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The interplay between nap and nighttime sleep in preschool-aged children: an actigraphic study

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Abstract

Background Although most children nap at age 2, 94% have ceased by the age of 5. Naps may allow children to meet their sleep needs but may also delay and reduce nighttime sleep. The aim of the study was to understand the interrelation between objectively measured naps and nighttime sleep in children aged 2 to 5 years.

Methods Participants were recruited within six French preschools in 2021. Sleep was measured by actigraphy during an average of 7.8 days (5 to 10 days) in 85 children ($M_{age}=3.8$ years, $SD_{age}=0.56$, 46% girls). Paired t-tests were used to study the difference in nap and nighttime sleep between school days and weekends, and linear mixed models, adjusted for age and sex, to analyze the day-to-day effect of naps on nighttime sleep.

Results On school days, when all children had the opportunity to take a nap and the time was regulated by the school, naps were more frequent (72% vs 38%) but shorter (62 vs 81 min) and occurred earlier (rise time 15:17 vs 16:00) than on weekends (all $p<0.003$). Although naps were twice as frequent on school days than on weekends, nighttime sleep onset was earlier on school days (21:20 vs 22:00 $p<0.001$), with no difference in nighttime sleep duration. Day-to-day mixed model analyses showed that an hour increase in nap duration reduced nighttime sleep by 13.6 min (SE = 6.1, $p=0.027$), and increased sleep onset latency by 6.38 min (SE = 3.01, $p=0.035$). On days when children napped, 24-h total sleep time increased by 45 min (SE = 4.97, $p<0.001$). Conversely, nighttime sleep duration had no effect on the following day's nap.

Conclusions Naps delayed and reduced nighttime sleep, but the effect was clinically marginal, and naps contributed to longer 24-h total sleep time. Large differences were observed between school days and weekends, suggesting that sleep habits do not follow sleep needs.

Keywords Nap, Sleep, Actigraphy, Pediatrics

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The shift from polyphasic sleep, which involves several sleep episodes including naps, to monophasic sleep, characterized by a single consolidated nighttime sleep, is a natural part of a child's developmental process. During the first years of life, naps allow younger children to meet their total sleep need. This transition typically occurs during the preschool years, when children gradually shift to a predominantly nighttime sleep schedule. Indeed, almost all children nap at age 2 whereas 94% have ceased napping by age 5 [1]. The variability in nap prevalence is substantial during this period and nap cessation does not necessarily reflect the lack of a physiological need. External factors, including parental and cultural beliefs about naps as well as practical considerations in families and daycare, significantly influence nap practices [2].

One of the hypotheses behind the need for children to nap is that sleep pressure (i.e. sleep homeostasis) builds up faster in younger children [3]. Kurth et al. [4] found that sleep slow-wave activity (SWA), the main marker of sleep pressure, was more prominent during naps in 2 and 3-year-old children than in 5-year-olds. Spencer and Riggins [5] recently proposed a model to explain the underlying mechanisms behind this faster increase in sleep pressure: younger children are exposed to a large amount of new information to learn, but their neural system for learning and memory is still immature and not yet efficient (overproduction of cortical synapses, increased neural firing rates), which results in high energy expenditure, which may explain the fast increase in sleep pressure [6]. Naptime sleep thus allows synaptic plasticity to be restored, making the brain available for further learning in the developing brain. Consequently, the cessation of napping parallels brain maturation and can be seen as a marker of development.

The importance of nighttime sleep for children has gained significant interest in the past years. In preschool-aged children, short nighttime sleep duration has been associated with numerous adverse health outcomes, including increased risk of obesity [7], higher blood pressure [8], cognitive and behavioral difficulties [9] and altered brain functions and structure [10]. However, the supposed benefits of naptime remain subject to debate. On the one hand, experimental data have shown that naps have a beneficial effect on numerous cognitive functions, including memory consolidation [11], reading fluency [12], emotion regulation [13] and self-regulation [14]. The benefits of napping appear to be greater for habitual nappers compared to non-habitual nappers. On the other hand, observational and cross-sectional studies occasionally report naps to be associated with negative outcomes, including a reduction in nighttime sleep duration, as well as behavioral and cognitive delays [15]. However, cross-sectional observational studies can be misleading. First, because the child's brain maturation can be a confounding factor in the association between naps and cognition [16]. Indeed, cross-sectional comparison of children who nap to those who do not, can amount to comparing children within different maturational states regarding their neural system rather than understanding the role of naps. Second, a child may nap or cease napping for various reasons (e.g. napping to compensate for sleep debt, to facilitate parent's schedule etc.), thus the effects of naps can be very different.

The lack of consensus and guidelines regarding the management of naps makes it difficult for parents, preschools and childcare institutions to decide how and when to implement or cease napping. Since children can attend public preschool as early as age two, naps become a concern that extends beyond the household and must also be addressed at the institutional level. Reaching a consensus might be hindered by shortcomings in the existing literature, such as the fact that cross-sectional correlations can be misleading when attempting to understand the impact of naps on nighttime sleep. Additionally, there is a lack of objective sleep data addressing the specific question of the association between naps and nighttime sleep [1], and a distinction between weekdays and weekends is rarely provided.

Using objective measures of sleep, the first goal of this study was to compare naptime and nighttime sleep on school days, in a preschool setting where all children are provided with access to nap time, and on weekends, in a home setting where naps were decided by parents. The second objective was to investigate the bidirectional day-to-day relation between napping and nighttime sleep.

Methods

Study population and setting

Teachers from six French preschools informed parents about the study. One hundred twenty parents ($n = 120$) agreed for their child to participate and signed an informed consent. Children were recruited regardless of their nap habits. The study took place between October 1 and December 10, 2021. The study was approved by the ethics evaluation committee and the institutional Review Board of the French National Institute of Health and Medical Research (CEEI/IRB Opinion N°22–901 bis). In all, 16 children were excluded due to equipment malfunctions and 19 children were excluded because their sleep recordings lasted less than five days (described in "measures"). Thus, the present analyses were conducted on a sample of 85 children, selected based on sufficient duration and quality of actigraphy recordings. The ethnicity of the children could not be disclosed as French legislation does not allow for this data. Because the recruitment took place at the school level, individual socio-demographic data were limited to those provided by the school, namely sex and age.

In France, preschool is mandatory from the age of 3 years, typically running from 8:30 a.m. to 4:30 p.m. Preschools are expected to accommodate children's sleep needs; however, in classes facing logistical constraints (e.g., limited space or availability of beds), naps are preferentially offered to the youngest children and are generally no longer provided after the age of 5. Naps, when available, are scheduled at the very beginning of the afternoon, immediately after lunch. In the present study, we only included schools where naps were made available according to the child's needs, regardless of age.

Measures

Sleep measures were obtained by actigraphy (Actiwatch 2; Philips-Respironics, Murrysville, USA,), which is a wrist-worn device containing a piezoelectric accelerometer. Movement intensity is recorded at a 32 Hz frequency and aggregated into 60-s epochs. Data was manually scored using Philips Actiware software version 6.0.1, with the embedded proprietary algorithm, which has been validated in preschool-aged children [17]. As recommended for this age range, the threshold used to differentiate sleep from wake was set to 80 counts [17]. Default settings were applied for sleep onset and sleep offset criteria, namely 10 min of immobility.

Table 1 Definition of sleep parameters

Sleep parameters	Definitions
Timing measures	
Bedtime (BT)	Time at which the child was in bed, ready to sleep
Sleep onset time (SOT)	Time at which the child fell asleep
Wake time (WT)	Time at which the child woke up for the last time before getting out of bed
Rise time (RT)	Time at which the child physically got out of bed
Duration measures	
Time in bed (TIB)	Time spent in bed, defined as the duration between BT and RT
Total Sleep Time (TST)	Time spent sleeping, calculated as the duration between SOT and WT, minus the duration of wake after sleep onset
- Nighttime TST	TST during the night period.
- Unconditional nap TST	TST during daytime, regardless of nap status. Duration of naps were coded as 0 if no naps occurred, thus this metric was available for all subjects and is a representation of the mean time spent sleeping during the day. It is dependent on the length and the frequency of naps
- Conditional nap TST	TST during daytime when a nap occurred. Duration of naps were coded as missing if no naps occurred, thus this metric is only available on days when the child napped. It represents the mean duration of naps when they do occur
- 24-h TST	TST per 24-h period, from noon to noon. Defined as the sum of unconditional naptime and nighttime sleep duration
Sleep quality measures	
Wake after sleep onset	Time spent awake between SOT and WT
Sleep onset latency (SOL)	Time spent awake between BT and SOT
Sleep efficiency	Percentage of time spent sleeping while in bed:TST / TIB × 100
Daytime sleep prominence	
Nap prevalence	Number of days on which a nap occurred divided by the number of days of recording
Daytime Sleep Ratio	Unconditional naptime TST divided by the 24-h TST

Instructions regarding the actigraphs were to wear the device for 10 consecutive days and nights but to remove the device for baths, showers, swimming, and any sport that involved physical contact. The child's data was used in analyses if the recording lasted at least 5 valid days, which is the recommended duration when assessing sleep efficiency [18]. A day was considered valid if data was available from noon to noon (with the exception of non-wear time for specified reasons, such as bath time, or periods of time short enough so that no sleep data could have been missed). Parents and children were asked to press on an event marker to signal when the child was in bed, ready to sleep, and again when the child was out of bed. In parallel, parents kept a sleep diary where, in addition to the child's sleep schedule, they also reported when the device was taken off and why (including showers and baths). Caregivers at school were instructed to remind children to press the event marker before naps and to notify parents at pick-up if and when the child napped. Sleep measures are described in Table 1. Bedtime (BT) and rising time (RT) were set to the moment the event marker was pressed; when the button was not pressed, BT and RT were estimated using the sleep diary, light-sensor data and movement. Sleep onset time (SOT) was defined as the moment the child started sleeping, and Wake Time (WT) as the moment the child stopped sleeping. For all time-based measures (BT, RT, SOT and WT) decimal hours format was used for analyses (1.5 = 1 h and 30 min), however the hours:minutes (hh:mm) format was used in the results to ease interpretation. Sleep Onset Latency (SOL, in minutes) was defined as the duration between BT and SOT. Total sleep time (TST, in minutes) was defined as the duration between SOT and WT, minus the duration of wake after sleep onset, which represents the duration during which the child actually slept. Sleep Efficiency (in percentage) was defined as TST divided by time in bed (TIB, duration between BT and RT). All previously mentioned sleep measures were computed separately for naps and nighttime sleep. The 24-h Total Sleep Time (24-h TST) was calculated as the sum of naptime TST and the following nighttime TST, which represents the time actually spent sleeping per 24-h period, from noon to noon. Nap prevalence was calculated as the number of days when a nap occurred divided by the number of days of recording. The Daytime Sleep Ratio (DSR) was calculated as the nap TST divided by the 24-h TST, which reflects the percentage of total daily sleep occurring during naps. We used two metrics to define nap total sleep time (TST). The *unconditional nap TST* includes all nap durations; on non-nap days, nap TST is coded as 0 min. This metric is available for all participants and reflects the average amount of daytime sleep, regardless of whether a nap occurred. In contrast, the *conditional nap TST* excludes non-nap days by coding them as missing. It is therefore only available on days when a nap took place and represents the average duration of naps when they did occur. No naps occurred in the morning, and no nighttime sleep ended after noon.

Sleep duration and timing can differ greatly according to the day of the week, even in young children [19]. Naptime sleep recordings were divided into "school days" (for those occurring on Monday, Tuesday, Thursday or Friday), and "weekends" (for those occurring on Saturday or Sunday). For nighttime sleep, the day type was based on the weekday on which sleep ended and was defined as "preceding a school day" or "preceding a weekend". In France, children do not necessarily have class on Wednesdays, thus nighttime sleep ending on a Wednesday and naptime sleep occurring on a Wednesday were not included in analyses comparing day types. On school days, nap BT and RT are usually set between 13:30 and 15:00.

Analyses

All analyses were conducted with the R software, version 4.3.0 [20]. Regression coefficients are presented as Beta coefficients and standard error ($\beta \pm SE$), with statistical significance set at $p < 0.05$.

As an illustrative and preliminary analysis, we first analyzed sleep data averaged across the data collection period (reporting mean and standard deviation). The averages were weighted by day type, to mimic a full week $(weekday \times 5 + weekend \times 2)/7$. This averaged data was used for descriptive purposes and to study the difference in sleep according to sex and age, using respectively student t-test and Pearson's correlation. We also conducted linear regressions, with sleep measures as the dependent variable, and age and sex as independent variables, to verify that bivariate results were not confounded. Then, paired t-tests were used to study the difference in nap and nighttime sleep between school days and weekends. It was expected that the 24-h TST would be shorter in older children, along with fewer and shorter naps [21]. Differences in nighttime sleep between school days and weekends have been largely described in older individuals and were expected, but to a lesser extent, in this young population [22]. As the context of naps greatly differs between the school and home setting, differences were expected, however our hypotheses were non-directional.

Secondly, in order to understand the day-to-day effect of napping on nighttime sleep, sleep data was analyzed separately per day per subject. To do so, linear mixed models were computed (packages LME4 [23] and Flexplot for Figs. [24]) to take into account dependency in data stemming from a same subject. Models were constructed so that level 1 predictors were those that assessed daily sleep variations and level 2 predictors those that were stable within subject (sex and age). For each model, one nighttime sleep parameter was used as the dependent variable (outcome), one naptime sleep parameter was used as a level 1 predictor (with a random intercept), the child's subject number (ID) was the cluster variable and age and sex were used as level 2 predictors. In this way, a model indicated how, within-person, an increase of 1 in the naptime sleep predictor affected the nighttime sleep parameter. In addition, we investigated whether age and the type of day presented an interacting effect on the association between the outcome and the sleep predictor. Because it is a frequent complaint by parents, we hypothesized that naps delay nighttime sleep onset. The aim was to quantify and objectify the extent to which naps affect nighttime sleep, and understand which factors interacted with these associations.

Lastly, linear mixed models were computed to understand the day-to-day effect of nighttime sleep on the next day's nap. Models were similar, with the exception that outcome and predictor were inverted with one naptime sleep parameter used as the dependent variable (outcome), and one nighttime sleep parameter used as a level 1 predictor. We hypothesized that a shorter or less efficient nighttime sleep would increase nap TST the following day.

Results

Description of the sample

A total of 85 children aged from 3 to 5 years were included in the analyses ($M_{age} = 3.8$ years, $SD_{age} = 0.56$, 46% girls). The average duration of actigraphy recording was 7.8 days (± 1.49, range [5–13]). For two children, actigraphy recordings took place only on school days and were thus excluded from the analyses comparing school days and weekends. Seven children (8%) did not nap at all, whereas 14 children (17%) napped every day.

Sleep differences on school days and weekends

Sleep differences between school days and weekends are described for naptime sleep (Table 2) and for nighttime sleep (Table 3). Nap prevalence (i.e. the percentage of days when the child took a nap) was 71.6% on school days against 38.3% on weekends. However, when naps did occur on weekends, they were longer (81.4 min vs

Table 2 Daytime sleep, measured by actigraphy, comparing naps during school days and naps during weekends

	Naps, all days	Naps on School days	Naps on Weekends	*p*-value[a]
Nap prevalence (%)	59 (30.1)	71.6 (34.9)	38.3 (41)	< 0.001
Unconditional nap TST[b]	40.1 (24.5)	44.7 (25.4)	32.3 (40.5)	0.005
Conditional nap TST[c]	66.2 (19)	61.9 (19.4)	81.4 (31.5)	< 0.001
Nap Onset Time (hh:mm)	14:04 (0:28)	14:01 (0:27)	14:17 (0:58)	0.014
Nap Wake Time (hh:mm)	15:13 (0:29)	15:05 (0:28)	15:43 (1:01)	< 0.001
Nap Sleep Onset Latency (min)	19.4 (8.6)	19.9 (9.7)	15.7 (9.5)	0.004
Nap Sleep Efficiency (%)	65.5 (11.6)	64.9 (13.6)	68.9 (14.1)	0.047
Daytime sleep ratio (%)	7.1 (4.1)	7.8 (4.3)	5.6 (6.8)	0.002

[a]Difference between school days and weekends, by paired t-test

[b]Duration of nap was coded as 0 min if no naps occurred

[c]Duration of nap was coded as missing data if no nap occurred. Nap prevalence, and unconditional nap TST include all subjects ($N=85$ for total and school day, and $N=83$ for weekends). All other nap variables include only children who napped at least once ($N=78$ for total, 76 for school days and $N=42$ for weekends). Data is presented as mean (standard deviation)

Table 3 Nighttime sleep, measured by actigraphy, comparing nights preceding school days with nights preceding weekends

	All nights	Nights Preceding School days	Nights Preceding Weekends	*p*-value[a]
Night Sleep Onset Time (hh:mm)	21:34 (0:41)	21:20 (0:40)	22:00 (0:54)	< 0.001
Night Wake Time (hh:mm)	7:12 (0:37)	6:59 (0:31)	7:35 (0:58)	< 0.001
Night TST (min)	519.2 (32.1)	520.2 (32.3)	515.6 (49.3)	0.465
Night Sleep Onset Latency (min)	40.4 (20.1)	41.8 (22.7)	36.3 (23.1)	0.035
Night Sleep Efficiency (%)	80.0 (4.7)	80.5 (5.0)	79.1 (5.8)	0.032

[a]Paired t-tests were used to test the difference between nights preceding school days and nights preceding weekends. Data is presented as mean (standard deviation). TST (total sleep time)

61.9 min, $p < 0.001$) and took place later (nap onset time 14:17 vs 14:01, $p = 0.014$) than naps occurring on school days. Sleep timing and duration by weekday is described in supplementary data.

On a daily average, children slept 559.3 min (± 36.17) per 24-h period; 565.1 min (± 36.4) on school days and 548.4 min (± 59.6) on weekends ($p = 0.011$). On nights preceding weekends, both sleep onset time and wake time were delayed by about 40 min each compared to nights preceding school days, resulting in a comparable nighttime TST between day types.

Sleep differences with respect to child's sex and age.
Few differences were observed between boys and girls regarding their sleep, with no significant differences in nap prevalence, timing or duration (all $p > 0.4$). Regarding nighttime sleep on school days, boys had a later sleep onset time, with sleep starting at 21:29 (± 00:41) vs 21:06 (± 00:32) for girls ($p = 0.008$), and a shorter nighttime TST than girls (513.9 ± 28.6 min vs 530.5 ± 35.2 min, $p = 0.024$). No differences between boys and girls were observed regarding the other sleep measures nor for nights preceding weekends.

As could be expected, older children had smaller daytime sleep ratios ($r = -0.52$, $p < 0.001$) with shorter naps ($r = -0.33$, $p = 0.005$). However, nighttime TST was not correlated with age ($r = 0.14$, p = 0.217). Congruently, the 24-h total sleep time was shorter in older children compared with younger ones ($r = -0.22$, $p = 0.050$). Also, nighttime sleep efficiency increased with age ($r = 0.28$, $p = 0.013$).

All results were confirmed when conducting linear models adjusted on age and sex (see supplementary Table 2). When accounting for the interaction between gender and age, significant effects were found with nap TST and nap WT (respective interactions of $\beta = 1.72 \pm 0.63$, $p = 0.0078$ and $\beta = 0.044 \pm 0.017$, $p = 0.0115$). Nap TST was shorter in boys ($\beta = -76.75 \pm 28.71$, $p = 0.0094$) and older children ($\beta = -1.711 \pm 0.426$, $p < 0.001$), which was explained by an earlier nap WT. With increasing age, nap TST decreased significantly in girls ($\beta = -1.71 \pm 0.35$, $p < 0.001$) whereas no significant age-related change was observed in boys ($\beta = 0.01 \pm 0.518$, $p = 0.985$).

Daily interrelations between daytime sleep and the following nighttime sleep
Table 4 summarizes the mixed model analyses conducted to examine the day-to-day effect of napping on subsequent nighttime sleep. On days when napping occurred (presence of nap = 1, the reference being no nap = 0), the following nighttime TST was reduced by 19.45 min (± 4.78), sleep onset time was delayed by 11.48 min (± 4.63), sleep onset latency was increased by 18.95 min (± 2.33) and sleep efficiency reduced by 3.4% (± 0.62). For an hour delay in nap wake time, the following night's TST was reduced by 13.55 min (± 4.01), sleep onset time was delayed by 16.35 min (± 3.30), sleep onset latency was increased by 6.08 min (± 2.02) and sleep efficiency reduce by 1.8% (± 0.53) (Fig. 1). On days when children napped, the 24-h total sleep time was 45.3 (± 4.97) minutes longer ($p < 0.001$), thus largely compensating for the average 20 min loss in nighttime TST.

The age of the child was a significant interacting factor in the association between naptime and nighttime sleep. The older the child, the stronger the association

Table 4 Effect of napping on following nighttime sleep parameters

	Night TST (minutes)		Night SOT (minutes)		Night WT (minutes)		Night SOL (minutes)		Night Sleep efficiency (%)	
	β (SE)	*p*	β (SE)	*p*	β (SE)	*p*	β (SE)	*p*	β (SE)	*p*
Presence of nap (yes = 1)	**−19.45 (4.78)**	***p* < 0.001**	**11.48 (4.63)**	***p* = 0.014[b]**	−6.00 (4.55)	*p* = 0.188	**18.95 (2.33)**	***p* < 0.001**	**−3.36 (0.62)**	***p* < 0.001**
Conditional nap TST (hour)	**−13.59 (6.12)**	***p* = 0.027**	**13.03 (4.93)**	***p* = 0.009**	−6.22 (5.70)	*p* = 0.276	**6.38 (3.01)**	***p* = 0.035**	−1.42 (0.8)	*p* = 0.077
Nap SOT (hour)	−7.16 (4.94)	*p* = 0.149	**14.72 (4.18)**	***p* < 0.001[a]**	**12.87 (4.67)**	***p* = 0.006**	3.98 (2.54)	*p* = 0.119	**−1.31 (0.65)**	***p* = 0.047**
Nap WT (hour)	**−13.55 (4.01)**	***p* < 0.001[a]**	**16.35 (3.30)**	***p* < 0.001[a,b]**	3.45 (3.83)	*p* = 0.368	**6.08 (2.02)**	***p* = 0.003[b]**	**−1.79 (0.53)**	***p* < 0.001**
Nap SOL (hour)	−14.37 (11.75)	*p* = 0.222	−4.78 (9.68)	*p* = 0.621	−21.08 (10.92)	*p* = 0.054	**14.72 (5.81)**	***p* = 0.012**	**−3.68 (1.53)**	***p* = 0.017**
Nap Sleep efficiency (%)	0.1 (0.17)	*p* = 0.547	5.27 (8.23)	*p* = 0.522	5.55 (9.37)	*p* = 0.553	−0.07 (0.08)	*p* = 0.427	0.03 (0.02)	*p* = 0.113

Each cell represents the result of a mixed model, with one nap parameter as an independent variable and one nighttime sleep parameter as the dependent variable and the subject as the cluster variable; analyses are adjusted on age and sex. The reported estimates describe how an increase of 1 in the nap parameter changes the following nighttime sleep parameter (e.g. one hour increase in nap TST, one hour delay in nap SOT), expressed by β (Standard error) and *p*-value

TST Total sleep time, *SOT* Sleep Onset Time, *WT* Wake Time, *SOL* Sleep Onset Latency

[a]Significant interaction for age

[b] Significant interaction by type of day (school days and weekends)

between nap wake time and nighttime TST (interaction $p = 0.020$); between nap wake time and night sleep onset time (interaction $p = 0.025$) and between nap sleep onset time and night sleep onset time (interaction $p = 0.001$). Interactions are illustrated in Fig. 2, with mixed models presented by age tertile. More specifically, an hour delay in nap wake time delayed nighttime sleep onset by 10.60 min ($p = 0.027$) below the age of 3.4 years; by 20.16 min (0.002) in children aged between 3.4 and 3.9 years and by 22.86 min ($p = 0.002$) in children over 3.9 years. Similarly, an hour delay in nap wake time reduced nighttime TST by 6.78 min ($p = 0.278$) below the age of 3.4 years, by 20.44 min (0.007) in children aged between 3.4 and 3.9 years and by 22.06 min ($p = 0.007$) in children over 3.9 years. However, nap TST did not display a different effect on nighttime sleep according to age.

On school days, nap wake time had a stronger effect on nighttime sleep onset time and sleep onset latency than on weekends (with respective p-values for interaction of 0.017 and 0.044). Similarly, the presence of a nap had a stronger effect on nighttime sleep onset latency on school days (interaction $p = 0.005$) than on weekends.

Daily interrelations between nighttime sleep and the next day's daytime sleep

Mirroring the preceding analyses, mixed models were conducted to analyze daily interrelations between nighttime sleep parameters and the next day's nap parameters, for which the results are reported in Table 5. Nighttime TST was not associated with either the duration or timing of the following nap. Wake-time had statistically significant but clinically small effect on the following nap: a one-hour delay in night wake time was associated with a 4.40 min (± 2.15) reduction in the following nap's TST ($p = 0.042$), a delayed nap sleep onset time (10.78 min, ± 2.83, $p < 0.001$) and wake time (18.00 min, ± 3.35, $p < 0.001$).

Discussion

The present study, based on the actigraphy recordings of 85 children aged 3 to 5 years, firstly illustrates that even in preschool years, sleep recommendations are rarely met. The significant differences in observed sleep routines according to the day of the week suggest that sleep is highly dependent on the environment and sleep opportunity offered to the child, and is thus not solely based on the child's need. Secondly, results showed that on days when children napped, nighttime sleep was shorter compared to days without naps, but the 24-h total TST was longer. On the other hand, nighttime sleep had minimal influence on naps the following day.

On average, children slept 9 h and 20 min per 24-h period, which is 40 min less than the minimum recommended by the American Academy of Sleep Medicine [25] for children aged 3 to 5 years (10 to 13 h per day). It should be noted, however, that these guidelines are based primarily on parental reports, such as diaries or questionnaires. Naps allowed for a 45-min increase in the 24-h

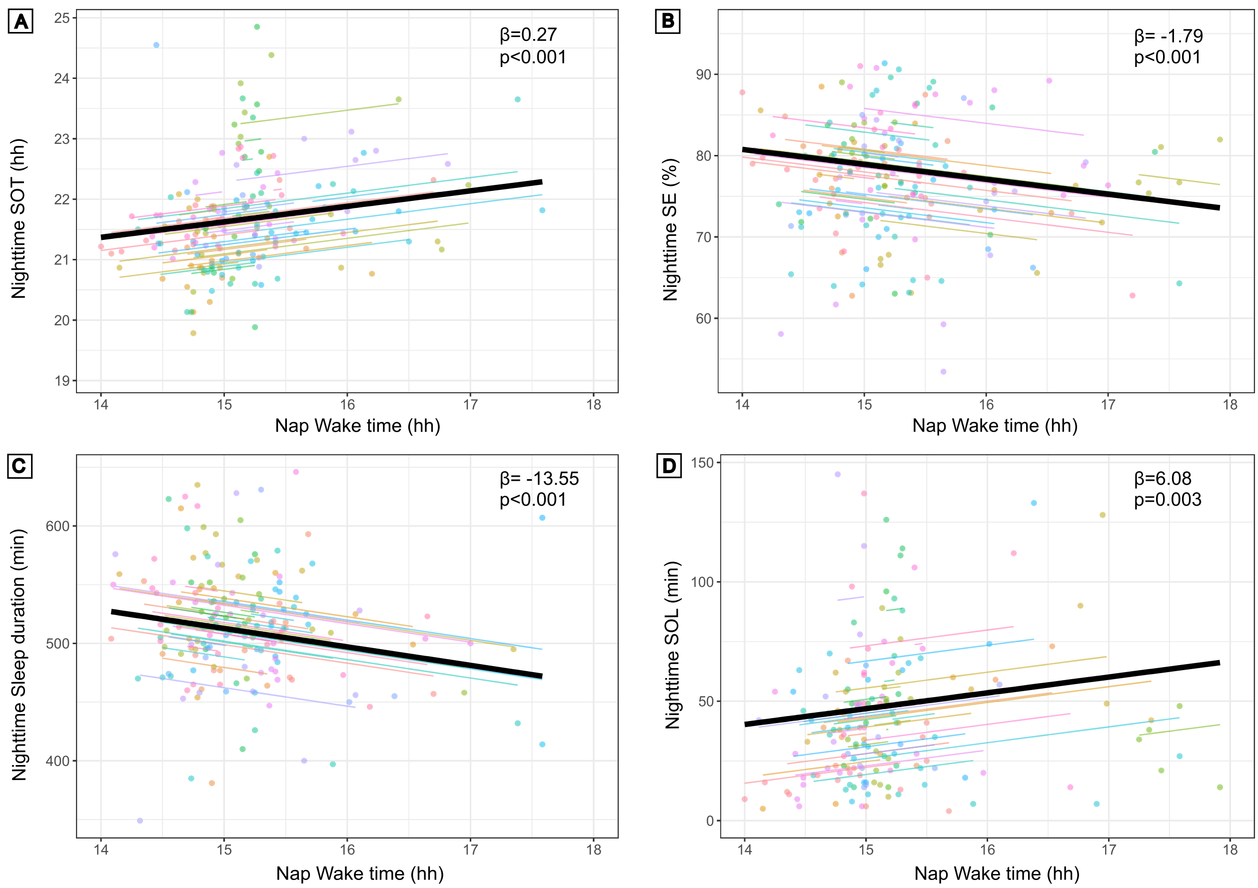

Fig. 1 Daily associations of nap wake time and subsequent nighttime sleep parameters. Mixed model representation of the day-to-day association between nap wake-time and Panel **A**) nighttime sleep onset time (SOT), Panel **B**) nighttime sleep efficiency, Panel **C**) nighttime Total sleep time, Panel **D**) nighttime sleep onset latency (SOL). Each dot is a day, each color line is the regression line per subject and the black line is the average regression line for the full sample. A SOT above 24 indicates a SOT occurring after midnight

total sleep time, bringing children closer to these recommendations. Nighttime TST was 8 h and 39 min on average, which corresponds to the average values reported in Galland et al.'s meta-analysis of actigraphy data for the 3 to 5 age range [26], with a pooled mean estimate of 8:38 (95% CI 7:50—8:41). Nighttime sleep efficiency was 80% and naptime efficiency was 65.5%. These findings align with Sahlberg et al. [27], who reported nighttime efficiencies of 77% (ages 2–3) and 79% (ages 4–5), and naptime efficiencies of 67% (ages 2–3) and 63% (ages 4–5).

Nighttime TST was not correlated with age but the 24-h TST was shorter in older children compared with younger ones, due to naps. Similarly, Acebo et al. [21] compared actigraphy-derived sleep duration across 7 age groups ranging from age 12 months to 60 months. They found that nighttime sleep was very similar in all age groups while naptime sleep allowed for a longer 24-h total sleep time in younger children. The 24-h total sleep time was longer on school days than on weekends. This difference was largely explained by naps, as nighttime TST was equivalent in both settings. However, timing was very different with sleep onset time starting on average 40 min later on nights preceding weekends, at about 10 pm. These results are consistent with Iwata and colleagues' findings [22] who reported sleep onset time at 21:40 on school days and 22:08 on weekends.

Seven children (8%) did not nap at all, whereas 14 children (17%) napped every day. On average, naps occurred on 59% of days, with a mean daytime TST of 40 min, representing 7% of total 24-h sleep. Similarly, Sahlberg et al. [27] reported in their actigraphy study of 78 children aged 3 to 5 years that 11% of children did not nap during the week of recording and that a nap was observed on 50% of days. The difference between 24-h TST and night TST was 28 min, which is notably shorter than the 40 min daytime TST found in our study. By contrast, longer nap durations were found in Tétreault et al.'s study [28], with an average of 105 min in their 3 to 4 year-olds, and in Lam et al.'s study [29], with an average of 56 min. It should be noted that nap durations in these studies were reported as *unconditional* values, where on non-nap days, nap TST counted as 0 min. Therefore, differences in nap duration across studies may reflect both fewer naps and shorter naps. Moreover, the context in which naps

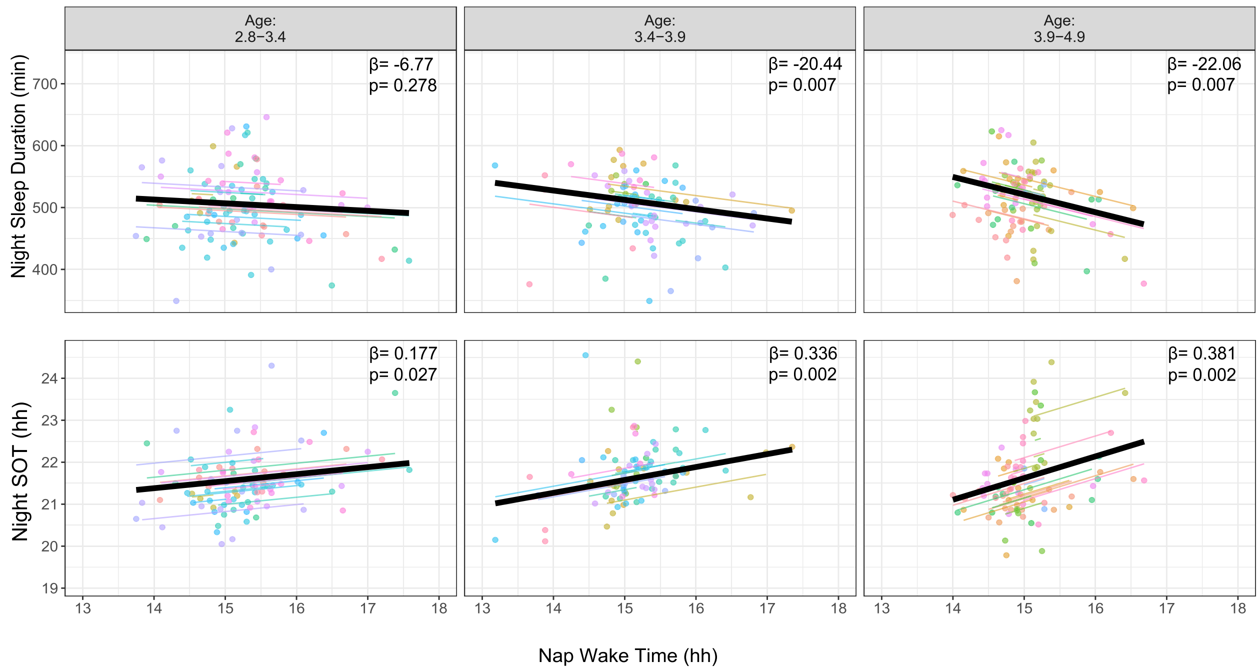

Fig. 2 Daily associations of nap wake-time and subsequent nighttime sleep by age tertile. Mixed model representation of the day-to-day association between nap wake-time, nighttime Total sleep time and nighttime sleep onset time (SOT), separately by age tertile. Each dot is a day, each color line is the regression line per subject and the black line is the average regression line SOT above 24 indicates a SOT occurring after midnight. An hour delay in nap wake time reduced nighttime sleep duration by 6.78 min ($p = 0.278$) below the age of 3.4 years, by 20.44 min (0.007) in children aged between 3.4 and 3.9 years and by 22.06 min ($p = 0.007$), in children over 3.9 years. An hour delay in nap wake time delayed nighttime sleep onset by 10.60 min ($p = 0.027$) below the age of 3.4 years, by 20.16 min (0.002) in children aged between 3.4 and 3.9 years and by 22.86 min ($p = 0.002$), in children over 3.9 years

Table 5 Effect of nighttime sleep parameters on next day's nap parameters

	Conditional Nap TST (minutes)		Nap SOT (minutes)		Nap WT (minutes)		Nap Sleep efficiency (%)	
	β (SE)	***p***	**β (SE)**	***p***	**β (SE)**	***p***	**β (SE)**	***p***
Night TST(hour)	3.17 (1.9)	$p = 0.096$	−0.92 (2.48)	$p = 0.711$	0.90 (3.07)	$p = 0.771$	2.27 (1.16)	$p = 0.052$
Night SOT (hour)	1.15 (2.05)	$p = 0.575$	**9.77 (2.77)**	$\boldsymbol{p < 0.001}$	**14.53 (3.27)**	$\boldsymbol{p < 0.001}$	−0.17 (1.28)	$p = 0.893$
Night WT (hour)	**4.40 (2.15)**	$\boldsymbol{p = 0.042}$	**10.78 (2.83)**	$\boldsymbol{p < 0.001}$	**18.00 (3.35)**	$\boldsymbol{p < 0.001}$	1.74 (1.34)	$p = 0.193$
Night SOL (hour)	0.70 (3.70)	$p = 0.849$	**−14.12 (4.75)**	$\boldsymbol{p = 0.003}$	**−14.53 (5.92)**	$\boldsymbol{p = 0.015}$	−1.19 (2.29)	$p = 0.604$
Night Sleep efficiency (%)	7.77 (13.85)	$p = 0.575$	4.55 (18.17)	$p = 0.803$	8.28 (22.40)	$p = 0.712$	0.18 (0.14)	$p = 0.205$

Each cell represents the result of a mixed model, with one nighttime parameter as the independent variable, one nap parameter as the dependent variable and the subject as the cluster variable; analyses are adjusted on age and sex. Estimates (β (Standard error), *p*-value) describe how an increase of 1 in the nighttime parameter changes the next day's nap parameter

TST total sleep time, *SOT* Sleep Onset Time, *WT* Wake Time, *SOL* Sleep Onset Latency

occur may also complicate comparisons across studies. Moreover, the context in which naps occur may contribute to cross-study variability, as differences between naps at home and at school are substantial yet rarely reported [27, 28].

Many differences were observed between school days and weekends. On average, the prevalence of naps was twice as high on school days than on weekends. However, when naps did occur, they were 20 min longer and took place later on weekends. To the best of our knowledge, only Lam and colleagues [29] reported actigraphy data regarding naps separately for school days and weekends, in their study of 59 children. They found that the time spent napping was longer in daycare, 63 vs 32 min per day on weekends, which is similar to our results where unconditional nap TST was 45 min on school days vs 32 min on weekends. The differences in nap and nighttime parameters between school days and weekends are likely influenced by differences in sleep opportunity in these contexts. Parental beliefs and cultural factors are significant determinants of nap prevalence, timing and duration [2, 30]. Factors associated with nap cessation include the presence of an older sibling, female sex, parents who are not employed or enrolled in school [31], and white ethnicity [31, 32]. Another possibility which could explain the difference in sleep between school days and weekends is that children may have a greater need for naps during school days due to increased learning and social demands on those days. Also, because wake-up time is earlier on school days, children feel tired earlier, and therefore require a nap. An interesting observation is that within-subject analyses, on days when a child napped, showed that nighttime sleep occurred later; however, on average, nighttime sleep started 40 min earlier on school days than on weekends, although naps were almost twice as frequent at school than at home. This suggests that the effect of naps on sleep onset time is likely minimal compared to other factors, such as families' schedules and routines. The misalignment between sleep timing on weekdays and weekends, referred to as *social jetlag*, is observed as early as the preschool years [33] and is more common in children attending preschool than in those who do not [33]. At this age, it has also been associated with emotional and behavioral difficulties [34].

We observed a significant impact of naps on the following nighttime sleep: on days when a nap occurred nighttime TST was reduced by 20 min and nighttime sleep efficiency was reduced by 3.4%. However, the 24-h TST was 45 min longer on those days, over-compensating for the reduced nighttime TST. The effect of napping on nighttime sleep was stronger on school days. This could be explained by the difficulty for schools to adapt to individual children's needs. Another explanation could be that because the timing of nighttime sleep is earlier on school days, sleep pressure has less time to build up between the end of the nap and bedtime, resulting in a later sleep onset. Unsurprisingly, the effect of naps on nighttime sleep was more pronounced in older children [3, 4]. Specifically, later nap wake time delayed and reduced the duration of nighttime sleep more in older children than in younger ones. Thus, later naps might reduce sleep pressure too close to bedtime in children with a more mature homeostatic process. However, the effect of nap TST on nighttime sleep did not change according to age. This suggests that the timing of naps could be addressed first before deciding to suppress naps. The age effect is not surprising since, with the maturation of the homeostatic process, there is less need for napping and therefore, taking a nap reduces sleep pressure unnecessarily before bedtime.

Nighttime TST had little effect on the next day's nap, suggesting that naps weren't implemented primarily to compensate for a previous night's short sleep. The lack of an effect of night TST on the following day's nap might be attributed to the fact that on school days, the timing of naps is scheduled rather than individualized according to each child's needs. As a result, naps cannot occur earlier than usual or extend beyond the allocated time to compensate for sleep debt. Also, we cannot exclude the possibility that different results would have been observed in a context of greater sleep deprivation.

Two studies have previously investigated day-to-day association between naps and nighttime sleep. Although self-reported diary measures were used, similar results were observed [35, 36]. Komada and colleagues [36] showed that naps delayed night bedtime, but only after the age of 2, and only when the naps lasted longer than one hour. In Fukuda and Sakashita's study [35], naps delayed sleep onset latency during the night by about half an hour.

There are limits to be noted in the present study. The sample is not representative of the general population, limiting the extrapolation of results. Different findings may be observed in contexts where preschool is not mandatory, as it is in France. Also, due to French legislation, we did not have access to the ethnicity or race of participants and the recruitment process prevented the access to their socio-economic profile, thus important potential confounding factors were not taken into account. One of the strengths of the present study resides in the within-subject approach, which reduces the effect of confounders, such as differences in brain maturation and socio-economic context, unlike other observational approaches. Another main strength is the objective nature of actigraphy, which, while not allowing sleep stage assessment as polysomnography does, remains a widely recognized, non-invasive method for evaluating sleep patterns across multiple nights in young children. A 15-s epoch length could have further improved the distinction between sleep and wake during daytime [37], compared to the 60-s length used here; however such short epochs are only feasible for short periods of recording with this device and were therefore not used here. Finally, while we observed a slight reduction in nighttime sleep efficiency on days with a nap, actigraphy does not allow us to assess sleep architecture, limiting our ability to determine whether naps influenced subsequent sleep stages. Kurdziel and colleagues [38] observed that, compared to nighttime sleep, naptime sleep showed a higher proportion of Slow Wave Sleep (SWS) but almost no Rapid Eye Movement (REM) sleep. Also, nighttime sleep had more SWS when there was no nap during the day, which is to be expected, as the absence of naps leads to a greater accumulation of sleep pressure.

In conclusion, although there was a statistically significant impact of naps on nighttime sleep, the effect sizes were small and nap timing had a greater effect than nap duration. The older the child, the greater the effect of naps on nighttime sleep. Therefore, the challenge resides in determining when a child no longer requires a nap. As naps increasingly delay and shorten nighttime sleep with age, parents may be inclined to suppress naps when faced with nighttime sleep difficulties [39]. However, the difficulties could be transitory or arise from other factors. Indeed, we found that the type of day (school day vs weekend) was a stronger predictor of nighttime sleep duration and timing than naps, suggesting that it could be important to investigate family organization before suppressing naps. Also, naps allow for a longer 24-h total sleep time and the increased nighttime sleep seen in the absence of a nap could be a manifestation of sleep debt. Lastly, experimental data from previous studies have shown that napping improves cognitive tests (such as declarative and procedural memory and speed of processing) even in adults [40]. Therefore, we hypothesize that deciding on when a child should cease napping should take into consideration not only nighttime sleep but also how the child is regulating emotions, behavior and learning towards the end of the day. In France, where preschool ends around 4:30 pm, naps may allow children to remain mentally available for further learning in the afternoon. The decision to cease naps could be facilitated by good communication between different caregivers. To provide nap schedules that best meet individual needs, early childhood care settings can implement strategies that promote communication with parents about the child's sleep [41] and allow flexibility in adapting sleep opportunities.

Supplementary Information

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Supplementary Material 1.

Supplementary Material 2.

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Authors' contributions

E.R. carried out the analyses and drafted the initial manuscript. L.M. collected data. A.E.R. and S.M. coordinated and supervised data collection, conceptualized and designed the study. E.T., L.M.,A.E.R. and S.M critically reviewed and revised the manuscript.

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Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Parents agreed for their child to participate and signed an informed consent. The study was approved by the ethics evaluation committee and the institutional Review Board of the French National Institute of Health and Medical Research (CEEI/IRB Opinion N°22–901 bis). All procedures performed in this study involving human participants were conducted in accordance with the 1964 Declaration of Helsinki and its later amendments.

Consent for publication

Not applicable. This manuscript does not contain any individual person's data in any form.

Competing interests

The authors declare no competing interests.

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