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Abstract

Important changes in sleep are believed to occur in the preschool years, but studies that have documented these changes were generally cross-sectional or based on subjective sleep measures. The current longitudinal study modeled the developmental trajectories followed by five sleep variables objectively assessed during the preschool period. Children (N = 128) wore an actigraph over three days at 2, 3, and 4 years of age and change in sleep variables was assessed with growth curves. The results showed a linear decrease of daytime, total, and nighttime sleep duration, and a linear increase of sleep efficiency and proportion of nighttime to total sleep. For all sleep variables, the rhythm of change was relatively uniform across children, but there was significant inter-individual variation around the initial status for most variables. To our knowledge, this study is the first to model the developmental trajectories followed by several sleep variables during the preschool period.

Keywords: child sleep, development, longitudinal, preschool, actigraphy

Normative developmental trajectories of actigraphic sleep variables during the preschool period: A three-wave longitudinal study

During childhood, healthy development requires sleep of sufficient quantity and quality (El-Sheikh & Sadeh, 2015). Unfortunately, sleep problems are frequent among children (Mindell & Owens, 2015) and may have negative consequences on school adjustment (Williams, Nicholson, Walker, & Berthelsen, 2016), cognition (Bernier, Beauchamp, Bouvette-Turcot, Carlson, & Carrier, 2013) and on emotional (Miller, Seifer, Crossin, & Lebourgeois, 2015) and behavioral (Bélanger, Bernier, Simard, Desrosiers, & Carrier, 2018) regulation. Moreover, sleep problems often persist throughout childhood (Mindell & Owens, 2015) and predict emotional and learning difficulties in adolescence (Silva et al., 2011). Hence, early identification of children experiencing sleep difficulties is important for prompt intervention. In order to identify children with sleep problems, knowledge about the normative development of sleep is necessary.

Normative sleep at preschool age

It is generally accepted that the preschool period is characterized by a decrease in the duration of daytime sleep and total 24-hour sleep (see Galland et al., 2012 for a review of studies using subjective measures). Parents report that their children sleep an average of about 14 hours at 2 years and 12 hours at 4 years (Iglowstein, Jenni, Molinari, & Largo, 2003; Jenni, Molinari, Caflisch, & Largo, 2007). Naps usually correspond to a total of 90 to 110 minutes of daytime sleep during the preschool period (Iglowstein et al., 2003). However, nap duration decreases between ages 2 and 4, both as measured objectively by actigraphy (Acebo et al., 2005; Ward, Gay, Anders, Alkon, & Lee, 2008) and as reported by parents (Iglowstein et al., 2003). Nighttime sleep duration remains relatively stable across the preschool years, with an average of 10 hours of nocturnal sleep (according to both actigraphy and parent reports; see Mindell & Owens, 2015 – although some cross-sectional studies suggest a small decrease of nighttime sleep duration during this period:

Acebo et al., 2005; Ward et al., 2008). Moreover, sleep becomes increasingly concentrated during the night period (see Davis et al., 2004; Sheldon, 2006 for reviews), as growing proportions of total sleep take place at night, from about 85% at 2 years to 97% at 4 years according to both actigraphy and parent reports (Acebo et al., 2005; Iglowstein et al., 2003).

Less is known about indicators of sleep quality in the preschool period, such as awakenings and efficiency. Jenni, Fuhrer, Iglowstein, Molinari, and Largo (2005) found that nighttime awakenings remain frequent: 22% of parents reported that their child woke up at least once every night at 2 years and 54% at least once a week at 4 years. However, the duration of awakenings tends to diminish after infancy, from an average of 2 hours at 1 year to a maximum of 82 minutes between 2 and 4 years (Acebo et al., 2005). Consequently, sleep efficiency (the percentage of time spent asleep between sleep onset and morning awakening) tends to increase, from an average of 81% at 1 year to averages between 86% and 93% during preschool years (Acebo et al., 2005; Scholle et al., 2011 using polysomnography; Ward et al., 2008).

Developmental patterns of change in sleep

The research presented above provides estimates of average values of different sleep variables at different ages. Importantly, however, conclusions about “increases” and “decreases” in different sleep variables are often drawn based on comparisons of mean-level estimates obtained across studies that examined children of different ages, or on cross-sectional studies that included subsamples of children distributed in distinct age groups (e.g., Acebo et al., 2005; Crosby et al., 2005; Ward et al., 2008). In both cases, child age is inherently confounded with other subsample characteristics or study parameters, limiting the possibility to draw reliable conclusions about developmental increases and decreases. In contrast, longitudinal studies with at least three assessment time points on the same children allow for the study of true patterns of developmental change (Bornstein, Putnick, & Esposito, 2017; Fraley, Roisman, & Haltigan, 2013). Such designs are essential to answer key developmental questions, such as those pertaining to the shape of developmental trajectories, timing and chronicity of sleep problems, and how improvements or deteriorations in sleep predict changes in other domains of functioning (El-Sheikh & Kelly, 2017). Yet, few studies have used longitudinal designs along with objective actigraphic measures to document stability and change in preschoolers' sleep. Scher, Epstein, and Tirosh (2004) assessed children's sleep from 20 to 42 months of age and found rank-order stability in nighttime sleep quality, but not in nighttime sleep duration. With children around 41 months of age, Anders, Iosif, Schwichtenberg, Tang, and Goodlin-Jones (2011) found that 24-hour sleep duration decreased and nighttime sleep quality increased over a six-month period. Finally, Staples, Bates, and Petersen (2015) found that 24-hour sleep duration decreased significantly between 30 and 42 months, which was explained by reduced daytime sleep duration.

Of note, these three studies used mean-level differences or continuity in rank order to characterize stability and change in preschoolers' sleep. While important, these approaches do not offer information about intra-individual development (i.e., within-person changes across time; Bornstein et al., 2017). In contrast, growth modeling approaches lend themselves to examining intra-individual patterns of development and comparing individuals on these patterns (inter-individual differences in intra-individual rates of change). Longitudinal designs supplemented by such statistical approaches allow for the identification of developmental patterns in children's sleep (often called sleep growth curves), an aspect of development that is mostly unknown thus far (El-Sheikh & Kelly, 2017), particularly in the preschool period.

With school-age children and adolescents, a limited literature has examined sleep growth curves, mostly in relation to youths' adjustment (e.g., depression, internalizing and externalizing problems, cognition; Bub, Buckhalt, & El-Sheikh, 2011; El-Sheikh, Bub, Kelly, & Buckhalt, 2013; Fredriksen, Rhodes, Reddy, & Way, 2004; Goodnight, Bates, Staples, Pettit, & Dodge, 2007).

Together, these studies suggest that the developmental trends in sleep indices bear meaningfully on child adjustment. Given that sleep seems to undergo even more significant developmental changes in the preschool years, documenting the developmental patterns in sleep before age 5 is a critical step toward understanding their implications for young children's adjustment.

To our knowledge, few studies have used contemporaneous statistical techniques of longitudinal analysis to do so. Touchette et al. (2008, 2009) addressed nighttime sleep duration between 2 and 6 years, Magee, Gordon, and Caputi (2014) examined daily sleep duration between 0 and 7 years, and Weinraub et al. (2012) as well as Hsu (2017) focused on nocturnal awakening between 6 and 36 months. Recently, Kocevska et al. (2017) examined sleep disturbances between 2 months and 6 years. Thus, each of these studies focused on one sleep variable only. Furthermore, five of these six studies used a group-based approach (growth mixture modeling or latent class trajectory modeling) to identify groups of children following distinct developmental patterns. A growth curve approach (Hsu, 2017) provides complementary information, describing how each sleep variable develops on average and how each child varies around the average. Most importantly, all six aforementioned studies used parental reports to measure children's sleep, which can lead to different biases inherent to the parent, the level of adhesion, and the burden that filling the questionnaire may represent (Sadeh, 2015).

Overall, current knowledge on developmental patterns of change in sleep during the preschool period is limited for several reasons. To begin with, the majority of studies are cross-sectional and the statistical approaches used generally do not estimate intra-individual changes in sleep and inter-individual differences in these changes. Moreover, in many studies, sleep is measured using parental reports. Finally, most studies focus on one or two sleep indices, indicative of either duration or quality of sleep, although Dewald, Meijer, Oort, Kerkhof, and Bögels (2010) observed that duration and quality represent distinct domains of sleep that are differently associated with developmental outcomes, and therefore should be studied separately. In most studies using actigraphy, sleep duration represents the quantity of sleep (i.e., actual time spent asleep), whether during the day, the night, or over the whole 24-hour period. Sleep quality usually refers to indices such as the number or duration of night awakenings, as well as sleep efficiency (proportion of the sleep period spent asleep). There is some evidence for compensatory mechanisms between sleep duration and quality. Ward et al. (2008) observed that night awakenings were more frequent among children who napped compared to non-nappers and hypothesized that children with lower-quality sleep needed a nap during the day to meet their total sleep needs. In addition to duration and quality, sleep can also be characterized by its distribution over the 24-hour day period (Sadeh, 2015). Accordingly, in the current study, variables relevant to sleep duration, quality, and distribution were assessed.

The current study

The current three-wave (2, 3, and 4 years of age) longitudinal study investigated the developmental patterns of change in five actigraphic sleep variables during the preschool period. As proposed by Bornstein et al. (2017), these developmental changes were examined using complementary approaches. First, traditional analytic methods were used, including examination of group averages at each age and change in the relative order of individuals through time (indexed by correlations). Next, a multilevel modeling (MLM) framework was used to examine intra-individual change (from age to age) and whether there were significant inter-individual differences in rates of change. To our knowledge, this study is the first to characterize developmental patterns of change in actigraphy-derived preschool sleep variables formally, in addition to quantifying intra-individual change across time and inter-individual differences in these patterns of change. Considering the results of previous studies, we predicted stability in nighttime sleep duration, a linear decrease of daytime and total daily sleep duration, and a linear increase in the proportion of nighttime sleep and sleep efficiency across the preschool years.

Method

Participants

This study is part of a larger longitudinal project on early parent-child relationships and children's developmental pathways (***: blinded for review). The current sample consisted of 128 children (67 boys and 61 girls) for whom sleep trajectories were estimated. Families lived in a large Canadian metropolitan area and were recruited using random birth lists provided by the Ministry of Health and Social Services. Criteria for participation (upon recruitment when children were 7-8 months old) were a full-term pregnancy (i.e., at least 37 weeks of gestation) and the absence of any physical or mental abnormality in the child. Written informed consent was obtained from mothers prior to the beginning of the study and the study protocol was approved by the university's institutional review board. Upon recruitment, mothers were between 20 and 45 years (M = 31.73, SD = 4.5), had an average of 16 years of education (SD = 2.2) and were mostly Caucasian (91.4%). Fathers were between 21 and 58 years (M = 34.09, SD = 5.8), had an average of 16 years of education (SD = 2.4) and were generally Caucasian (81.3%). Annual family income (in Canadian dollars) varied from less than $20,000 to over $100,000, with a mean situated in the $60,000 –$79,000 bracket. Finally, 37% of children were first born and 63% had older siblings.

Procedure

Children's sleep was assessed on three consecutive days at 2 (22 to 28 months; M = 25.1 months), 3 (35 to 41 months; M = 36.8 months) and 4 years of age (47 to 51; M = 48.8 months). The three-night period was chosen with the aim of reducing child and family burden and thus optimizing compliance. Although Acebo et al. (1999) recommended the use of at least five nights of actigraphy recordings to obtain optimally reliable measures, one notes from closer inspection of their data that satisfactory levels of reliability (close or superior to .70) can be obtained with three days of assessment. Families took part in home visits at the end of which a research assistant left an actigraph and a sleep diary with the mother and provided her instructions for each one. Parents were asked to choose three days during which their child had a fairly usual routine for the sleep assessment. Overall across children, most nights of assessment (70% at 2 years, 71% at 3 years, and 67% at 4 years) took place on weekdays. Estimates of sleep variables were unrelated to the type of day (weekday vs. weekend; all *p*s > .25). A financial compensation of $20 was offered to families when the child wore the actigraph in accordance with instructions and the mother filled out the sleep diary.

Among the 128 children, 85 had analyzable sleep data at 2 years, 63 at 3 years, and 65 at 4 years. Missing data were attributable to the fact that families missed the first assessment (did not have time or could not be contacted at 2 years; n = 12), left the study afterward (moved away or no longer had time; 33 at 3 years, and 29 at 4 years), children refused to wear the actigraph (n = 12 at 2 years, 22 at 3 years, and 18 at 4 years), the mother did not complete the sleep diary (used to double-check the actigraphy data; see below) on any of the three days (n = 13 at 2 years, 3 at 3 years, and 11 at 4 years), or all data had to be discarded due to the identification of potential artefacts in the actogram (n = 6 at 2 years, 7 at 3 years, and 5 at 4 years). The number (one, two or three) of sleep assessment time points was not significantly associated with sleep estimates or sociodemographic variables (maternal and paternal ethnicity, education, and age, family income, child sex, or number of siblings; all *p*s > .06). In all, 128 children had usable data on at least one of the sleep assessment points; in keeping with best practices to handle missing data in longitudinal designs (Enders, 2010), these 128 children formed the analytic sample.

Measures

Actigraphy. At 2, 3 and 4 years, children wore an actigraph (Mini-Mitter® Actiwatch, Respironics; AW-64), a small watch-like computerized monitor that continuously records body movements through an accelerometer. Children wore the actigraph around the ankle or wrist for 72 consecutive hours, except when they were in contact with water, for example when bathing or swimming. Activity level was recorded in 30-second epochs and data were downloaded to a computer and analyzed to convert the motor activity data into estimates of sleep and wake periods. As actigraphy tends to overestimate night awakenings because of young children's higher level of motor activity during sleep (Meltzer, Montgomery-Downs, Insana, & Walsh, 2012), data were analyzed initially with the manufacturer's low sensitivity threshold algorithm (80 activity counts per epoch). This algorithm has been found to be the most appropriate for preschoolers (Bélanger, Bernier, Paquet, Simard, & Carrier, 2013). However, even this more appropriate algorithm (relative to those involving 20 or 40-activity count thresholds) overestimates awakenings (Bélanger et al., 2013). Thus, a secondary "smoothing" algorithm, developed specifically to address the problem of overestimation of night waking, was then applied to the nighttime data derived from the 80-activity count threshold. This smoothing method requires a minimum 2-min awakening period following sleep onset to score an awakening (Sitnick, Goodlin-Jones, & Anders, 2008). This algorithm has been validated against videosomnography (Sitnick et al., 2008) and home-based polysomnography (Bélanger et al., 2013).

All actigraphic data were scored by a research assistant who was experienced with actigraphy data scoring. To score nighttime sleep, the research assistant examined the actogram (graphical representation of activity level provided by the actigraphy software) and manually defined sleep onset (the start of the first consecutive minutes of sleep; i.e., consecutive minutes for which the activity count was at or near zero) and sleep offset (the end of the last minutes of sleep). To guide examination of the actogram, the assistant used sleep onset and offset times indicated on the diary. To identify naps, the assistant identified periods during the day (i.e., between wake up in the morning and 5 pm) where the activity count was at or near zero and looked for maternal confirmation of a nap at that time on the diary. Mothers were also asked to note on the diary all moments where their child was not wearing the actigraph, which allowed the research assistant to make sure that moments without motor activity were attributable to sleep, and not to the child having removed the actigraph.

Sleep variables derived from actigraphy were: (a) nighttime sleep duration (number of minutes scored as sleep between nighttime sleep onset and offset); (b) daytime sleep duration; (c) total sleep duration over a 24-hour period (the sum of nighttime and daytime sleep duration); (d) proportion of nighttime sleep (percentage of total daily sleep occurring at night – an index of sleep distribution) and (e) sleep efficiency (number of minutes scored as sleep between nighttime sleep onset and offset/ [number of minutes scored as sleep + number of minutes scored as wake between sleep onset and offset] x 100). For each sleep variable, the average over the three days of assessment was used.

Actigraphy constitutes an objective and minimally invasive way to collect sleep data in the natural environment, and several studies have demonstrated its validity for sleep assessment in children (Acebo et al., 1999; Sadeh, Lavie, Scher, Tirosh, & Epstein, 1991; Sung, Adamson & Horne, 2009). The actigraph model used in this study demonstrates good to high correspondence (77-98%, depending on the sleep variable studied) with polysomnography for this age group, regardless of location (ankle or wrist; Bélanger et al., 2013).

Sleep diary. During the same 72 hours that the child was wearing the actigraph, the mother was asked to fill out a sleep diary, used to confirm the validity of actigraphic data. To minimize memory biases, the mother was asked to complete the sleep diary in real time (i.e., as the day unfolded rather than retrospectively at the end of the three-day period). The mother had to note, on a 24-hour timeline divided into 30-minute periods, whether the child was awake or asleep for each period. She also indicated where the child was sleeping and whether particular events (such as illness, medication taking, or visitors at home) could have disrupted her child's sleep. The specific days where sleep data might be unrepresentative of the child's usual sleep patterns were discarded. Specific days when examination of the sleep diary suggested that the actogram was invalid (e.g., recording of movement induced by an external object, such as while the child slept in a stroller or car; child removing the actigraph), or when actigraphy data showed low correspondence with the sleep diary were also rejected to ensure optimally reliable data. The majority of children had, at each age, 3 days of data. At 2 years, 68 children had 3 days of valid data, 10 had 2 days, and 7 had 1 day. At 3 years, 44 children had valid data on 3 days, 15 on 2 days, and 4 children had 1 day of data. Finally, at 4 years, 53 had 3 days of valid data, 7 had 2 days, and 5 had 1 day. Overall, only 4 children (i.e., approx. 3% of the sample) had valid data for one day at each time point.

In order to be scored as sleep, a daytime sleep period had to be both indicated by the mother on the diary as a nap and identified as sleep in the actigraphy data. At each age, the majority of children attended daycare (81.7% at 2 years, 87.3% at 3 years, and 92.9% at 4 years). In these cases, the mother asked the child care educator about nap periods at the end of each day and reported them on the diary.

Analytic Strategy

To eliminate the need to delete individuals with missing data, and consequently increase statistical power, full information maximum likelihood (FIML) estimation was used. Numerous studies have shown the superiority of FIML in comparison with classical methods of handling missing data (e.g., listwise and pairwise deletion; Enders & Bandalos, 2001; see Enders, 2010).

Contrary to other methods, FIML produces unbiased and stable estimates under a missing at random data mechanism, such as that observed here (Enders, 2010).

With the aim of describing patterns of change in children's sleep during the preschool period, growth curves were fitted in Mplus 7.4 using a multilevel modeling (MLM) framework, also known as Hierarchical Linear Modeling (HLM). MLM was chosen here because it can easily handle the difficulties generated by specific conditions such as small samples (groups as small as 30–50 are sufficient for reliable modeling), partially missing data, and unequally spaced time points (Burchinal, Nelson, & Poe, 2006; Singer & Willett, 2003), which were encountered in the current study. MLM treats repeated observations as nested within individuals and models change on two levels: level 1 that represents individual (within-person) change over time and level 2 representing the extent to which change differs across individuals (between-persons; Singer & Willett, 2003).

The first step is to specify an intercept-only model (null model) that does not include any explanatory variables (i.e., any level-1 or level-2 predictors) and postulates that there is no change over time. This model is particularly useful for calculating the intraclass correlation coefficient (ICC) and thus allows decomposing the total variance of the studied phenomenon into inter-individual and intra-individual variance (Geiser, 2012; Luke 2004). Next, in order to identify the best-fitting model of change in children's sleep, two unconditional models were specified for each sleep variable : 1) Model A (i.e., fixed linear model), which included the fixed effect of child exact age in years and months as level-1 predictor, coded such that the intercept represented the average for the sleep variable at the first assessment and the slope represented the average yearly decrease or increase in this variable, and 2) Model B (i.e., random linear model), which included the random effect of time, that is, between-person variability in individual slopes. Using child exact age at each assessment point enabled us to flexibly handle individually varying assessment times and to estimate change in child sleep across a broad range of ages (from 1.83 to 4.25 years). Finding Model A to be the best-fitting model for a given variable would indicate that the developmental trajectory for this sleep variable is best represented by a linear pattern of change that is relatively uniform (i.e., negligible differences) across children, whereas Model B as best-fitting would rather suggest that there is variation between children in rate of change. Finally, a fixed quadratic term was added (Model C) to explore whether there was a significant acceleration or deceleration in rate of change across time (i.e., indicating a decreasing or increasing curvilinear trajectory). Different indicators were used to determine which growth model presented the best fit to the data: the random effects and quadratic terms were retained if the pertinent p-value for the estimates were < .05 or if the model's log likelihood (-LL) differed significantly with the addition of the random or quadratic slope terms, based on a chi-square difference test. The best-fitting models are presented in Table 3.

Results

Preliminary analyses: Traditional analytic methods

Table 1 presents the means, ranges, correlations across time points, and inter-correlations among sleep variables. Examination of average scores suggests that nighttime, daytime, and total daily sleep durations tend to decrease overall during the preschool period, whereas sleep efficiency and proportion of nighttime sleep seem to increase slightly. The low to moderate coefficients of stability (correlations across age) for sleep variables indicate changes in inter-individual differences across time. These changes suggest the presence of between-children differences in patterns of growth in sleep across time, which will be formally examined next with multilevel growth modeling. At each time point, nighttime sleep duration was positively and significantly associated with total daily duration, proportion of nighttime sleep, and sleep efficiency. It was also negatively associated with daytime sleep duration, and this correlation increased in magnitude and statistical significance from age to age. Total daily sleep duration was negatively associated with proportion of nighttime sleep and positively associated with sleep efficiency. Daytime sleep duration was strongly negatively associated with proportion of nighttime sleep as expected, but unrelated to sleep efficiency. Finally, sleep efficiency and proportion of nighttime sleep were unrelated to each other.

[*Insert Table 1*]

Main analyses: Describing children's sleep growth curves

In addition to the models discussed below, a fixed quadratic model was tested for all sleep variables, but no significant change in slope (i.e., quadratic effect) was obtained, and this model (Model C) was not the best fitting for any of the sleep variables. Accordingly, quadratic models are not discussed further. Correlations between initial status and rate of change were also examined for all variables, and none was significant. Figures 1 to 5 illustrate each sleep variable's growth curve, described next.

[*Insert Figures 1 to 5*]

Nighttime sleep duration. The intercept-only model (see Table 2) revealed that 22% of the variance in nighttime sleep duration was inter-individual (vs. 78% intra-individual), as shown by the intra-class correlation (ICC; .22). With regard to unconditional growth models, the best-fitting model was a fixed linear model (Model A; Table 3), indicating a constant albeit non-significant decrease across time. This decrease, however, is non-negligible, given that Model A provided better fit to the data than the intercept-only model, which postulates that there is no change over time. When the effect of age was removed, the fit of the model decreased (LL = -252.89), further suggesting that it is important to retain age in the model even though the rate of change is not statistically significant. Model A showed that nighttime sleep duration started at 9.45 hours ($\gamma00$) and decreased by 5.4 minutes ($\gamma10$) per year. The small magnitude of the slope ($\gamma10$) shows a slow decrease across time. There was significant inter-individual variability around the initial status (σ_0^2 = .16). When the random effect of time (i.e., between-person variability in individual slopes) was added (Model B), there was no inter-individual variability around the rate of change ($\sigma_1^2 = .09$) and the fit of the model decreased, which indicates that the decrease in nighttime sleep duration was relatively uniform across children. In sum, nighttime sleep duration was characterized by a slight, non-significant decrease that did not vary significantly from one child to another.

[*Insert Table 2*]

Daytime sleep duration. The ICC (.19) of the intercept-only model (see Table 2) indicated that the variance was mostly intra-individual (81%). The best-fitting model was a fixed linear model (Model A; Table 3), indicating a significant and consistent decrease in daytime sleep across time. Model A showed that, on average, daytime sleep started at 2.22 hours (γ00) at the beginning of the preschool period and decreased by 18 minutes per year (γ10). There was significant between-person variability around the initial status (σ_0^2 = .22). When the random effect of time was added (Model B), the fit of the model was reduced (LL = -217.94) and there was no significant between-person variability around the rate of change (σ_1^2 = .11). Therefore, daytime sleep duration was characterized by a significant decrease that did not vary significantly across children.

Total daily sleep duration. According to the intercept-only model (see Table 2), only 10% of the total variance was inter-individual (ICC = .10). The best fitting model for total daily sleep duration was a random linear model (Model B; Table 3), indicating a significant and consistent decrease in children's total sleep across time. This model indicated that on average, total daily sleep duration decreased by 22 minutes (γ10) per year, starting at 11.63 hours (γ00) at the beginning of the preschool period. There was significant between-person variability around the initial status (σ_0^2 = .97), but not around the rate of change (σ_1^2 = .17). Although the variability around the slope was not significant, removing the slope variance decreased the fit of the model

(LL = -253.03), which indicates that Model B is the model that best describes change in total daily sleep duration across the preschool years. This change was characterized by a significant decrease that did not vary significantly from one child to another, although that variation was non-negligible.

Proportion of nighttime sleep. The intercept-only model (see Table 2) suggested that about half of the variance in the proportion of nighttime sleep was inter-individual (ICC = .52). The model with the best fit was a fixed linear model (Model A; Table 3). The proportion of nighttime sleep thus followed a linear trajectory characterized by a significant and constant increase across the preschool years. According to this fixed linear model, the proportion of nighttime sleep started on average at 81.18% (γ00) and increased by 2.23% (γ10) per year. There was marginal variability around the initial status (σ_0^2 = 13.53). When the random effect of time was added (Model B), the fit of the model was reduced (LL = -568.15) and there was no significant between-person variability around the rate of change (σ_1^2 = 12.57), which confirmed that Model A better represented the trajectory of this variable. In sum, there was a significant increase in the proportion of nighttime sleep that did not vary significantly between children.

Sleep efficiency. The intercept-only model (see Table 2) indicated almost exclusively intra-individual variance in sleep efficiency (ICC = .05). The best fitting model for sleep efficiency was a random linear model (Model B; Table 3), characterized by a significant and constant increase over time. On average, sleep efficiency increased by 2.14% (γ10) per year, starting at 90.55% (γ00) at age 2. There was significant between-person variability around the initial status (σ_0^2 = 21.40), but not around the rate of change (σ_1^2 = 3.87). Although there was no significant variability around the slope, removing this parameter decreased the fit of the model (LL = -652.83), so Model B remained the model that best described change in sleep efficiency, namely a significant increase that did not vary significantly from one child to another, although that variation was non-negligible.

[*Insert Table 3*]

Discussion

The aim of this study was to formally characterize the developmental changes in sleep that take place across the preschool years using actigraphy-derived indicators of sleep analyzed with state-of-the-art statistical techniques. Multilevel modeling was used to examine intra-individual change (from age to age) in each sleep variable and whether there were significant inter-individual differences in rates of change. The results suggested that significant changes in children's sleep occur between 2 and 4 years (specifically, between 1.83 and 4.25 years) and that different sleep variables show distinct (albeit all linear) patterns of growth across time. Findings also indicated relatively similar shape and rhythm of change across children on all sleep variables, although some variables showed significant variability between children around the initial status at 2 years. In addition, there was some indication of non-negligible (albeit non-significant) between-children variability in the slope of two of the considered parameters. Importantly, the results also suggested that rank-order relative stability could occur alongside significant intra-individual increases or decreases, and vice-versa, highlighting the importance of disentangling intra- and inter-individual aspects of developmental changes in sleep.

Sleep during the preschool period: Traditional analytic methods

Before considering the findings of the growth curves analyses, it may be useful to consider first the results that emanated from the more traditional approaches as used in previous studies. Age-specific average levels of sleep duration (daytime, nighttime, and total) appeared to decrease slightly between 2 and 3 years of age, and more markedly between 3 and 4 years of age, while sleep efficiency and proportion of nighttime sleep seemed to increase, although sometimes very modestly. These observed trends were broadly consistent with the findings of previous studies (e.g., Acebo et al., 2005; Iglowstein et al., 2003; Magee et al., 2014; Ward et al., 2008), and tested more formally next with multilevel modeling.

At each age, nighttime sleep duration was negatively associated with daytime sleep duration, and this correlation increased in magnitude and statistical significance from age to age, becoming reliable at age 4. This negative correlation is consistent with previous actigraphic studies (Acebo et al., 2005; Ward et al., 2008; see El-Sheikh, Arsiwalla, Staton, Dyer, & Vaughn, 2013 for an exception) and might suggest that napping leads to a lesser need for sleep at night, or conversely, that shorter nighttime sleep results in a greater need to nap during the day so as to meet total sleep requirements (Thorpe et al., 2015; Ward et al., 2008). However, such compensation mechanisms do not appear to be at play at age 2, which might indicate that naps are more necessary in the early preschool period and slowly become mostly compensatory for lack of nighttime sleep as children approach age 4.

Findings also revealed generally low to moderate stability (i.e., low to moderate correlation coefficients between assessment times) for sleep variables, suggesting changes across time in inter-individual differences (i.e., children do not tend to maintain their position relative to other children, potentially because their sleep does not change at the same pace as other children). These analyses thus suggested that sleep is characterized by an instability in children's rank-order across the preschool years. To examined this further and increase our understanding of the normative development of sleep during this period, it is necessary to examine intra-individual patterns of change in distinct sleep variables, which requires growth curve modeling (Bornstein et al., 2017).

Patterns of growth in children's sleep during the preschool period

Multilevel growth modeling showed that all sleep variables followed a linear trajectory, indicating a constant rate of change across the preschool period. Hence, the apparent increases or decreases suggested above were confirmed and shown to be relatively constant across time, as no significant acceleration or deceleration in change was observed. All sleep variables inherent to sleep duration (nighttime, daytime and daily duration) followed a linear decrease, whereas the proportion of nighttime sleep and sleep efficiency followed a linear increase. For all sleep variables, Model A (postulating change over time) proved to be a better fit to the data than the intercept-only model (postulating a flat trajectory), which indicates the presence of a non-negligible effect of time on all sleep indices assessed in this study. It is important to note that the decrease was not statistically significant in the case of nighttime sleep duration. However, although the slope estimate was not significantly distinguishable from 0, it may have been with a larger sample size, given that the intercept-only model, postulating no effect of time, was a worse fit to the data than the fixed linear model, which includes change over time. Thus, we tentatively suggest that nighttime sleep duration likely exhibits a slow (vs. no) decrease across the preschool years.

In sum, the significant slopes observed on four on the five studied sleep variables suggest that sleep undergoes significant linear developments at the intra-child level (individual changes from age to age) across the preschool period. It is interesting to note that in the growth analyses, these increases or decreases were estimated as relatively constant (i.e., no significant acceleration or deceleration in change), whereas initial examination of average scores suggested that the decrease of daytime, nighttime, and total sleep duration appeared more pronounced between 3 and 4 years of age than between 2 and 3 years. When lumping children's sleep values into group averages at each age, their values appear to change more rapidly between 3 and 4 years than between 2 and 3 years, which speaks to average group-level tendencies. In contrast, growth curve analyses first model one slope across time per child, and then average out these slopes. Hence, growth modeling analyses focus first on the changes that occur over time for each child, allowing to capture within-child developmental tendencies, and suggest in this case that the average child's sleep does not change more rapidly between 3 and 4 than between 2 and 3 years. Such results highlight the importance of examining different types of change and stability (i.e., distinguishing between group tendencies and intra-individual patterns) in order to obtain a more complete picture of a longitudinal process (Bornstein et al., 2017). To our knowledge, this study is the first to do so with several sleep variables objectively assessed among preschoolers.

In addition to the examination of intra-individual changes across time and individual differences therein, another uniquely informative aspect of growth modeling is the possibility to partition the observed variance in two sources, intra-individual and inter-individual. These analyses revealed that large proportions of the variance (78%-93%) in four of the five sleep variables (with the exception of proportion of nighttime sleep; 48%) were intra-child, and thus could be attributed to within-individual factors, namely increasing age and associated intrinsic maturational processes. Indeed, it appears sensible that maturation could play a substantial role in the changes found in this study, which together represent increasingly more mature sleep patterns. The development of sleep-wake cycles is driven partly by the maturation of two intrinsic bio-regulatory processes: a homeostatic process, whereby sleep pressure accumulates with time awake and dissipates during a sleep episode, and a circadian process, which is independent of prior waking and provides cyclical signals promoting alertness versus sleep (Jenni & LeBourgeois, 2006; see also Borbély, 1982). It has been observed that the homeostatic process slows down at preschool age, resulting in the need for sleep to accumulate less rapidly during wake episodes as children get older. This deceleration in the homeostatic process is believed to contribute to the gradual decrease in children’s sleep duration, particularly daytime sleep (Jenni & LeBourgeois, 2006). The circadian process also undergoes development during the preschool period, with circadian sleep regulation (i.e., the proportion of variance in sleep and wake that is explained by the circadian process) becoming increasingly more important (Dearing, McCartney, Marshall, &

Warner, 2001). Maturation of the circadian process facilitates adaptation to the 24-hour light and dark cycles, which is likely to promote sleep consolidation and efficiency. Thus, overall, normative maturation of homeostatic and circadian processes may partly explain the developmental changes observed here in sleep variables, namely shorter total and daytime duration as well as better consolidation (proportion of nighttime sleep) and efficiency.

Another set of findings that emanated from this study pertained to individual differences in the developmental trends just described. The rate of change appeared relatively similar for all subjects, as variance around the slope was statistically non-significant for all sleep variables. This suggests that changes in preschoolers' sleep occur at a rhythm that is relatively uniform across children (at least those not drawn from clinical populations). It is possible that this similarity in the rate of change is due to the influence, described above, of maturational factors (e.g., maturation of homeostatic and circadian processes) that generally affect same-age children in relatively similar ways – this also contributes to explaining the large proportion of intra-individual variance observed on most sleep variables. However, all sleep variables presented significant or marginal (in the case of proportion of nighttime sleep) inter-individual variation around the initial status (i.e., age-2 level). This suggests that although their sleep patterns develop at relatively similar rates, not all children enter the preschool period at the same level in sleep indices. These early individual differences in the initial status are likely due to both biological and environmental factors.

One last finding that could not have been obtained with conventional statistical analyses is the independence of the intercept and rate of change on all variables considered. This indicates that initial status does not predict preschoolers' patterns of change in sleep; hence, children who slept less or less well than their peers at 2 years did not catch up with them over the 2.5-year period covered by this study (22 to 51 months). The persistence of these differences suggests that early sleep patterns may set children on a trajectory that could have significant long-term consequences. These results also indicate that initial status and rate of change are two distinct ways to characterize preschoolers' sleep, which could predict different outcomes.

Limitations

This study presented some limitations that need to be noted. The use of a low-risk community sample limits the generalizability of the results, most notably to clinical samples that may, in fact, be characterized partly by failure to follow the normative trends described here. Also, the relatively low diversity of the sample may have influenced the findings; in particular, one may speculate that the small proportion of inter-individual variation found in most sleep variable is due in part to the relatively homogeneous sample. Further studies with children from more varied backgrounds would be useful in determining whether there is greater inter-individual variation in more diverse samples (e.g., in terms of family socioeconomic status, ethnicity, and others). For instance, there is some evidence that family income relates to sleep trajectories in the preschool period (e.g., Magee et al., 2014), thus suggesting that there may be more inter-individual variation in more diverse samples. As is often the case in studies that use objective sleep measures with young children (e.g., Berger, Miller, Seifer, Cares, & LeBourgeois, 2012; Scher, Hall, Zaidman-Zait, & Weinberg, 2010; Vaughn et al., 2011), the sample was relatively small, which, however, was handled using an MLM approach, chosen based on its demonstrated capacity to yield unbiased and accurate estimates with small samples. It has been suggested that groups as small as 30–50 are sufficient for reliable modeling (Burchinal et al., 2006) and simulation studies have shown that only sample sizes of 50 or less can result in biased estimates in MLM (Maas & Hox, 2005). Also, many participants had missing sleep data at some assessment waves, especially at 3 and 4 years, as attrition is an inevitable characteristic of longitudinal research. Consequently, suitable methods were used to handle missing data and minimize bias associated with attrition (Enders, 2010): group equivalence was examined, and an appropriate method to handle missing data (FIML) was used, which yields stable and robust estimates under the pattern of missing data observed here. Moreover, actigraphy data were available for a maximum of three nights. Although this is not unusual when working with young children (e.g., Scher et al., 2010; So, Buckley, Adamson, & Horne, 2005; Ward et al., 2008), it is preferable to use at least five days (Acebo et al., 1999). Also, most children attended daycare and daycare facility policies with regard to napping (e.g., if napping was required, facilitated, or discouraged), which we did not assess, may have influenced napping opportunity and consequently daytime and total sleep duration. Finally, both weekdays and weekends were included in the sleep assessment, which could constitute a confounding factor. However, the type of day (week or weekend) was unrelated to any sleep variable, consistent with studies suggesting that among young children and in contrast to older children or adolescents, sleep patterns do not vary between weekends and weekdays, including on the variables examined here (e.g., Goodlin-Jones, Tang, Liu, & Anders, 2008; Hatzinger et al., 2012; Price et al., 2013).

Conclusion

The current study relied on a longitudinal design, an advanced statistical approach, and an objective measure of sleep and is the first (to our knowledge) to describe the developmental trajectories followed by several actigraphy-derived sleep variables during the preschool period and to examine individual differences in these developmental trends. Future research should aim to test the role of biological and environmental factors in the prediction of inter-individual differences in both initial status and rate of change of different sleep variables at preschool age. Given that developmental trajectories of sleep at school age and in adolescence are meaningfully associated with child functioning in several areas (Bub et al., 2011; El-Sheikh et al., 2013; Fredriksen et al., 2004; Goodnight et al., 2007), research should strive to identify domains of functioning that are impacted by preschoolers’ sleep trajectories as well.

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Table 1

Descriptive Statistics, Correlations across Time Points, and Inter-Correlations among Variables

Age	M (SD)	Range	Correlations across age: 2 yrs	3 yrs	4 yrs	Inter-correlations among sleep variables: Nighttime sleep	Daytime sleep	Total daily sleep duration	Proportion of nighttime sleep	Sleep Efficiency
Nighttime sleep duration										
2 yrs	564.94 (59.82)	389.25-678.34	--	.09	.30*	--	-.02	.75***	.27*	.71***
3 yrs	560.89 (44.87)	466-666.50	--	--	.46**	--	-.24^{t}	.54***	.38**	.57***
4 yrs	532.50 (46.16)	414-646.67	--	--	--	--	-.48***	.45**	.58***	.31*
Daytime sleep duration										
2 yrs	124.28 (52.57)	10-225	--	.23	-.02	--	--	.66***	-.93***	.07
3 yrs	117.42 (52.52)	0-228	--	--	.64***	--	--	.69***	-.98***	.05
4 yrs	92.96 (51.99)	4-183.50	--	--	--	--	--	.55***	-.99***	.23^{t}
Total daily sleep duration										
2 yrs	687 (77.66)	542-851.50	--	.17	.20	--	--	--	-.45***	.57***
3 yrs	679.53 (60.94)	507.75-802.75	--	--	.12	--	--	--	-.57***	.48***
4 yrs	644.61 (50.53)	527.33-760.33	--	--	--	--	--	--	-.47***	.57***
Proportion of nighttime sleep										
2 yrs	82.33 (6.75)	67.20-98.15	--	24	.13	--	--	--	--	.11
3 yrs	83.08 (7.10)	69-100	--	--	.67***	--	--	--	--	.05
4 yrs	86.35 (7.63)	71.46-100	--	--	--	--	--	--	--	-.23^{t}
Sleep efficiency										
2 yrs	90.61 (7.09)	67.03-99.57	--	05	.12	--	--	--	--	--
3 yrs	94 (5.52)	70.93-100	--	--	.22	--	--	--	--	--
4 yrs	94.75 (4.39)	76.57-100	--	--	--	--	--	--	--	--

$^{t}p < .10$. $^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$. Note. SD = Standard deviation.

Table 2

Intercept-Only Models of Children's Sleep during the Preschool Period

	Nighttime duration	Daytime duration	Total daily sleep duration	Proportion of nighttime sleep	Sleep efficiency
Within					
Variances	0.58** (0.09)	0.65** (0.12)	1.14** (0.18)	140.65** (19.69)	36.46** (4.98)
Between					
Means	9.34 (0.06)	1.88 (0.07)	11.19 (0.09)	81.31 (1.48)	92.94 (0.44)
Variances	0.15* (0.08)	0.15 (0.12)	0.11 (0.14)	151.21** (27.65)	1.80 (3.57)
Goodness-of-fit					
LL	-263.41	-229.07	-264.70	-763.25	-678.39

*$p < .05$. **$p < .001$. Note. Standard errors are within parentheses; LL = log likelihood.

Table 3

Unconditional Growth Models of Children's Sleep during the Preschool Period

		Nighttime duration	Daytime duration	Total daily sleep duration	Proportion of nighttime sleep	Sleep efficiency
Best-fitting model		Model A	Model A	Model B	Model A	Model B
	Par					
Fixed effects						
Initial status, π_{0i}						
Intercept (2 years)	γ_{00}	9.45** (0.10)	2.22** (0.12)	11.63** (0.17)	81.18** (0.96)	90.55** (0.80)
Rate of change, π_{1i}						
Linear slope	γ_{10}	-0.09 (0.07)	-0.29** (0.08)	-0.37** (0.10)	2.23** (0.63)	2.14** (0.49)
Change in slope (quadratic)	γ_{20}					
Variance components						
Within-person (residual)	σ_E^2	0.56** (0.08)	0.54** (0.10)	0.81** (0.17)	37.53** (6.80)	26.58** (3.50)
In initial status	σ_0^2	0.16* (0.08)	0.22* (0.11)	0.97* (0.43)	13.53t (6.93)	21.40* (8.92)
In rate of change	σ_1^2			0.17 (0.19)		3.87 (2.61)
Slope intercept Covariance	σ_{01}			-0.40 (0.27)		-9.10t (4.74)
Goodness-of-fit	LL	-254.63	-218.45	-248.84	-569.84	-646.81

t*p* < .10. **p* < .05. ** *p* < .001. Note. Standard errors are within parentheses; Par = parameters; LL = log likelihood; Model A: fixed linear model; Model B: random linear model.