed their mouths with water >15 min before each saliva sample. Children remained in a sitting posture for 5 min before and during each saliva sample. Saliva samples were collected by having children chew on a braided dental cotton roll (Henry Schein Inc., Denver, PA, USA) for 1–2 min. Lux levels were obtained with each saliva sample using a light meter (Extech Instruments, Nashua, NH, USA) held ~5 cm adjacent to the child's eye and directed in the angle of gaze. Samples were immediately centrifuged and refrigerated on-site and then frozen (-20°C) within 12 h. Assays were performed at the Bradley Hospital Sleep and Chronobiology Laboratory (Providence, RI, USA) or SolidPhase Inc. (Portland, ME, USA) using radioimmunoassay (ALPCO Diagnostics, Salem, NH, USA), minimum detection 0.2 pg mL^{-1} . Circadian DLMO phase was defined as the clock time evening salivary melatonin concentrations increased and remained above a 4 pg mL^{-1} threshold using linear interpolation between successive samples. This is a well-accepted standard with children and adolescents (Carskadon *et al.*, 1997) and was derived from reports that salivary melatonin concentrations are about 40% of plasma levels in healthy young adults (10 pg mL^{-1} is the most common DLMO threshold for plasma melatonin) (Deacon and Arendt, 1994).

Actigraphic estimates of sleep and DLMO times in a subset of this sample have been published previously (LeBourgeois *et al.*, 2013a).

Data processing and analysis

For the Boulder, CO, sample, chronotype data were collected and managed using the Research Electronic Data Capture (REDCap) tool hosted at University of Colorado. REDCap is

a secure, web-based application designed to support data collection for research studies (Harris *et al.*, 2009).

Statistical analyses were performed with PASW statistics package version 21.0 (IBM Corp., Armonk, NY, USA). Summary measures are presented as frequency distributions, mean \pm standard deviation (SD), median or range. Pearson's correlations were used to assess associations between continuous variables, and Spearman's correlations were used to assess associations between ordinal variables. One-tailed tests were used to examine the following hypotheses: (i) chronotype is associated positively with DLMO and actigraphic sleep timing measures and (ii) chronotype measures are positively correlated. Two-tailed tests were used to explore correlations between chronotype and sleep duration and age. Sex and napping status differences in chronotype were examined with two-tailed independent *t*-tests. Finally, a paired *t*-test was used to test differences between midsleep time on free and scheduled days.

RESULTS

Table 1 reports descriptive statistics for the three CCTQ chronotype measures (MSF, ME, CT), DLMO and actigraphic sleep measures. Frequency histograms of MSF, ME and CT are illustrated in Fig. 1. Using the single-item chronotype (CT) score, 18.8% of children were rated by parents as 'definitely a morning type', 39.6% as 'rather a morning than evening type', 31.3% as 'neither a morning nor an evening type', 10.4% as 'rather an evening type' and 0% as 'definitely an evening type' (Fig. 1c). We observed significant intercorrelations between the three chronotype measures: MSF with ME ($r = 0.60$, $P < 0.001$); MSF with CT ($r = 0.27$, $P < 0.05$); and ME with CT ($r = 0.50$, $P < 0.001$). Midsleep time on days when children's sleep was influenced by structured activities (scheduled days) was 01:53 \pm 0:34, which differed from midsleep time on free days 01:47 \pm 0:35, $t_{(47)} = 2.9$, $P < 0.05$, $d = 0.20$.

Correlation coefficients quantifying associations between the three chronotype variables and DLMO and sleep

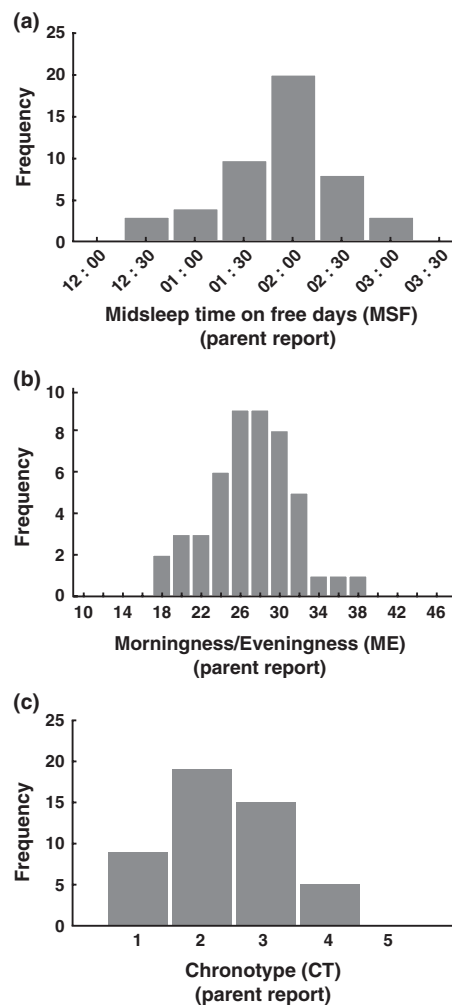


Figure 1. Frequency distributions of 48 toddlers assessed with the Children's Chronotype Questionnaire (CCTQ; lower values = more morningness, higher values = more eveningness): midsleep time on free days in 30-min bins (MSF; a); morningness/eveningness score (ME; b); and chronotype score (CT; c). For the CT score, 1 = 'definitely a morning type', 2 = 'rather a morning type', 3 = 'neither a morning type nor an evening type', 4 = 'rather an evening type than a morning type' or 5 = 'definitely an evening type'.

Table 1 Descriptive statistics for chronotype, circadian and actigraphic sleep measures ($n = 48$)

All subjects	Mean	SD	Minimum	Maximum
MSF (hours)	01:47	0:35	00:15	02:57
ME	26.8	4.3	18	37
CT	2.0 (median)		1	4
DLMO	19:26	0:51	17:35	21:07
Bedtime (hours)	20:12	0:38	19:03	22:00
Sleep start time (hours)	20:38	0:45	19:12	22:31
Midsleep time (hours)	01:41	0:38	00:00	02:55
Wake time (hours)	06:46	0:43	04:41	08:16
24-h sleep duration (h)	11.7	0.7	10.3	13.0

DLMO, dim light melatonin onset; MSF, midsleep on free days; ME, morningness/eveningness score; CT: chronotype score.

measures are shown in Table 2. Toddlers with earlier DLMOs were more likely to have earlier MSFs and a stronger preference for morningness, as reported by parents (Fig. 2). Children with an earlier parent-reported circadian preference as assessed with MSF or the ME scale, had earlier objectively measured habitual bedtimes, sleep midpoint times and wake times (Fig. 3). Chronotype as rated with the single-item CT score was associated positively with DLMO, bedtime, sleep onset time and sleep midpoint time. We found no correlations between any of the chronotype measures and 24-h sleep duration. Chronotype did not differ by sex or napping status and was not associated with age.

DISCUSSION

In this study, we collected parent reports of chronotype in a sample of 30–36-month-old children with the CCTQ. We also obtained a reliable marker of circadian phase, DLMO, and objective actigraphic estimates of sleep timing and duration.

Table 2 Correlation coefficients quantifying associations between the three Children's Chronotype Questionnaire (CCTQ) parent-report measures and DLMO and actigraphic sleep measures

	CCTQ chronotype measures		
	MSF	ME	CT
DLMO	0.45**	0.26*	0.32*
Bedtime	0.78**	0.54**	0.27*
Sleep onset time	0.80**	0.52**	0.33*
Midsleep time	0.90**	0.53**	0.27*
Wake time	0.72**	0.34*	0.11
24-h sleep duration (h)	-0.03	-0.10	-0.19

DLMO, dim light melatonin onset; MSF, midsleep on free days; ME, morningness/eveningness score; CT: chronotype score. * $P < 0.05$; ** $P < 0.001$.

With these data, several important findings emerged. First, toddlers exhibit substantial interindividual differences in chronotype, with a relative preference for morningness. Secondly, DLMO time was related to chronotype, such that toddlers with later circadian phases were more likely to be evening types ('owls'). Thirdly, toddlers reportedly exhibiting a stronger morning preference had earlier bedtimes, sleep onset times, sleep midpoints and wake times, as measured with actigraphy. Findings are discussed in the context of understanding chronotype in the early years, as it pertains to maturational changes in sleep and circadian rhythms as well as to health and developmental outcomes.

Our results add to the ongoing discussion about changes in chronotype across the first two decades of life (Carskadon *et al.*, 1993; Harada *et al.*, 2007; Roenneberg *et al.*, 2004; Wickersham, 2006). Using the CCTQ, Werner and colleagues found that MSF was 02:26 in a cohort of 4–11-year-old Swiss children (Werner *et al.*, 2009), and in a large-scale study by Roenneberg *et al.*, MSF was roughly 02:55 in 10-year-olds, 04:30 in 15-year-olds and 04:55 in 20-year-olds (Roenneberg *et al.*, 2004). Although the current analysis was not based upon a community sample, we found that 30–36-month-olds had an average MSF of 01:47. Similarly, the average ME score of our sample suggests an overall preference towards morningness in young children compared to the 4–11-year-olds studied by Werner *et al.* (2009). This trend was supported further by the percentage of parents responding to CT categories. None of our toddlers were rated as 'definitely an evening type', whereas 21% of Swiss school-age children were reported as such (Werner *et al.*, 2009). Our findings also build upon those from several cross-sectional studies describing circadian preference in early childhood, all of which used parent-report, multi-item morningness/eveningness questionnaires. For example, data from a large sample of Japanese children attending daycare/school showed a phase delay in chronotype from infancy to mid-adolescence (Harada *et al.*, 2007). Additionally, an

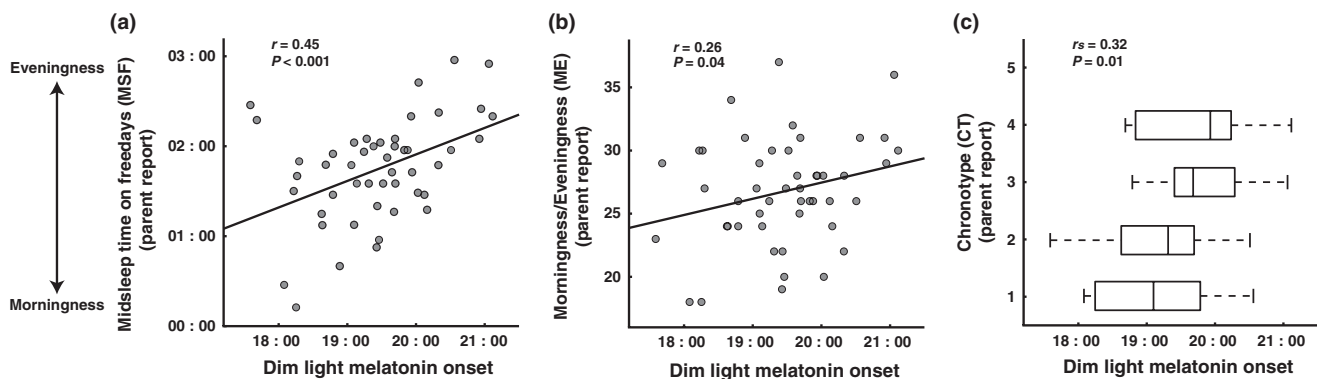


Figure 2. Scatterplots showing associations between dim light melatonin onset (DLMO) and parent-reported midsleep time on free days (MSF; a) and morningness/eveningness scores (ME; b). Box-plots showing the association between DLMO and the parent-reported single-item chronotype score (CT; c). Upper and lower borders of box-plots represent upper and lower quartiles, tails represent minimum and maximum scores, and the vertical midline represents the median. Lower MSF, ME, and CT values = more morningness, higher values = more eveningness.

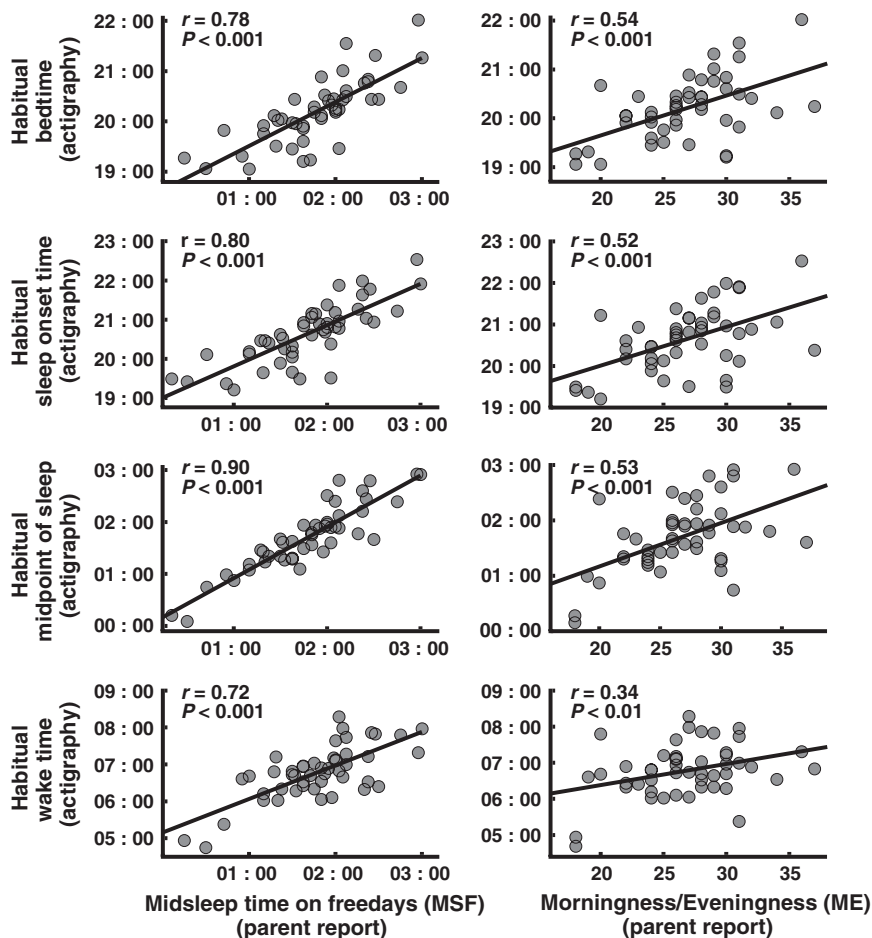


Figure 3. Scatterplots showing associations between parent-reported chronotype measures [midsleep time on free days (MSF); morningness/eveningness (ME) score] and actigraphic sleep measures. Lower MSF and ME values = more morningness, higher values = more eveningness.

age-related change in the chronotype of preschool children was found by Wickersham (2006): 90% of 2-year-olds versus ~58% of 6-year-olds were reportedly morning types, with only 3% of the sample rated by their parent as having a preference for eveningness. Taken together, these findings provide evidence that young children exhibit a stronger tendency for morningness than school-age children and adolescents. Future research using representative diverse longitudinal samples is needed to understand the distribution, cultural/ethnic differences, interindividual variability and development of chronotype in early childhood and how it may change across the lifespan.

The optimal timing of young children's sleep is a common concern of parents and educators, as well as a frequent topic in the media. In this study, our measures of both extrinsic parent-influenced bedtimes and intrinsic child-determined sleep onset times were associated with chronotype. Such distinctions are important because, unlike older teens and adults who choose their own sleep schedules, caregivers largely influence the sleep timing of toddlers. From a child-orientated approach guided by the 'goodness-of-fit' framework (Jenni and O'Connor, 2005), optimal sleep schedules may be best identified when taking children's intrinsic individual circadian characteristics, such as chronotype, into consideration (Jenni and LeBourgeois, 2006). This perspective is supported by our

recent findings indicating that dissonance between toddlers' melatonin phase and bedtimes influenced evening settling difficulties: children put to bed at a time too close to their DLMOs were more likely to exhibit parent-reports of bedtime resistance and to show longer sleep onset latencies, as estimated by actigraphy (LeBourgeois *et al.*, 2013b). Furthermore, midpoint of sleep on weekends may serve as a real-world proxy for the MSF chronotype measure used in this and other studies. For example, children with later weekend sleep midpoints are more likely to be obese/overweight (Spruyt *et al.*, 2011) and at-risk for poor academic success, as reflected in their scores on a standardized assessment of school readiness (Crosby *et al.*, 2006).

The determinants and outcomes of chronotype represent a complex interplay between circadian physiology, genetics and behaviour in the context of an individual's social and solar clocks (Roenneberg *et al.*, 2003). Based upon the adolescent and adult literature (Duffy *et al.*, 2001; Labege *et al.*, 2000; Wright *et al.*, 2013), we expected that individual differences in chronotype would be associated with the timing of toddlers' circadian clocks. Our findings supported this hypothesis: children rated as more evening types had later melatonin phases. Light, the strongest *zeitgeber* of the human circadian system, probably plays a key role in this bidirectional relationship (Roenneberg *et al.*, 2003). In

modern society, light exposure may be influenced by a host of behaviours or environmental factors (e.g. school start time, sleep times, electric lighting, screen time). Indeed, in a recent study of Japanese preschoolers, 30% of children slept in bedrooms with blackout shades, and those using shades exhibited a stronger evening preference as rated by their parents (Nakade *et al.*, 2012). Evening types were also reportedly exposed to light for shorter durations in the morning between wake time and school arrival. The later bedtimes and wake times of evening types in our study suggest that they may be exposed to more evening light after sunset and less light during the early-morning hours. This pattern corresponds to ideal conditions for later circadian phases, as predicted by the adult phase–response curve to light (Khalsa *et al.*, 2003) and as demonstrated experimentally in response to increased exposure to natural light during the daytime and reduced exposure to light at night (Wright *et al.*, 2013). Further evidence for the latter comes from a study showing that individuals without electric lighting in the home have earlier bedtimes (Peixoto *et al.*, 2009). Finally, diurnal sensitivity to light is thought to undergo maturational changes, with sensitivity declining with age (Carskadon *et al.*, 2002; Crowley *et al.*, 2007). If true, the early years of life may represent a sensitive period in determining chronotype that may track across the lifespan.

Although this research was not designed specifically to evaluate the psychometric properties of the CCTQ, our results provide further construct validity for parents reporting on their child's chronotype. To date, the youngest age assessed with the CCTQ was 4 years, and validity was evaluated initially with parent sleep diaries and actigraphic estimates of sleep timing (Werner *et al.*, 2009). We found concordance rates between the three CCTQ measures that were similar to those reported in school-age children (Werner *et al.*, 2009). Additionally, our findings showing parent-reported chronotype was associated not only with objective sleep timing but also with endogenous circadian phase in a younger population help to establish the utility of the CCTQ as a convenient, cost-effective tool that may be used in epidemiological, clinical and experimental studies with young children. However, similar to the findings of others (Giannotti *et al.*, 2002; Werner *et al.*, 2009), our analysis of associations between chronotype and sleep timing is inherently subject to the issue of multi-collinearity. This is a particularly important consideration when utilizing MSF as a measure of chronotype, as it is computed based upon reported bedtime, sleep onset latency and wake time. The circular nature of sleep timing and chronotype is also a concern when utilizing multi-item morningness–eveningness questionnaires because they include items about individual's preferred sleep timing (Carskadon *et al.*, 1993; Horne and Ostberg, 1976). Although we employed actigraphy as an objective measure of sleep, a comprehensive understanding of sleep–chronotype links necessitates the collection of physiological data. For example, we recently reported moderate-to-strong associations between circadian phase and

actigraphic estimates of sleep timing, such that toddlers with later DLMOs were more likely to go to bed, fall asleep and wake up at later times (LeBourgeois *et al.*, 2013a). Such findings complement the current data indicating relationships between chronotype, circadian physiology and sleep timing.

It is important to note that the current findings are from a cohort of healthy children with 'regular' sleep schedules and no history of sleep problems, which may limit their generalizability. Thus, it is likely that obtaining data from a large community or population-based sample would produce more variability in chronotype ratings, especially evening types. Additionally, the small difference (6 min) between midsleep time on 'free' days compared to those when children's sleep schedules were influenced by structured activities (e.g. school, daycare, parent work schedules) may not be representative of the general population. Furthermore, the overestimation of wakefulness during sleep when assessed by actigraphy is an important consideration for future research studying associations between sleep quality and chronotype in children.

Associations between chronotype and outcomes were not examined in this study; however, our findings may have significant implications for children's health and development. Even in older children and adolescents, evening chronotype is related to negative outcomes, including dysregulated mood and poor academic achievement (Gelbmann *et al.*, 2012; Goldstein *et al.*, 2007). Because early childhood is a sensitive period in the development of many basic skills and functions (e.g. emotion regulation, expressive and receptive language, executive function) predictive of future health, research targeting individual difference factors placing children at-risk for poor outcomes is critical. Additionally, the developmental trajectory of chronotype starting in the early years, including the tracking of individual standing, is an unexplored research area. Given the well-documented circadian phase delay during puberty (Carskadon *et al.*, 2002; Carskadon *et al.*, 1993), eveningness in the early years may represent a vulnerable phenotype for a more severe maturational phase delay and potential development of sleep and mood disorders in the emerging teen years (Gelbmann *et al.*, 2012). Furthermore, co-sleeping is a common arrangement that varies across cultures and socio-economic statuses (Jenni and O'Connor, 2005). Sleeping with someone at a different stage of sleep–wakefulness development may be an important factor to consider in understanding children's sleep timing and chronotype. Finally, large-scale studies indicate that about 25% of young children suffer from sleep disturbance, including bedtime resistance and prolonged sleep onset delay (Owens, 2008). Such early sleep problems commonly persist into late childhood and are associated independently with concurrent and future poor health outcomes in adolescence (Gregory *et al.*, 2005). Although some have suggested that behavioural sleep problems may occur in part due to dissonance between children's individual chronotype and social demands, data supporting this hypothesis are scarce (Jenni and O'Connor, 2005). In summary, our

findings provide evidence of links between parent reports of chronotype and circadian physiology and objectively measured sleep timing, supporting the concept of chronotype and its assessment by questionnaire in young children.

ACKNOWLEDGEMENTS

We are most grateful to the children and families for their generosity, time and effort in making this study possible. We also appreciate all Brown University and the University of Colorado Boulder undergraduate students and research assistants who collected these data. Hannah LeBourgeois assisted in the scoring and management of actigraphy data. This research was supported primarily with funds from the National Institute of Mental Health (K01-MH074643, R01-MH08656). Supplemental funds were provided from the following grants: Sepracor, Inc., ESRC026, HHMI to the Biological Sciences Initiative at the University of Colorado Boulder, and NIH/NCRR Colorado CTSI UL1-TR000154.

AUTHOR CONTRIBUTIONS

MKL, MAC, OGJ and KPW conducted the study design. MKL, CTS, KGG and LDA carried out the data collection. Manuscript preparation was carried out by MKL, CTS, KGG, LDA, MAC, OGJ and KPW.

CONFLICT OF INTEREST

No conflicts of interest declared.

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